AN ABSTRACT OF THE DISSERTATION OF

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Abstract approved:

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The certified organic blueberry (*Vaccinium* sp.) market has continued to expand in the last two decades, including in Oregon. The development of an industry-public research coalition has fostered expansion. In 2015, a survey consisting of on-site, in-person interviews with certified and transitional organic growers in Oregon found the majority of the 28 operations interviewed were small farms of 8 ha or less and had a total blueberry area less than 2 ha – 71% also grew other crops. Production systems used varied among farms: 70% had blueberry fields at least 10-years-old; 14% used drip irrigation, 61% overhead and 25% a combination of both; slightly less than half were grown on flat ground; and all pruned at least some part of their fields annually. Soil and tissue testing, use of pre-plant soil amendments, and fertility management practices varied widely among growers. The most important pest problems were noted. Growers described a wide variety of harvest methods and marketing outlets for their blueberry fruit with the vast majority producing for fresh direct consumer sales or for fresh wholesale or retail buyers. A comprehensive organic highbush blueberry (*Vaccinium corymbosum* L.) research trial was established at Oregon State University's North Willamette Research and Extension Center in Oct. 2006 with industry funding and advisement on research priorities. A subset of this trial was studied in 2015-2016 for the effect of fertilizer source (fish solubles and feather meal at 140 $kg\cdot ha^{-1}$ N), mulch [porous, black polypropylene ground cover ("weed mat") and sawdust], and cultivar ('Duke' and 'Liberty') on dry weight (DW), and nutrient concentration, content, and allocation for plant parts (roots, crown, wood, fruit, and leaves) at various stages of development (immature fruit and postharvest in 2015 and dormancy in 2015 and 2016), senescent leaves and ripe fruit in 2015. There were multiple treatment effects on nutrient concentrations at all stages of development in multiple plant parts. Leaf nutrient levels, on average per plant, either decreased from the immature green fruit stage to the postharvest stage and then to senescence (N, P, K, S), increased (Ca, B, Fe, Mn, Al), or remained relatively stable (Mg, Cu, Zn). Declines in leaf N, P, K, and S concentrations from the postharvest stage to senescence likely indicated remobilization of these nutrients prior to dormancy. Dormant plant parts differed in nutrient concentrations between years for all macronutrients except K and S in stems and roots, N and Ca in whips, P and K in old wood, and N and K in the crown, often with a cultivar interaction. Many fruit nutrients changed in concentration during fruit ripening with values affected by year, harvest number (season), cultivar, fertilizer source, and mulch, depending on the nutrient. Cultivar had the greatest effect on nutrient concentrations and 'Liberty' had more DW and nutrient content and losses than 'Duke'. Fertilization with fish

solubles, a product that also contains higher levels of P, K, Mg, and B than feather meal, increased %N and %P of roots, crown, and fruit, %P of stems and leaves, and %K of leaves and fruit, depending on cultivar. Fish solubles also increased plant uptake of K. Fertilization with feather meal increased DW (roots, green fruit, and total) and Ca concentration (fruit, roots) and content of roots and crown, compared to fish solubles, confirming feather meal was a good source of Ca. Fertilizer source had little other impact on nutrient content or losses. Plants grown with weed mat, on average, had greater DW of senescent leaves than with sawdust and a greater above- to below-ground DW ratio. Weed mat also increased N, P, K and B, but reduced Ca and Mg concentrations of many plant parts at various stages, compared to sawdust mulch, with some interactions with fertilizer source. Plant uptake of N, P, K and B was increased with weed mat compared to sawdust, but the opposite was found for Mg. Weed mat increased N content of green and ripe fruit, leaves at postharvest stage, and dormant stems and old wood. The increased uptake of N with weed mat compared to sawdust was lost in senescent leaves. Mulching with weed mat increased K content of ripe fruit, leaves and stems at postharvest stage, and senescent leaves. The average total estimated nutrient losses in harvested fruit, senescent leaves, and pruning wood for the mature planting were 34.8, 3.5, 25.2, 20.7, 4.5, and 3.7 $kg \cdot ha^{-1}$ of N, P, K, Ca, Mg, and S, respectively, and 162, 1038, 1336, 40, and 73 $g \cdot ha^{-1}$ of B, Fe, Mn, Cu, Zn, respectively. If planting management could be modified to recover organic matter and nutrients currently lost in senescent leaves and pruning wood, making them available to the blueberry plants in the row, application of fertilizer nutrients may be reduced. Greater nutrient uptake and losses with weed mat, a common mulch used by growers, may indicate a need for nutrient management programs specific to this mulch.

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Organic Blueberry Production Systems – Grower Practices and Impact on Plant Nutrient Concentration, Content, and Biomass

by

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Javier A. Fernandez-Salvador, Author

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CONTRIBUTION OF AUTHORS

Dr. Bernadine C. Strik was involved in the experimental design, statistical interpretation, and editing of all the chapters in this document. Dr. David Bryla was involved in the interpretation and statistical analysis of Chapters 3 and 4 in this document.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

Table Page

APPENDICES

Chapter 1: General Introduction

Organic blueberries *(Vaccinium* sp.) are one of the most important specialty fruit crops, grown on over 2,145 hectares across the U.S. and capturing over $100.5 million in sales in 2019 (NASS, 2019). Significant expansion in organic blueberry plantings is also expected to continue in the next ten years, as an important component of the total sales of organic produce, which surpassed $50 billion in 2019, and as growers continue to look for new and innovative high value crops (OTA, 2019).

As the demand for organic blueberries have grown globally, Oregon has become one of the top producing states in the United States, accounting for over 333 hectares of production in 2019 and $13.2 million in sales (NASS, 2019). Oregon's location, specifically the Willamette Valley and other valleys in western Oregon and near the coast, are particularly suited for optimum organic highbush blueberry production, due to climatic conditions including adequate, but not excessive cold periods with the right amount of precipitation and relatively dry summers; soil characteristics with the right ranges of pH and organic matter; and relatively manageable pests and disease pressure compared to those in the Midwest and southeastern production areas (e.g. Michigan, Florida; Strik 2014).

Given the rapid growth of the organic blueberry market, it is important that growers have access to innovative research on production methods. However, Oregon's organic blueberry growers range in farm size, availability of resources and complexity, making it challenging to provide pertinent information. While many organic growers have adopted early recommendations from certified organic blueberry trials (Larco et al., 2013a, 2013b; Strik, 2014), including planting on raised beds, reducing the rate of N applied in fish solubles, and choosing weed mat mulch to reduce weed control costs, there was a need to further characterize the practices used by organic blueberry growers and then adapt research topics and extension methods to better serve producers.

One of the important production practices for effective blueberry production is routine soil and leaf nutrient testing for optimum fertility management (Hart et al., 2006). Results from such testing informs the grower on the concentration of nutrients in the plants, which can help to determine fertilization strategies. Given the diverse but reduced weed control and fertilization options used by organic producers, it becomes important to better understand how treatments can affect the nutrient allocation in the different systems used by organic growers.

Most blueberry fertilization recommendations are derived from studies conducted in conventional production settings (Hart et al., 2006) where fertilizer sources are often readily available, lower in cost and more nutrient specific. While some research has been published on nutrient concentration, content, and allocation in young, conventional blueberry plants (Bañados, 2006; Bañados et al., 2012; Strik et al., 2020b) and organic systems at establishment and maturity (Davis and Strik, 2021; Larco et al., 2013a; Strik and Vance, 2015; Strik et al., 2017), there is limited information on concentration, content, and allocation of plant parts at different stages of development for mature plantings. Because fertilizer options are limited in organic production to primarily natural, non-synthetic sources (OMRI, 2019), growers are particularly interested in optimizing their nutrient management for uptake and yield improvements. Larco et al. (2013a) studied different nutrient management practices during establishment of blueberries and showed success with using organic liquid and solid fertilizer sources. Yet, it is still not well understood how different fertilizer sources affect plant growth and nutrient concentration in all plant parts in long-term studies. In particular, more knowledge is needed to determine how fertilizer source, mulch and cultivar affect plant biomass and nutrient allocation as options are reduced in organic production systems.

In addition to fertilizer concerns, weed management is another important aspect to successful organic blueberry production. Natural mulches are often used in both organic and conventional blueberry systems because they lend benefits such as increased yield and plant growth when used with synthetic fertilizers (Clark and Moore, 1991; Goulart et al., 1997; Karp et al., 2006; Kozinski, 2006; Krewer et al., 2009; White 2006). Douglas fir (*Pseudotsuga menziesii* M.) sawdust is commonly used by blueberry producers in Oregon and Washington, but it can immobilize N applied from fertilizers (Burkhard et al., 2009; Cox, J. 2009; Granatstein and Mullinix, 2008; Julian et al., 2012; Sullivan et al., 2015; White, 2006).

Another mulch option is a weed mat, a permeable landscape fabric that is laid directly over the raised planting bed. It is approved for use by the National Organic Program (NOP, 2017) and is advantageous for economic weed control (Julian et al., 2012; Strik and Vance, 2017). However, there are some disadvantages to its use, including increased soil temperatures which can reduce plant growth (Neilsen et al., 2003; Strik et al., 2020a; Williamson et al., 2006) and yield (Davis and Strik, 2021; Krewer et al., 2009). Larco et al. (2013b) found that berry yield was highest using weed mat in the first fruiting season and Strik et al. (2017) found weed mat increased cumulative yield of ‘Liberty’, but not ‘Duke’, in a long-term organic blueberry study. Strik et al. (2019) noted that soil organic matter may decline under weed mat over the long term, reducing yield, which was later confirmed by Davis and Strik (2021). Little is known of the effects of weed mat on biomass and nutrient allocation in mature blueberry plants.

Plant nutrient status is commonly determined by sampling leaf tissue (Hart et al., 2006) and is used as a tool by many growers to evaluate their fertility programs. Understanding the concentration and content of nutrients in different plant parts at multiple stages of development can help determine changes in plant nutrient status through the season and better inform nutrient management. Plant biomass allocation and nutrient content have been studied during establishment in conventional systems (Bañados et al., 2012; Bryla et al., 2012; Strik et al., 2020b). While nutrient concentration in organic blueberry leaves (Strik et al., 2019; Strik and Vance, 2015) and other blueberry plant parts has been studied (Bañados et al., 2012; Strik et al., 2020b), there is no information on changes in nutrient concentration or content for multiple plant parts or stages of mature, organic blueberry during the growing season. Measuring nutrient content and calculating losses as has been done for young conventional blueberry plants (Bañados et al., 2012; Bryla et al., 2012; Strik et al., 2020b) can also help inform fertilizer nutrient application rate through replacement (Bryla and Strik, 2015).

The overall goals of this study were to 1) document current grower practice at organic blueberry farms and research needs; 2) evaluate the effect of cultivar, fertilizer source and mulch treatments in a long-term, mature blueberry organic production system on biomass, and nutrient concentration and content, and allocation in plant parts at different developmental stages.

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The Organic Blueberry Industry in Oregon: Results of In-person, On-site Interviews with Growers in 2015

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Chapter 2: The Organic Blueberry Industry in Oregon: Results of In-Person, On-Site Interviews with Growers in 2015

Abstract

Certified organic blueberry area in the U.S.A. grew nearly ten-fold from 2003 to 2011. In 2015, there were an estimated 283 ha of certified organic blueberry in Oregon. New transitional and organic blueberry (*Vaccinium* sp.) fields continue to be planted in this region by small and diversified organic farmers at a rapid rate. In 2015, a survey was developed to conduct on-site in-person interviews with certified and transitional organic growers in Oregon. Quantitative and qualitative data were collected including pre-planting practices and soil amendments, management systems, cultivars and area grown, soil pH and fertility programs, pruning, irrigation, pest management, average yields, harvesting and postharvest practices, sales, and marketing. Different farm sizes and business structures were included in the 28 interviews conducted. Although the diversity of farms varied, the majority of operations were small farms of 8 ha or less total certified organic land and a total blueberry area less than 2 ha. Seventy one percent of the farmers interviewed had diverse organic production systems including crops other than blueberry. Blueberry production systems were diverse among farms including: 14% using drip irrigation, 61% overhead and 25% a combination of both; slightly less than half were grown on flat ground; 70% had fields with plants at least 10-years-old; and all pruned at least some part of their fields annually. Soil and tissue testing, use of pre-plant soil amendments, nitrogen and other fertility management practices varied widely among growers. The most important pest problems noted were weeds, Spotted Wing Drosophila (*Drosophila suzukii*), Mummy berry (*Monilina vaccinii-corymbosi*) and Blueberry Shock Virus (BlShV). Other important pests included birds, rodents and deer. Growers described a wide variety of harvest methods and

marketing outlets for their blueberry fruit with the vast majority of them producing for fresh direct consumer sales or for fresh wholesale or retail buyers.

Introduction

Worldwide blueberry (*Vaccinium* sp.) production and consumption have steadily increased since the 1990s (Strik, 2014), mainly due to an increase in crop profitability, high consumer demand for the crop, and successful marketing campaigns showcasing the human health benefits of consuming the fruit (Brazelton and Strik, 2007; DeVetter et al., 2015). Certified organic blueberry area in the U.S.A increased from an estimated 194 ha in 2003 to 1,665 ha in 2011(Strik, 2014). There has also been an increase in the number of organic producers, quantity of fruit produced and value of crop sales (USDA, 2010; 2015), notably in the western part of the United States with 26% of the planted blueberry area (Strik, 2014). A great driver of the increase in production is the higher value of certified organic fruit and the relative ease of organic production in this region (Strik, 2014). Increased interest in organic blueberry production, has been supported by research on organic production systems (Larco et al., 2013a, 2013b; Strik, 2006; 2015), root physiology (Valenzuela-Estrada et al., 2015), disease (McGovern et al., 2012), insect (Van Timmeren and Isaacs, 2013), and weed (Krewer et al., 2009) control, consumer preferences for organic blueberries (Hu et al., 2009), and production costs (Julian et al., 2011; 2012).

In 2014 there were 88 ha of certified organic blueberry in production in Oregon (Organic Survey, USDA Census of Agriculture, USDA, 2015). However, industry and extension estimates were much higher for planted (perhaps not yet in production) area in 2011 (305 ha; Strik, 2014). New transitional and organic blueberry fields continue to be planted in this region by small and diversified organic farmers at a rapid growth rate. An actual, on-site assessment of the organic blueberry industry has never been conducted in Oregon and would be useful for obtaining more information on the challenges and successes faced by organic blueberry growers. Additional information regarding production practices, marketing strategies and price premiums, as well as verifying basic information such as existing and planted area and cultivars of importance was needed. The objective of the study was to characterize and describe the current status of the organic blueberry industry in Oregon through conducting an on-site, in-person survey and interviews with diverse, certified and transitional growers across the state.

Materials and Methods

In 2015, a survey was developed with the approval of the Oregon State University Human Research Protection Program and Institutional Review Board (IRB), to conduct on-site in-person interviews with certified and transitional organic blueberry growers in Oregon. The complete survey can be found in Appendix 1. A list of certified growers was obtained from the USDA National Organic Program database (USDA, AMS), and accredited organic certifiers. The survey was conducted as an oral, on-site, in-person questionnaire. Quantitative and qualitative data collected included cultivars and area grown, pre-planting practices and soil amendments used, management systems, soil pH and fertility programs, pruning, irrigation and pest management, average yields, harvesting and postharvest practices, and sales and marketing information for each farm. Different farm sizes and business structures were included in the survey. Growers were located throughout Oregon. Only one interviewer (Fernandez-Salvador) conducted the survey to ensure consistency, after completing IRB required training for survey interviewing compliance.

Data were analyzed and one-way tables were chosen to present most of the quantitative results. Multiple response data were analyzed using separated table analysis. A rating scale was used to ask growers about their reasons for choosing to be organic in regard to their farm practices and production system; five options were provided: philosophical; environmental impact; health concerns for self, family and/or workers; market opportunity; fashionable production trend; and awareness of synthetic pesticide impacts. The survey results presented here included all the data available at time of publication.

Results

Certifier supplied information. Based on information obtained from the USDA National Organic Program (NOP) database, there were six accredited certifiers operating in Oregon that certified blueberry growing operations: Oregon Tilth Certified Organic (OTCO; Corvallis, OR), Stellar Certification Services (Stellar; Philomath, OR), California Certified Organic Farmers (CCOF; Santa Cruz, CA), Organic Certifiers (Ventura, CA), Oregon Department of Agriculture (ODA; Salem, OR) and Washington State Department of Agriculture (WSDA; Olympia, WA). Once these were contacted to confirm the number of operations certified, we determined that only the first four actively certified blueberry farms in Oregon for a total of 66 operations (as of July, 2015). In addition, one transitional operation (in the process of converting the blueberry area to certified organic) was also interviewed for a total of 67 potential survey participants.

To estimate existing and future organic area in the state, information was obtained from the certifiers and later updated and verified by the operations surveyed. Based on the certifier data, there were an estimated 355 ha of certified organic blueberries in Oregon prior to conducting the survey.

State crop area and farm characteristics. This report includes 28 growers interviewed, equating to a 42% participation rate. These growers had 429 ha of certified organic blueberry. A more accurate estimate (including those growers not yet surveyed) would be for a total of 468 ha of certified organic area. Additionally, if area not currently certified, but planted and in transition, is included, we estimate there will be 597 ha of certified organic blueberry within the next 2 to 3 years in Oregon, based on our survey.

The majority of organic operations surveyed (53%) had a total farm area between 0.1 and 8 ha, followed by 25% of farms with 8.1 to 20 ha (Figure 2-1a). Additionally, most had certified blueberry area ranging from 0.1 to 2 ha (78%), followed by 14% of farms having from 2.1 to 8 ha of blueberry (Figure 2-1b). There were no farms with certified blueberry area in the range of 8.1 to 20 ha, but 8% had more than 20.1 ha (Figure 2-1b).

Farmers had diverse operations with a variety of crops other than blueberry being grown, including other small fruits, pome fruits, nuts, vegetables, herbs, agronomic crops, pastures, and animal production. Twenty-nine percent of growers were exclusively producing blueberries including northern highbush (*V. corymbosum*), complex hybrids between northern and southern highbush (e.g. ‘Legacy’), and rabbiteye (*V. virgatum*) cultivars (up to 46 cultivars grown). Eleven percent of growers had parallel production of blueberries as organic and conventional at the same farm. All organic certified operations were located in the western side of the State with 86% of all farms surveyed in the central corridor in between the Coast and Cascade Mountain Ranges in the Willamette, Umpqua and Rogue valleys and the remaining 14% were in the Hood River and South Coast areas.

The majority of blueberry producers considered philosophy, environmental impact, health concerns, and awareness of synthetic pesticide impacts as “very important” reasons for being organic, while almost half (46%) and 40% considered a marketing opportunity as a “very important” or “important” reason for being organic, respectively. The majority of growers (68%)

did not consider their organic production being a fashionable trend “an important” reason for choosing to be organic.

A considerable number of the certified organic growers surveyed also had the “Salmon Safe” and “Good Agricultural Practices” certifications (43% and 32%, respectively) concurrently. In contrast, 36% of participating farms had no additional certifications and only 4% were either “Biodynamic”, “Food Alliance”, “Fair Trade/social practices” certified or had a different alternative certification not included in this list.

Production practices. Blueberry production practices varied widely among operations depending on the growers’ approach. Modifying soil pH was common amongst the surveyed organic growers with 56% adjusting their soil pH prior to planting, mostly with sulfur or other approved acidifying agent for organic production (78%; coffee grounds, acidified barks or plant residues or other low pH alternatives) and 22% using lime to increase soil pH to the desired range of 4.5 to 5.5 (Hart et al., 2006). Soil testing was done by 30% of the growers once a year, 5% twice a year, 12% every other year, 18% did not test their soil at all and 37% tested at some other frequency. For those using soil testing, 42% tested in the spring, 31% in the fall, 8% in both spring and fall, and 19% at other times of the year (mostly winter or early and late summer in the row when using drip irrigation). Half of the growers had never used leaf tissue testing, whereas the rest tested either once a year (25%), every other year (7%) or at some other frequency (18%). Of the growers doing tissue testing, 24% did it in late July to early August (as recommended; Hart et al., 2006), 29% in the spring (March–May), 12% after fruiting and 35% at different times (June or during late fall growth).

There was a wide range of organic or other soil amendments, and nitrogen and other macro- and micro-nutrient fertilizers used for fertility management varying widely amongst growers. Fertility sources used included animal meals and manure products, vegetable-based meals and mineral sources, all in liquid and solid forms (granular, pelletized or powdered).

Of all surveyed growers, 14% used drip, 61% overhead and 25% a combination of both types of irrigation systems. Forty eight percent of growers had flat ground as their row management system, either when blueberries were planted by them or by the previous owner of the farm, while 36% of the remaining operations had raised beds and 6% had a combination of both systems at the same farm. The remaining operations (10%) had an alternative row management system including circular mounded plantings, containers with substrate or a grass/legume rotational or grazing system around the blueberry plants.

Plant age varied widely with 70% of operations having plants at least 10 years old and the remaining planted after 2006 (less than 7-years-old). Most interviewed operators (96%) pruned all, or at least part, of their blueberry area annually. Hard, detailed pruning, the recommended method by Oregon State University (Strik et al., 1990; 2004) was done by 82% of the operations, by taking out big canes and non-fruitful or twiggy growth at the top of bush, thinning to the most vigorous and fruitful wood and shaping the bush to a vase for better light and air flow. The remaining 18% of growers practiced one or a combination of speed pruning (making only big cuts lower on bush; Strik et al., 2004), renovation pruning (for older bushes with large and aged wood), light pruning (quickly taking out a limited amount of wood from the top of the bush) or other alternatives such as mechanical hedging, use of ruminant animals to thin plants or fast chainsaw cuts to the base as well as combinations of all of the above.

The most important pest problems noted by growers were weeds (mentioned by 82%), Spotted Wing Drosophila (*Drosophila suzukii*; 48%), Mummy berry (*Monilina vaccinii-corymbosi*; 19%) and Blueberry Shock Virus (BlShV; 19%). Vertebrate problems were common amongst organic blueberry growers with 89% of them having issues with birds, 86% with rodents (voles, moles, squirrels or others), and 46% with deer. A wide range of additional challenges facing organic blueberry producers in Oregon were mentioned, including labor, weather and climate change, fertility and plant nutrition management, and financial and other farm specific problems (Figure 2-2).

*Harvest methods and marketing***.** Eighty two percent of the organic growers surveyed harvested fruit by hand only and 11% by machine harvest exclusively, while the remaining 7% harvested fruit using both techniques. A variety of methods were used when picking including field packing for fresh or processing, packing and sorting in the field or at a separate facility, and bulk harvesting all in different packages including clamshells, recycled paper hallocks, bulk cardboard or plastic containers. The largest share of the producers surveyed sold their fresh blueberries directly to the final consumer (45%), while 20% sold fresh fruit to retailers and 20% to wholesale buyers. Only 15% of the interviewed growers sold their fruit to processors.

Conclusions

Planted as well as production area for organic blueberries in Oregon has continued to expand as shown by the survey data collected to date. A wide variety of organic production systems are used depending mostly on the grower’s approach and management philosophy.

Figures

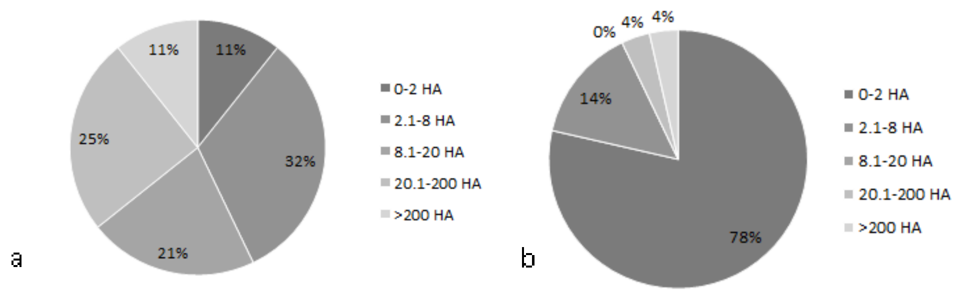

Figure 2-1. Percent of organic blueberry farms surveyed in Oregon (2015) by farm area category: a) total farm size and b) total blueberry acreage.

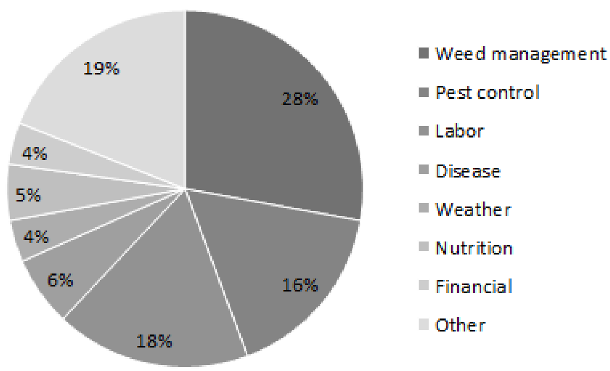

Figure 2-2. Greatest challenges faced by organic blueberry producers surveyed in Oregon (2015).

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Chapter 3: Organic Production Systems in Northern Highbush Blueberry: Impact of Fertilizer Source and Mulch on the Nutrient Concentration of Plant Parts in Mature 'Duke' and 'Liberty'

Abstract

Fertilizer source (fish solubles and feather meal at 140 kg·ha^{-1} N), mulch [porous, black polypropylene ground cover ("weed mat") and sawdust], and cultivar ('Duke' and 'Liberty') were evaluated in mature, certified organic northern highbush blueberry (*Vaccinium corymbosum* L.) for their effect on the nutrient concentration of plant parts (roots, crown, wood, fruit, and leaves) at various stages of development (immature fruit, postharvest, and dormancy in 2015–2016) as well as for ripe fruit and senescent leaves. There were multiple treatment effects on macro- and micronutrient concentration of various plant parts at all stages of development. Leaf nutrient levels, on average per plant, either decreased from the immature green fruit stage to the postharvest stage and then to senescence (N, P, K, S), increased (Ca, B, Fe, Mn, Al), or remained relatively stable (Mg, Cu, Zn). Declines in leaf %N, P, K, and S from the postharvest stage to senescence likely indicated remobilization of these nutrients prior to dormancy. Dormant plant parts differed in nutrient concentrations between years for all macronutrients except K and S in stems and roots, N and Ca in whips, P and K in old wood, and N and K in the crown, often with a cultivar interaction. Many fruit nutrients changed in concentration during ripening with values affected by year, harvest number (season), cultivar, fertilizer source, and mulch, depending on the nutrient. Cultivar had a large effect on tissue nutrient concentrations, possibly indicating genetic differences in uptake or allocation. Fertilization with fish solubles, a product that also contains higher levels of P, K, Mg, and B when compared to feather meal, increased %N and P of roots, crown, and fruit, %P of stems and leaves, and %K of leaves and fruit, depending on cultivar, but there were no effects on plant %Mg or B. In contrast, feather meal was a good source of Ca increasing levels in fruit and dormant roots, depending on mulch type. Growing plants with weed mat mulch rather than sawdust led to increased %N, P, K and B, but reduced Ca and Mg of many plant parts at various stages, with some interactions with fertilizer source. Nutrient concentrations of mature blueberry plant parts changing with plant development and often affected by cultivar, fertilizer source, and mulch type, indicate that fertilizer or nutrient uptake and allocation is complicated in these organic production systems. More information is needed on nutrient content to suggest any changes in assessment of plant nutrient status or system-specific fertilizer recommendations.

Introduction

The United States is the largest organic blueberry producer worldwide with Oregon and Washington having the most certified harvested area in the nation, an estimated 1620 and 1215 ha, respectively, in 2021 (North American Highbush Blueberry Council, unpublished). Organic blueberry production in the Pacific Northwestern region continues to expand mainly because of good soil, climatic, and production conditions for the crop and relative ease of management of pests and diseases for optimum fruit quality and maximum yield (DeVetter et al., 2015; Fernandez-Salvador et al., 2017; Strik, 2014, 2016).

This study was part of a long-term research trial with the goal of developing best organic production practices for a nascent, larger scale, organic blueberry industry in Oregon when the project was initiated in 2006 (Strik et al., 2017a). The original project focused on grower-identified objectives for organic production, including row planting method (raised or flat beds), weed management, including mulch type, adaptation of cultivars, fertilizer source and rate of application (Strik et al., 2017a, 2017b, 2019). Results of a survey of organic blueberry producers in Oregon (Fernandez-Salvador et al., 2017) indicated that organic growers were adopting the best management practices found in the long-term study for new plantings, most notably planting on raised beds, using weed mat mulch, and lower rates of fish solubles (Strik et al., 2017a). However, growers, particularly those with blueberry farms less than 8 ha in size and with more mature plantings (older than 10 years) grown without new planting techniques, indicated a need for more information on fertility management practices (Fernandez-Salvador et al., 2017).

While there are publications that address general fertility management for organic blueberry, most of the information provided is adapted from conventional research (Carroll et al., 2016; Krewer and Walker, 2006; Kuepper, 2004), and more recent studies using organic production methods are finding multiple relationships between mulch, cultivar, fertilizer source and rate (Davis and Strik, 2021; Strik and Vance, 2015; Strik et al., 2017a, 2017b, 2019).

In conventional blueberry production studies, optimum nitrogen (N) fertility rate recommendations vary between 25−100 $kg \cdot ha^{-1}$ mostly increasing as the plant develops (Bañados, 2006; Bañados et al., 2012; Eck, 1977, 1988; Hanson, 2006; Hart et al., 2006). Other nutrients are recommended, if needed, to maximize growth and yield (Hart et al., 2006; Townsend, 1973). Research on fertility management of organic blueberry determined that lower N rates (28 compared to 56 $kg \cdot ha^{-1}$ during establishment and 73 compared to 140 $kg \cdot ha^{-1}$ at maturity) resulted in greater cumulative yield (Strik et al., 2017a). In addition, fertilizer source and rate affected cultivars differently, with ‘Duke’ having reduced yield when fertilized with fish solubles, high in K, particularly at the high rate as compared to feather meal; in contrast, yield of ‘Liberty’ was not affected by fertilizer source or rate (Larco et al., 2013a, Strik et al., 2017a, 2019). Yield increased when application of organic sources of K ceased in mature organic blueberry, regardless of mulch type (Davis and Strik, 2021).

Results from soil analysis are used for amending and preparing sites prior to planting and, after planting to verify nutrient presence, accumulation and fertilizer needs (Griggs and Rollins, 1947; Larco et al., 2013b; Sullivan et al., 2019; White, 2006; Williamson et al., 2006). Leaf tissue testing is an important tool for growers to determine if fertilization and plant nutrient uptake are within published sufficiency levels (Hart et al., 2006; Strik, 2014; Strik et al., 2017a), particularly as it has been shown that concentrations of leaf nutrients change during the growing season in both organic and conventional systems and are affected by cultivar (Strik and Vance, 2015). While some research has been published on nutrient concentrations in young, conventional blueberry plant parts (Bañados et al., 2012; Bryla et al., 2012), the impact of organic production systems such as cultivar, mulch, and fertilizer source on nutrient concentrations of tissues in mature plants is of interest.

Weed management and plant development with different mulching options are important concerns in organic blueberry production. Organically approved herbicides and mechanical methods are available but are labor-intensive, expensive, and less effective than mulches, especially in long-term plantings (Burkhard et al., 2009; Granatstein and Mullinix, 2008; Julian et al., 2011, 2012; Krewer et al., 2009; Larco et al., 2013b; Strik and Vance, 2017; Strik et al., 2017a). The preferred cultural method for weed control has been mulching in both organic and conventional blueberry systems (Clark and Moore, 1991; Goulart et al., 1997; Karp et al., 2006; Kozinski, 2006; Krewer et al., 2009; White 2006). Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco var. *Menziesii*] sawdust is commonly used by blueberry producers in Oregon and Washington as an organic mulch, but it has a high carbon (C) to N ratio which can immobilize N applied from fertilizers (Burkhard et al., 2009; Cox, J. 2009; Granatstein and Mullinix, 2008; Sullivan et al., 2015; White, 2006). A now common weed management option is weed mat, a permeable, woven polypropylene ground cover that is laid directly over the in-row soil area of the raised bed or flat ground. Weed mat has production and economic advantages when compared to organic mulches (Dixon et al., 2016; Julian et al., 2012; Strik and Vance, 2017; Strik et al., 2017a), but there are potential disadvantages to its use, including increased soil temperatures, a reduction in soil organic matter, and added demand for irrigation (Cox, 2009; Davis and Strik, 2021; Larco et al., 2013b, 2014; Neilsen et al., 2003; Strik et al., 2006, 2017a, 2019; Williamson et al., 2006). In addition, use of weed mat mulch increased soil NO_3-N, P, K, Ca, and Mg and the concentration of N, P, and K in the leaves in mature plants, as compared to sawdust mulch (Strik et al., 2019). These mulches may also affect the nutrient concentration of other plant parts through a production cycle.

The objective of this study was to evaluate the impact of long-term organic production systems (cultivar, mulch, and fertilizer source) on the nutrient concentration of plant parts (fruit, leaves, shoots, wood, crown, and roots) at different stages of development in mature northern highbush blueberry plants.

Materials and Methods

Site and planting design. The study was conducted from 2015–2016 within a mature 0.4 ha blueberry research planting at the North Willamette Research and Extension Center in Aurora, OR [(lat. 45°17’ N, long.122°45’ W; elevation 46 m; United States Department of Agriculture (USDA) hardiness zone 8b (2012)]. The planting was certified organic starting in the first cropping year (2008) by a USDA-accredited agency (Oregon Tilth Certified Organic, Corvallis, OR). The soil at the site was identified as a Willamette silt loam (a fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll). For more information on soil properties and nutrient levels, and planting establishment and crop management practices during development refer to Larco et al. (2013a, 2013b) and Strik et al. (2017a).

Plant spacing was 0.8 m between plants and 3.0 m between rows (4385 plants/ha). Row aisles were planted with permanent fescue grass cover (*Festulolium braunii* K. Richt.) which was mowed during the growing season, as necessary. Depending on the year, weeds in the plots were controlled with an organically approved (OMRI listed) herbicide or hand weeded, depending on the mulch treatment (OMRI, 2019; Strik et al., 2017a). Planting, pest and disease management, crop harvest (by hand), and commercial pruning were done as per commercial practice, as described by Strik et al. (2017a).

Irrigation was set up with a single-line polyethylene drip tubing (Netafim, Fresno, CA), with pressure compensating emitters spaced every 0.3 m rated at a nominal flow of 2-$L \cdot h^{-1}$. Irrigation was adjusted as needed based on treatment and scheduled such that soil water content remained within 25% to 30% during the growing season. Irrigation was applied from early to mid-May through September in both years (Strik et al., 2017a).

Treatments. This study involved a sub-section of a larger production systems research trial (Strik et al., 2017a). There were eight treatments arranged in 2 x 2 x 2 balanced factorial split-plot design with five replicates. The main plots were fertilizer source (fish solubles and feather meal) and the sub-plots were cultivar (‘Liberty’ and ‘Duke’) and mulch (weed mat and sawdust). Plots were 4.6-m long with six plants in each at establishment. All were planted on raised beds and were fertilized with 140 $kg \cdot ha^{-1}$ of N from 2013–2016 (Strik et al., 2017a, 2019).

Fertilizer source treatments were granular feather meal (11–13% N; California Organic Fertilizers, Phyta Grow Super N, Fresno, CA; Pacific Calcium, Tonasket, WA) and liquid fish by-product solubles with acid-stabilized pH (4–5% N; TRUE Organic Products TRUE 512, Spreckels, CA; California Organic Fertilizers, Phytamin 420, Fresno, CA). The fertilizers used were analyzed and application rates and timings for the season are described by Strik et al. (2019). Feather meal was applied to the plot in-row area in two equal split-applications in March and May of each year. The fertilizer was applied to the surface of the sawdust mulch treatment, while the weed mat was opened (see below) before applying the product on the soil surface. Fish solubles fertilizer was pre-diluted with 10 parts water (v/v) and injected through the drip system (fertigation) in seven equal applications every 2 weeks from mid-April to early July.

The early-season cultivar ‘Duke’ and the mid-season ‘Liberty’ were chosen originally because of their popularity among growers and because fertility management for ‘Duke’ was expected to be more challenging. The latter was shown to be true in organic production, as ‘Duke’ had lower yield when fertilized with fish solubles, particularly at a high rate (Strik et al., 2017a, 2019).

Sawdust mulch was established with a 9-cm-deep layer of Douglas fir on top of the raised bed (360 $m^3 \cdot ha^{-1}$ approx.). The weed mat mulch used was a 1.5–m-wide black, permeable, woven polypropylene groundcover with a water infiltration rate of 6.8 $L \cdot m^{-2} \cdot h^{-1}$ and a density of 0.11 $kg \cdot m^{-2}$ (TenCate Protective Fabrics; OBC Northwest Inc., Canby, OR). For this trial, the weed mat was overlapped (zippered) when installed over the beds, allowing the mulch to be opened when fertilizing and checking irrigation functioning (Strik et al., 2017a).

Data collection. In 2015, one plant per plot was carefully dug at each of three developmental stages, immature fruit (fruit green in color, prior to color change or ripening; May 16 and 30, for ‘Duke’ and ‘Liberty’, respectively), postharvest (after the end of fruit harvest, but well before leaf senescence; 1 and 22 Aug., for ‘Duke’ and ‘Liberty’, respectively) and when dormant (early winter; 5 and 12 Dec., for ‘Duke’ and ‘Liberty’, respectively). In 2016, one plant per plot was dug in early winter (dormant stage; 3 and 10 Dec., for ‘Duke’ and ‘Liberty’, respectively). Plants were carefully dug using a shovel by a commercial nursery crew to retain as much of the root system as possible. The plants were separated into green fruit (picked prior to digging), leaves, shoots (current season, excluding leaf blades; these became one-year-old laterals for the dormant sampling), whips (current season, excluding leaf blades; these became one-year-old whips for the dormant sampling), old wood (older than one year), crown, and roots (carefully washed to remove soil). In addition to the three complete plant sampling stages, all ripe fruit were hand-picked [two picks per season for ‘Duke’ (15, 29 and 13, 27, Jun. 2015 and 2016, respectively) and three for ‘Liberty’(8, 15, 29 and 6, 18, 31 Jul. 2015 and 2016, respectively)] and senescent leaves were collected by placing nets around one plant per plot just prior to leaf senescence and the leaves collected after senescence with some leaves remaining on the plant being stripped until all leaves were collected. A representative tissue sample was obtained for each plant part and sent for complete nutrient analysis and percent moisture to Brookside Laboratories, Inc. (New Bremen, OH) using methods described in Strik et al. (2019). The fresh biomass of each plant part was weighed prior to sub-sampling for analysis and total yield was calculated per plant; these data and methodology are presented in Fernandez-Salvador (Chapter 4).

Statistical analysis. Data were analyzed by analysis of variance (PROC MIXED) for a split-plot with fertilizer source as the main effect, and cultivar and mulch as sub-plots using SAS software package version 9.4 (SAS Institute, Cary, NC). Dormant plant tissue nutrient data were analyzed as a split-split plot with year as the main effect. Harvested fruit tissue nutrient data were also analyzed as a split-split plot for both cultivars pooled with year as the main effect, and by cultivar with year as the main effect and harvest date as the subplot effect. Means were compared with 5% confidence level using Tukey's Honestly Significant Difference test. Mean comparisons within significant interactions were done using Least Square Means with 5% confidence level.

Results

In 2015, there were several main effects and interactions between cultivar, fertilizer source and mulch type treatments on the macronutrient (Table 3-1) and micronutrient (Table 3-2) concentrations of plant parts sampled at the developmental stages studied.

Macronutrients

Nitrogen. Green fruit (at the immature stage) and ripe fruit at harvest had higher N concentration (%N) in 'Duke than in 'Liberty', in plants fertilized with fish solubles rather than feather meal, and when mulched with weed mat, as compared to sawdust (Table 3-1). The %N of leaves was higher with weed mat than sawdust mulch at all stages (immature fruit, postharvest and leaf senescence). At the immature fruit stage, cultivars fertilized with fish did not differ in leaf %N, whereas 'Liberty' had a lower leaf %N than 'Duke' when fertilized with feather meal. Leaf %N was also higher in 'Duke' than 'Liberty' at the postharvest stage and when fertilized with fish than with feather, but only with sawdust mulch.

At the immature fruit stage, mulch type had no effect on stem %N in 'Duke', whereas in 'Liberty' weed mat increased stem %N compared to sawdust. At the postharvest stage, stem %N was greater in 'Duke' than 'Liberty' and fertilization with fish increased stem %N, but only in plants mulched with sawdust. When plants were dormant, 'Liberty' had a greater stem %N when fertilized with fish than with feather, whereas there was no effect of fertilizer source in 'Duke'. Plants grown with weed mat had higher stem %N than with sawdust mulch.

Whips had a greater %N when mulched with weed mat than with sawdust at the immature fruit and dormant stage. 'Duke' had higher whip %N than 'Liberty' at the postharvest stage and at dormancy, %N was higher with fish than feather fertilizer.

In old wood, 'Duke' had a greater %N at the immature fruit stage than 'Liberty', whereas the opposite was found at the dormant stage. At the immature stage, mulching with weed mat increased %N of old wood compared to sawdust. When plants were at the postharvest or dormant stage, plants fertilized with feather meal had higher %N in old wood when mulched with weed mat than sawdust, whereas there was no mulch effect when fertilized with fish.

Plants fertilized with fish had a greater %N in the crown than those fertilized with feather meal at three stages (immature fruit, postharvest, and dormancy). Additionally, crown %N was higher at the postharvest stage when mulched with weed mat than with sawdust.

The %N of roots was higher when fertilized with fish than with feather and when mulched with weed mat rather than sawdust at the immature stage. At the postharvest stage, 'Liberty' had greater root %N when fertilized with fish than with feather, whereas there was no fertilizer source effect in 'Duke'. At the postharvest and dormant stages, there was no fertilizer source effect when plants were mulched with weed mat, but plants mulched with sawdust had a lower root %N when fertilized with feather than with fish.

Phosphorus. 'Duke' had a greater %P in all above-ground parts [green and ripe fruit (immature and harvest stage), leaves (immature fruit and postharvest stage), stems (immature and postharvest stage), whips (immature, postharvest and dormancy stage), and old wood (immature fruit stage)] than 'Liberty' (Table 3-1). 'Liberty' had higher leaf %P than 'Duke' at senescence. Fertilization with fish increased %P, compared to feather, in old wood (only at the immature fruit stage), ripe fruit, leaves (postharvest), stems (postharvest and dormant), the crown [immature fruit stage (only in 'Liberty') and dormant], and roots [immature, postharvest (only in 'Liberty'), and dormant]. Mulching with weed mat increased %P, compared to sawdust mulch, in whips (immature fruit stage), ripe fruit, leaves (postharvest), stems (postharvest and dormant), and the crown (only at postharvest stage for 'Liberty').

Potassium. 'Duke' plants had a greater average %K than 'Liberty' in green fruit, leaves and old wood (immature fruit stage), stems (immature, postharvest, and dormant), whips [immature (only when fertilized with fish) and postharvest], and roots [immature and dormant (only when fertilized with fish) and postharvest] (Table 3-1). Fertilization with fish, compared to feather, increased %K of ripe fruit, leaves [postharvest stage, and senescence (only with sawdust mulch)], and roots (postharvest and dormant, but only in 'Duke'). In contrast, at the postharvest and dormant stages, plants fertilized with fish had a lower crown %K than those fertilized with feather meal.

Plants grown with weed mat had a higher %K than those grown with sawdust for ripe fruit, leaves [immature, postharvest (only in 'Liberty')], and senescence (only when fertilized with feather meal), whips (immature stage), stems (postharvest and dormant), old wood (postharvest), and the crown and roots (postharvest and dormant). At the postharvest stage, 'Duke' had higher %K in roots when fertilized with fish than feather, whereas fertilizer source had no effect in 'Liberty'.

Calcium. 'Duke' had higher %Ca than 'Liberty' in whips at the immature green fruit stage, stems (only when grown with sawdust), and leaves at postharvest and senescence stages, whereas the opposite was found for ripe fruit, whips, stems, old wood, and crown at the postharvest stage and stems, old wood and roots at dormancy (Table 3-1).

Fertilization with feather meal increased the %Ca of green and ripe fruit, stems at the immature stage, leaves at senescence, and roots at dormancy, but only when plants were mulched with sawdust, as well as leaves postharvest and stems at dormancy, regardless of mulch. Fertilizing with fish led to higher crown %Ca but only at the immature stage. Sawdust mulched plants had higher %Ca of whips (immature and postharvest stages) and roots (immature stage) as compared to weed mat.

Magnesium. 'Duke' had greater %Mg than 'Liberty' for green and ripe fruit, stems (immature stage), and leaves at postharvest (only when mulched with sawdust) but had lower %Mg in old wood at postharvest and dormancy stages and stems at dormancy (Table 3-1).

Plants fertilized with feather meal had greater %Mg in green fruit (only with sawdust mulch), but lower %Mg in whips (immature stage) as compared to fish solubles. In addition, mulching with sawdust increased %Mg of the crown at the immature stage, and leaves postharvest (only in 'Duke').

Sulfur. 'Duke' had a higher %S than 'Liberty' for green and ripe fruit, leaves at all stages, whips (immature fruit and dormant), and stems (immature and postharvest), whereas the opposite was found for stems (dormant stage, but only with fish fertilization), old wood (dormant) and the crown (postharvest and dormant) (Table 3-1). Fish fertilization increased %S of roots (immature stage), crown, ripe fruit (only with sawdust mulch), leaves and stems (postharvest stage), and the roots [postharvest (only in 'Liberty') and dormant (only with sawdust)].

Weed mat mulch increased %S, compared to sawdust, in ripe fruit (only when fertilized with feather), leaves and roots at the immature stage, leaves, stems, old wood (only when fertilized with feather meal) and the crown at the postharvest stage, and stems, whips, and roots when dormant.

Micronutrients

Boron. 'Duke' plants had a greater average B concentration than 'Liberty' for green and ripe fruit, stems, whips, and old wood at the immature stage, and leaves at senescence (Table 3-2). In contrast, 'Liberty' had a higher B concentration than 'Duke' for the crown [immature and postharvest stages (only with weed mat) and at dormancy], old wood (postharvest and dormant) and stems (dormant). Fertilization with fish increased green fruit (only with weed mat), whip (immature stage), and root (postharvest) B compared to feather meal. Weed mat mulch increased B, compared to sawdust, in leaves (immature and senescence), green fruit (only with fish fertilizer), ripe fruit, stems (immature) and crown (immature but only for 'Liberty'), roots at postharvest stage, and the stems, old wood, and roots at dormancy.

Iron. 'Duke' had a greater concentration of Fe than 'Liberty' for green fruit and stems at the postharvest stage, but had lower levels in leaves, whips, and old wood at the immature fruit stage, leaves at postharvest, and stems, whips (only when fertilized with fish), old wood, and crown at dormancy (Table 3-2). Growing plants with weed mat mulch increased leaf Fe at the immature fruit stage, but decreased Fe in the crown, compared to sawdust mulch. Whips at the postharvest stage had lower Fe with weed mat than with sawdust, but only when plants were fertilized with feather meal. When plants were dormant, Fe concentration in stems was greater when fertilized with feather meal than with fish solubles.

Manganese. Plant Mn concentration was most affected by cultivar and fertilizer source (Table 3-2). 'Liberty' had a greater Mn in green fruit, leaves, and stems, but lower levels than 'Duke' in old wood and the crown (only when fertilized with feather meal) at the immature fruit stage. At the postharvest stage, 'Liberty' had greater Mn in leaves and stems, but lower levels than 'Duke' in the crown and roots. 'Liberty' also had higher Mn than 'Duke' in senescent leaves and stems at dormancy, but lower levels than ‘Duke’ in dormant crowns. Plants fertilized with fish had a greater Mn in green fruit, stems (only with weed mat) and whips at immature fruit stage, as well as in leaves, stems, and old wood at the postharvest stage. Mulch only affected the Mn concentration in the crown at the immature fruit stage with higher levels when mulched with sawdust as compared to weed mat.

Copper. ‘Duke’ had a greater Cu concentration in leaves at the immature stage (only when fertilized with feather meal), postharvest and senescent leaves, and whips, and old wood at the immature stage, but had lower levels than ‘Liberty’ in stems and the crown at the immature fruit stage, old wood and the crown (only when fertilized with fish), and the roots at postharvest stage, and dormant stems (Table 3-2). Fertilization with feather meal increased Cu concentration of leaves (only when mulched with sawdust) and whips at the immature stage. The only impact of mulch was weed mat having higher Cu concentration in the crown at dormancy than sawdust.

Zinc. ‘Duke’ had higher concentrations of Zn than ‘Liberty’ for green and ripe fruit, leaves (at immature stage only when fertilized with feather meal; and at senescence when grown with sawdust), whips (immature, postharvest and dormant stages), and old wood at dormancy, but had lower levels than ‘Liberty’ for old wood and the crown at postharvest and the crown at dormancy (Table 3-2). Fertilization with feather meal increased Zn in whips, compared to fish solubles, at the immature stage and dormant stems, but the opposite was found for the crown at the immature stage, the crown and roots at the postharvest stage, and the crown at dormancy (only in ‘Liberty’). Growing plants with weed mat mulch increased stem Zn concentration (only when fertilized with fish and for ‘Liberty’), and the crown postharvest and at dormancy, as compared to sawdust.

Aluminum. ‘Duke’ had a higher Al concentration in green fruit than ‘Liberty’ (Table 3-2). However, ‘Liberty’ had higher Al levels than ‘Duke’ for old wood (immature stage), leaves (postharvest) and stems, old wood, and the crown when dormant. Stems had greater Al when fertilized with feather meal when dormant. Ripe fruit and the crown (immature and postharvest stages) had higher Al when plants were mulched with sawdust than with weed mat.

Year effect on dormant plants

In dormant plants, year affected the concentration of N, Ca, Mg, B, and Al (‘Liberty’ only), P, Mn, and Fe (‘Duke’ only) in stems, the concentration of N, Ca, Mg, S, B, Mn and Al (‘Liberty’), Fe, and Cu in old wood, crown concentration of Zn (‘Liberty’ only), P, Ca, Mg, S, B, Fe, Mn, Cu, and Al, and the level of Cu (‘Duke’ only), N, P, Ca, Mg, B, and Zn in the roots (Tables 3-3 and 3-4). The concentration for many nutrients was higher in 2015 than in 2016, but often only in ‘Liberty’, including N, Ca, Mg, B, and Al in stems, Fe in whips, N, Ca, Mg, S, B, Fe, Mn, and Al in old wood, and Zn in the crown. ‘Duke’ had higher Cu concentration in the roots in 2015 than in 2016, but the opposite was found for Fe concentration in the stems and old wood in this cultivar. On average, P in stems, whips, crown, and roots, K, Mg, and S in whips, and Ca, Mg, S, B, Fe, Cu, and Al in the crown had higher levels in 2016 than in 2015. Only stem, whip, and crown Mn, whip Al, and root Ca, Mg, B, and Zn, were of higher concentration, on average, in 2015 than in 2016.

On average, dormant ‘Liberty’ plants had higher concentrations of the following nutrients as compared to ‘Duke’: N in old wood (only 2015) and roots (2016), P and K in the crown, Ca and Mg in stems and old wood, Ca in roots, S in old wood, crown, and roots, B, Fe, Mn, and Cu in stems, B in old wood, crown (only with weed mat), and roots, Fe in whips and old wood (both only in 2015), Mn in old wood (2015), Cu and Zn in the crown, and Cu in the roots. In contrast, ‘Duke’ had higher concentrations of N in stems (2015), whips, and old wood (2016), P in whips, K in stems (with sawdust mulch) and roots, Mg and S in whips, Fe and Mn in old wood (2016) and in the crown, Mn in roots, and Zn in the stems, as compared to ‘Liberty’ (Tables 3-3 and 3-4).

Fertilization with fish solubles increased the concentration of N in whips, P in old wood (2016), crown, and roots, S in roots (only with sawdust), whips, and crown, and decreased Ca in roots, as compared to feather meal.

Mulching with weed mat, as compared to sawdust, increased the concentration of N in whips and old wood, P in old wood (2016), stems, and crown, K in stems (‘Liberty’ only) and roots, S in stems, whips, and old wood, B in roots, and Cu and Zn in stems (Tables 3-3 and 3-4).

Year effect on ripe fruit

There was a year by cultivar interaction on the concentration of many nutrients in ripe fruit (Tables 3-5 and 3-6). In ‘Duke’, fruit %Ca was higher in 2016 than in 2015, whereas %P was higher in 2015 (Table 3-5). ‘Liberty’ fruit had higher Fe and B concentration in 2016 than in 2015 (Table 3-6), whereas %K and S were lower in 2016 than in 2015. The %N of ripe fruit was higher, on average in 2015 than in 2016. Fertilization with fish solubles increased fruit %N (only with sawdust mulch), P, K, Ca and S, as compared to feather meal. Fruit nutrient concentration was higher with weed mat than with sawdust mulch for N (but only when fertilizing with feather meal), K and B (in 2015), S, and B (only in ‘Liberty’). In contrast, plants grown with weed mat had lower fruit Mn concentration (only in ‘Duke’) and Mg, as compared to those grown with sawdust.

Impact of harvest date on fruit nutrient concentration

In 'Duke' there were a few effects of harvest date (pick number) on fruit nutrient concentration (Tables 3-7 and 3-8). Fruit harvested on the first pick had higher concentrations of N (only with feather meal, 0.7% vs 0.5% in 2015, and 0.7% vs 0.5% in 2016), P (0.09% vs 0.07%, on average), K (only in 2016, 0.6% vs 0.5%), Ca (0.05% vs 0.04%), S (0.06% vs 0.05%), B (10 ppm vs 8 ppm), and Zn (7 ppm vs 6 ppm), than the second pick, respectively. In 'Liberty', which was picked three times, the impact of harvest date was similar between years (Tables 3-9 and 3-10). Fruit Ca was highest on the second pick (0.054%), and lowest on the first pick (0.048%). Fruit Mg and Mn were also lower on the first pick (0.026% and 18 ppm) as compared to the last two picks (0.028% and 21 ppm), respectively. Fruit B was more than double the other harvests on the third pick (2016 only); while the value appeared to be an outlier, it was verified with the analytical lab. Fruit Al was higher on the second pick (151 ppm) than the other two (averaged 101 ppm), but only in 2015. Fruit Zn was also higher on the second pick (6 ppm), but only when grown with weed mat, as compared to the other picks and with sawdust (averaged 4 ppm).

Discussion

A comprehensive analysis of all essential macro- and micronutrients in different plant parts and across seasons for mature highbush blueberry, particularly under certified organic management, has not been conducted in previous published studies. Previous research has covered nutrient concentration in both organic and conventional systems, mostly focusing on leaves and fruit (e.g. Strik and Vance, 2015), and on biomass and nutrient allocation during establishment of conventional plants (Bañados et al., 2012; Bryla et al., 2012).

Cultivar. 'Duke', on average, had higher concentrations of N and P than 'Liberty' in immature and ripe fruit and %K in immature fruit, but lower %Ca in ripe fruit. Our results agree with published differences between 'Duke' and 'Liberty' for ripe fruit in Oregon (Strik and Vance, 2015). 'Duke' also had higher concentrations of N, P, and K in many plant parts and sample dates as compared to 'Liberty'. While 'Duke' did have higher %Ca in stems and whips, depending on stage of development, 'Liberty' had higher %Ca in the old wood, crown, and roots, depending on stage. Cultivar effects on other macro- and micronutrients were inconsistent. Boron concentration was inconsistent for plant parts and stages, with 'Duke' having higher levels at all stages through harvest in fruit, whips, stems, old wood and leaves at senescence, while at the postharvest, senescence and dormancy stages 'Liberty' had higher levels of B in old wood, leaves, stems and crowns. Other studies have shown differences between cultivars in B concentration of leaves (Davis and Strik, 2021; Larco et al., 2013b; Strik and Vance, 2015; Strik et al., 2019) which our study corroborated for other plant parts and stages. Cultivar was the main treatment affecting plant Fe, Mn, and Al concentrations, with higher levels in 'Liberty' at most developmental stages, and lower levels than 'Duke' for Cu and Zn. Cultivar differences in leaf micronutrients have been found in both organic and conventional systems in Oregon (Davis and Strik, 2021; Larco et al., 2013b; Strik et al., 2019; Strik and Vance, 2015). While Zn was lower in 'Duke' leaves than in 'Liberty' during establishment (Larco et al., 2013b) our results confirmed those of Strik et al. (2019) for mature plants. In our region, Fe and Mn deficiencies have been found, but were mostly related to soil pH being above the recommended range (Hart et al., 2006). There was a fertilizer source by cultivar interaction on nutrient concentration for many nutrients (see below).

Fertilizer source. Prior studies in this same planting found that the N concentration of most recent fully expanded leaves in late July to early August (standard sampling time; Hart et al., 2006) was greater when fertilizing with fish than with feather meal, particularly at the high rate (Larco et al., 2013b; Strik et al., 2019). In this study, only the high N rate was included, but using fish as the fertilizer source increased %N in the roots and crown at all stages of growth and in immature and ripe fruit, on average, compared to feather meal; impacts of fertilizer source on %N of other plant parts at various stages, was inconsistent. The lack of an effect of fertilizer source on leaf %N at any stage (immature, postharvest, and senescence), compared to prior findings in this trial (Larco et al., 2013b; Strik et al., 2019), is likely a result of nutrient concentration levels being an average of all leaves on the plant rather than those sampled for standard tissue analysis. Higher %N levels in the roots, crown, and fruit in this study, and most recently expanded leaves in summer (Strik et al., 2019) may indicate more rapid uptake of fertilizer N from fish and accumulation in the predominant storage organs (Bañados, 2006; Bañados et al., 2012) and allocation of some of this fertilizer N to leaves and fruit. Strik et al. (2019) speculated that there was more efficient uptake of fertilizer nutrients when using fish solubles as compared to feather meal and noted that earlier applications of feather meal were needed to ensure the N was available when plants needed it during establishment (Larco et al., 2013b). Application of liquid fertilizers through the drip, as done with fish solubles in this study, has improved fertilizer N availability to blueberry plants (Bryla and Machado, 2011; Vargas and Bryla, 2015) as compared to granular products such as feather meal.

There is evidence that blueberry plants take up more fertilizer N than needed for growth or yield (“luxury uptake”), storing higher levels of N in leaves, shoots, and old wood with either no effect on plant growth or yield or negative effects (Bañados, 2006; Bañados et al., 2012;

Larco et al., 2013b; Strik et al., 2017a, 2019; White, 2006); plant responses to high rates of fertilizer may depend on cultivar or production system (Strik et al., 2017a, 2019). For these reasons, well-timed applications of solid or granular products or low but frequent applications of a liquid source of N timed to be available during shoot and fruit development would meet blueberry plant needs for N (Bañados, 2006; Bañados et al., 2012; Retamales and Hanson, 1989; Throop and Hanson, 1997). Davis and Strik (2021) noted an increase in leaf %N of mature blueberry plants when changing to lower rates of fertilizer N and switching from feather meal or fish solubles to a hydrolyzed soy-protein-based source of N applied through the drip system. They also recorded increases in yield for several years, particularly for plants that had previously received high rates of high rates of N using fish solubles. With some evidence for luxury uptake of N in this study, and a risk of higher rates of fish reducing yield (Strik et al., 2017a), growers should be cautious at using higher rates of N than needed.

Strik et al. (2017a) reported 35% lower cumulative yield of 'Duke' when fertilized with fish as compared to feather meal, whereas there was no effect of fertilizer source on yield of 'Liberty'. In this study, fertilizer source only had an impact on %N in 'Liberty' with higher levels in leaves at immature green fruit stage, roots at postharvest stage, and dormant stems when fertilized with fish as compared to feather. It appears that the impact of fertilizer source on yield (Strik et al., 2017a) was not related to the N source, confirming conclusions by Strik et al. (2019). However, as is common with organic fertilizer sources, the rate of other nutrients applied differed with fish and feather meal, despite similar rates of N. Application of fish increased the rate of P, K, Mg, and B by 7.5-, 11-, 9-, and 21-fold, respectively, as compared to feather meal, whereas feather meal increased Ca application by 7.3-fold (Strik et al., 2019). Davis and Strik

(2021) confirmed that ceasing application of K, in soils that had adequate K, increased plant yield.

Fertilizing with fish solubles increased %P of the roots at all stages (but only for ‘Liberty’ at postharvest stage), the crown at all stages (only for ‘Liberty’ at immature), ripe fruit, leaves postharvest as found in other studies (Larco et al., 2013b; Strik et al., 2019), and stems at postharvest and dormant stages, as compared to feather meal. Higher levels in crown and roots may indicate more availability and plant uptake of P from the fish solubles. However, this was not correlated with increased yield in either cultivar (Strik et al., 2019). Strik and Vance (2015) found that leaf %P was lower in organic blueberry as compared to conventional and that concentrations were near the bottom of currently recommended sufficiency levels (Hart et al., 2006); they recommended a lower sufficiency range (Strik and Davis, 2023). Blueberry plants may have an important, but very low requirement for P.

Levels of K in ripe fruit and leaves postharvest, similar to that previously reported (Larco et al., 2013b; Strik et al., 2019), and leaves at senescence (only with sawdust) were higher with fish than with feather meal; however, the opposite was found for %K in the crown at postharvest and dormant stages and in the roots postharvest (but only for ‘Duke’). Our results confirm higher levels of K in leaves (Strik et al., 2019) and in fruit from fertilization with fish as compared to feather meal. Strik et al. (2019) found that these higher levels of K were negatively correlated with yield in ‘Duke’, but not in ‘Liberty’. Davis and Strik (2021) confirmed that ceasing application of K for these mature plants, reduced soil and leaf K levels and increased plant yield in both cultivars; they recommended a lower sufficiency range for leaf K (Strik and Davis, 2023)

Despite 9-fold higher fertilization of Mg with fish than with feather, there were no measured impacts on tissue %Mg other than higher levels in whips at the immature stage with fish. Feather meal appeared to be a good source of Ca increasing the concentration in both immature and ripe fruit (but only with sawdust mulch). Growers are interested in increasing fruit Ca to improve fruit quality, particularly firmness, so these results are of particular interest. Foliar applications of Ca have been ineffective at increasing fruit Ca in organic and conventional blueberry studies when applied at product label rates (Arrington and DeVetter, 2017; Vance et al., 2017), likely because the stomata of blueberry fruit are only functional at very early stages of development (Yang et al., 2020). Use of feather meal also increased %Ca of dormant roots (only with sawdust) and stems. However, the crown at immature stage had lower %Ca when fertilized with feather meal as compared to fish. It is possible that lower concentrations in various tissues was due to dilution rather than differences in uptake of available nutrients.

Differences in cultivar response to P and K as affected by fertilizer source such as higher %P in the crown at immature stage and the roots at postharvest stage in 'Liberty' but not 'Duke' and higher %K in the roots at postharvest stage only in 'Duke', may point to genetic differences in allocation of available nutrients.

Plants fertilized with fish solubles, particularly for 'Duke', had higher S concentrations in most parts at multiple stages of development, except for postharvest and dormancy where crowns and old wood had greater %S in 'Liberty'. Strik et al. (2019) found similar effects, reporting higher %S in most-recent fully expanded leaves for 'Duke' plants and those fertilized with the high rate of fish. While elemental sulfur is used to reduce soil pH (Sullivan et al., 2015), when needed for blueberry production, high rates of soil-applied S did not affect yield of rabbiteye blueberry (*V. virgatum* Ait.), although %S in leaves increased (Spiers and Braswell, 1992).

Fertilization with fish solubles, as compared to feather meal, increased B concentration of immature fruit (only with weed mat), whips at the immature stage, and roots at postharvest stage, but had no effect on leaves, where fertilization with feather meal increased leaf B during establishment (Larco et al., 2013b). Similarly, Strik et al. (2019) reported higher leaf B with feather meal than fish, in contrast to our study where the average B concentration of all the leaves per plant was not affected by fertilizer source. The relative lack of effect of applying more B with fish than feather meal (Strik et al., 2019), may indicate that foliar applications of sodium tetraborate (borax; OMRI, 2019) or other organically approved boron complexes would be the most effective way to prevent deficiencies (Hart et al., 2006) although more research is needed on B fertilization in organic systems.

Fish fertilizer increased Mn concentration of many plant parts (fruit, whips, leaves, stems, and old wood) at multiple stages, similar to what was reported for leaves when using the high rate of fish, likely due to reductions in soil pH (Strik et al., 2019). There were no consistent effects of fertilizer source on Cu, Zn, and Al concentrations of various plant parts, confirming earlier work in this trial (Strik et al., 2019).

Mulch. Mulch had considerable effect on the nutrient concentration of plant parts at various stages. Plants grown with weed mat had higher %N in many plant parts at all stages of sampling, similar to what was reported for leaves by Strik et al. (2019), but in contrast to what was reported for leaves, fruit, and dormant plant parts for conventionally-grown blueberry during establishment (Strik et al., 2020). In organic blackberries, greater %N was also found in many plant parts with weed mat as compared to bare soil (Harkins et al., 2014).

Weed mat mulch led to increased P and K concentration in various plant parts (stems, crown and roots) at dormancy in both years, but effects were inconsistent for cultivars between plant parts as found previously for leaf tissue during establishment (Larco et al., 2013b, 2014) or the long-term life of the crop overall (Strik et al., 2019). In other studies from this trial, higher leaf %P with weed mat as compared to sawdust was found in young and mature plants as well as leaf %K in mature plants (Larco et al., 2013b; Strik et al., 2019). Weed mat mulch also increased %P and %K in blackberry leaves (Dixon et al., 2016; Fernandez-Salvador et al., 2015; Harkins et al., 2014) and in fruit (Dixon et al., 2016; Harkins et al., 2014) as compared to bare soil, similar to our findings. It is possible that plants grown with weed mat took up more nutrients because soil levels were higher; Strik et al. (2019) reported higher levels of many soil mobile nutrients under weed mat, likely due to less leaching with rainfall.

In contrast, %Ca was greater in multiple plant parts and %Mg was greater in leaves when mulched with sawdust as compared to weed mat, corresponding to results found in most recent fully expanded leaves at this trial site (Larco et al., 2013b; Strik et al., 2019) and for organic blackberries grown with weed mat as compared to bare soil (Dixon et al., 2016).

The use of weed mat mulch resulted in greater B concentration in multiple plant parts including leaves as compared to sawdust mulch. In contrast, earlier reports from this trial found no effect of mulch on leaf B (Larco et al., 2013b) or leaf B was higher for sawdust and compost mulches than for weed mat (Larco et al., 2014) during establishment. The Al concentration in crowns was higher when mulched with sawdust than with weed mat, however it is unclear if this is related to differences in accumulation or concentration/dilution.

Stage of development. There has been relatively little research showing changes in the nutrient concentration in blueberry plant parts over time, other than for leaves where levels in most recently-expanded leaves either decreased (for %N, P, K, S, Cu and Zn) or increased (e.g., %Ca, Mg, B, and Al) from spring to autumn (Bailey et al., 1962; Chuntanaparb and Cummings, 1980; Spiers and Braswell, 1992; Strik and Vance, 2015). While leaf nutrient levels in this study were an average of the whole plant, we observed decreases in concentrations from the immature green fruit stage to the postharvest stage and then to leaf senescence for N, P, K, and S, whereas concentrations of the other nutrients either increased during this time period (Ca, B, Fe, Mn, Al) or remained relatively stable (Mg, Cu, Zn). Declines in average leaf nutrient concentration from postharvest stage to senescence in N, P, K, and S likely indicate remobilization of these nutrients prior to dormancy.

Fruit nutrient concentrations changed during fruit ripening (Bañados et al., 2012; Tamada, 2002; Yang et al., 2020), as found in this study for many fruit nutrients. The concentration of N measured in green fruit and ripe fruit were about half of what was reported for young ‘Bluecrop’ blueberry by Bañados et al. (2012) but were similar to the concentration of N and other macro- and micronutrients reported for ripe fruit by Strik and Vance (2015). The concentration of all macronutrients in ripe fruit, except for Mg, was affected by harvest year, as has been reported by others in blueberry (Bañados, 2006; Bañados et al., 2012; Larco et al., 2013b; Strik and Vance, 2015) and in organic blackberry (Dixon et al., 2016).

In this study, there were effects of fruit harvest date within year and harvest date by year interactions for many fruit nutrients in each cultivar. Fruit nutrient concentrations may be sensitive to weather during fruit development and harvest season, variation in plant water status, and variability in fruit maturity at picking (harvesting crew). Annual climatic changes and preharvest factors directly influence flowering (Tuell and Issacs, 2010), harvest quality and yield (DeEll and Prange, 1998; Remberg et al., 2014) and may be one of the main reasons for the differences between year and harvest time. Fruit maturity and quality factors influence nutrient concentration and can vary depending on picker experience, harvesting method, or harvest frequency (Lobos et al., 2014; Retamales et al., 2012; Strik, 2019). In this study we also noted impacts of fertilizer source and mulch type on fruit nutrient concentrations in both cultivars.

The %N of older wood, crown and roots at the immature green fruit stage in this study were also about half of the levels reported by Bañados et al. (2012) for young plants at a similar stage of development, while %N of leaves (average of whole plant) and shoots were more similar. For dormant plants, %N of roots, crown, old wood and stems were considerably lower than those reported for young plants (Bañados et al., 2012). The %N of more mature or perennial plant parts may have declined with plant age due to a dilution effect.

The pattern of changes in nutrient concentration from immature green fruit stage to dormancy varied by nutrient and plant part. In stems, concentrations of N, P, and Mg tended to decline from immature to postharvest stage, but then levels increased to similar levels again by dormancy. In contrast, %K declined in stems through the season, whereas %Ca increased. Most nutrients in whips declined in concentration from immature to dormancy stages. In old wood, nutrient concentrations remained relatively stable from immature to postharvest stage but then increased (N, Ca, Mg), remained at a similar level (K) or decreased (P) by dormancy. The crown and roots are considered important storage organs for nutrients however, changes in average measured concentrations were relatively small through the season in this study, except for Mg (crown only) and N. In the crown, %N and %Mg tended to decline from immature stage to dormancy. However, in the roots %N increased from immature to postharvest stage (only when fertilized with fish solubles) and then continued to increase. Typically, %N would be expected to decline from bud break to about mid-season in mature plants as stored reserves are used for new growth and fruit development, and then increase to similar levels by the next dormant season to replenish reserves (Bañados, 2006). However, in this study since we were not able to sample plants just prior to bud break we may have missed the opportunity to measure higher %N as well as other nutrients at the start of the growing season.

Dormant plant parts differed in nutrient concentrations between years for all macronutrients except K and S in stems and roots, N and Ca in whips, P and K in old wood, and N and K in the crown, often with a cultivar interaction. Variation in the nutrient concentration of plant parts by year even at similar stages of development has been well documented in blueberry (Bañados et al., 2012; Bryla et al., 2012; Larco et al., 2013b; Strik et al., 2019).

Conclusions

There were significant effects of cultivar on the nutrient concentration of various plant parts throughout the growing season, confirming likely differences in cultivar fertilizer uptake or requirements. Seasonal differences in nutrient concentrations for various plant parts may indicate changes in nutrient uptake or allocation within the plant (Fernandez-Salvador, Chapter 4).

Fertilizing with fish solubles as compared to feather meal, increased the concentration of N and P, in general, in the roots, crown, and fruit, and sometimes in the leaves and stems indicating these nutrients in the fish product were readily available to the plants. The K in fish solubles led to increased %K in fruit and leaves, but decreased levels in the roots and crown compared to feather meal, depending on cultivar. Feather meal was a good source for Ca leading to increased concentrations in the fruit and roots at dormancy, depending on mulch.

Organic growers are increasing use of weed mat as a mulch for benefits related to weed management (Strik and Vance, 2017) with either no effect or increased yield compared to organic mulch sources, depending on cultivar (Strik et al., 2017a). We confirmed an impact of mulch on nutrient concentration, with higher levels of N, P, K, and B and lower Ca and Mg in various plant parts through the season, with weed mat than with sawdust, depending on cultivar. Further information is needed to determine whether these differences are important for fertilizer nutrient recommendations for growers using these mulching systems.

Tables

Table 3-1. Effect of cultivar (‘Duke’, ‘Liberty’), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments on the concentration of macronutrients for various plant parts of mature blueberry grown in a certified organic production system. Plants were destructively harvested at each of three stages (immature green fruit, postharvest, and dormant) in addition to an average of ripe fruit at harvest and leaves at senescence, 2015 (n=5).

Treatments	N		P	K		Ca		Mg		S	
					%						
Developmental Stage:											
Immature											
Green fruit											
Cultivar											
Liberty	1.22 b[y]		0.13 b	0.70 b		0.15		0.08 b		0.09 b	
Duke	1.51 a		0.17 a	0.73 a		0.14		0.09 a		0.11 a	
Fertilizer						Sawdust	Weedmat	Sawdust	Weedmat		
Feather	1.34 b		0.15	0.71		0.17 a	0.14 b	0.086 a	0.079 ab	0.10	
Fish	1.39 a		0.15	0.72		0.13 b	0.14 b	0.080 b	0.084 ab	0.10	
Mulch											
Sawdust	1.31 b		0.15	0.71		0.15		0.08		0.10	
Weed mat	1.42 a		0.15	0.73		0.14		0.08		0.10	
Significance[z]											
Cultivar (C)	0.0006		0.0002	0.006		NS		0.014		0.0001	
Fertilizer(F)	0.046		NS	NS		NS		NS		NS	
Mulch(M)	0.0002		NS	NS		NS		NS		NS	
F x M	NS		NS	NS		0.004		0.006		NS	
Leaves											
Cultivar	Feather	Fish									
Liberty	1.9 b	2.2 a	0.13 b	0.61 b		0.41		0.14		0.14 b	
Duke	2.2 a	2.3 a	0.19 a	0.72 a		0.44		0.14		0.17 a	
Fertilizer											
Feather	2.1		0.16	0.65		0.44		0.14		0.15	
Fish	2.2		0.16	0.68		0.42		0.15		0.15	
Mulch											
Sawdust	2.0 b		0.16	0.64 b		0.43		0.14		0.15 b	
Weed mat	2.3 a		0.16	0.69 a		0.42		0.14		0.16 a	
Significance											
Cultivar(C)	NS		0.0002	0.007		NS		NS		0.004	
Fertilizer(F)	NS		NS	NS		NS		NS		NS	
Mulch(M)	0.0001		NS	0.002		NS		NS		0.011	
C x F	0.010		NS	NS		NS		NS		NS	
Stems											
Cultivar											
Liberty	0.98		0.12 b	0.73 b		0.41		0.10		0.07	
Duke	1.30		0.18 a	0.83 a		0.47		0.16		0.10	
Fertilizer						Sawdust	Weedmat				
Feather	1.12		0.15	0.76		0.51 a	0.40 b	0.12		0.09	
Fish	1.16		0.15	0.79		0.41 ab	0.46 ab	0.13		0.09	
Mulch	Liberty	Duke				Liberty	Duke	Liberty	Duke	Liberty	Duke
Sawdust	0.93 c	1.30 a	0.15	0.76		0.40 b	0.51 a	0.09 b	0.16 a	0.07 b	0.10 a
Weed mat	1.04 b	1.29 a	0.15	0.79		0.43 ab	0.44 ab	0.11 b	0.15 a	0.08 b	0.10 a
Significance											
Cultivar(C)	NS		0.0002	0.0116		NS		NS		NS	
Fertilizer(F)	NS		NS	NS		NS		NS		NS	
Mulch(M)	NS		NS	NS		NS		NS		NS	
C x M	0.025		NS	NS		0.0289		0.036		0.042	
F x M	NS		NS	NS		0.0008		NS		NS	
Whips		-	-	-					-	-	-
Cultivar				Feather	Fish						
Liberty	2.02		0.16 b	0.70 ab	0.68 b	0.28 b		0.12		0.13 b	
Duke	2.26		0.22 a	0.70 ab	0.74 a	0.35 a		0.12		0.15 a	
Fertilizer											
Feather	2.13		0.20	0.70		0.31		0.11 b		0.14	
Fish	2.16		0.18	0.71		0.32		0.12 a		0.14	

Treatments	N	P	K	Ca	Mg	S
			%			
Mulch						
Sawdust	2.01 b	0.18 b	0.69 b	0.33 a	0.12	0.14
Weed mat	2.28 a	0.20 a	0.72 a	0.30 b	0.12	0.14
Significance						
Cultivar(C)	NS	0.001	NS	0.045	NS	0.013
Fertilizer(F)	NS	NS	NS	NS	0.018	NS
Mulch(M)	0.001	0.037	0.039	0.046	NS	NS
C x F	NS	NS	0.045	NS	NS	NS
Old Wood						
Cultivar						
Liberty	0.40 b	0.05 b	0.22 b	0.12	0.03	0.05
Duke	0.54 a	0.06 a	0.29 a	0.15	0.03	0.05
Fertilizer						
Feather	0.45	0.05 b	0.26	0.14	0.03	0.05
Fish	0.49	0.07 a	0.25	0.13	0.03	0.05
Mulch						
Sawdust	0.43 b	0.06	0.25	0.14	0.03	0.05
Weed mat	0.50 a	0.06	0.26	0.13	0.03	0.05
Significance						
Cultivar	0.0019	0.039	0.0009	NS	NS	NS
Fertilizer	NS	0.016	NS	NS	NS	NS
Mulch	0.0118	NS	NS	NS	NS	NS
Crown						
Cultivar		<u>Feather</u> <u>Fish</u>				
Liberty	0.58	0.09 b 0.14 a	0.18	0.15	0.07	0.07
Duke	0.57	0.10 ab 0.12 ab	0.20	0.11	0.05	0.06
Fertilizer						
Feather	0.50 b	0.10	0.19	0.12 b	0.06	0.06 b
Fish	0.65 a	0.13	0.18	0.14 a	0.06	0.08 a
Mulch						
Sawdust	0.56	0.11	0.19	0.13	0.07 a	0.06
Weed mat	0.59	0.11	0.19	0.13	0.05 b	0.07
Significance						
Cultivar (C)	NS	NS	NS	NS	NS	NS
Fertilizer(F)	0.002	NS	NS	0.045	NS	0.0003
Mulch(M)	NS	NS	NS	NS	0.041	NS
C x F	NS	0.016	NS	NS	NS	NS
Roots						
Cultivar			<u>Feather</u> <u>Fish</u>			
Liberty	0.81	0.16	0.26 b 0.26 b	0.18	0.10	0.10
Duke	0.84	0.17	0.28 ab 0.35 a	0.15	0.11	0.09
Fertilizer						
Feather	0.72 b	0.15 b	0.27	0.16	0.10	0.09 b
Fish	0.93 a	0.18 a	0.30	0.17	0.11	0.11 a
Mulch						
Sawdust	0.75 b	0.16	0.29	0.19 a	0.11	0.09 b
Weed mat	0.89 a	0.17	0.28	0.15 b	0.10	0.10 a
Significance						
Cultivar(C)	NS	NS	0.011	NS	NS	NS
Fertilizer(F)	0.0001	0.006	NS	NS	NS	0.001
Mulch(M)	0.003	NS	NS	0.004	NS	0.046
C x F	NS	NS	0.025	NS	NS	NS
<u>Harvest</u>						
Ripe fruit						
Cultivar						
Liberty	0.43 b	0.07 b	0.52	0.05 a	0.03 b	0.048 b
Duke	0.67 a	0.08 a	0.51	0.04 b	0.03 a	0.055 a
Fertilizer				<u>Sawdust</u> <u>Weedmat</u>		<u>Sawdust</u> <u>Weedmat</u>
Feather	0.53 b	0.071 b	0.51 b	0.06 a 0.04 b	0.03	0.047 b 0.054 a
Fish	0.58 a	0.074 a	0.53 a	0.04 b 0.04 b	0.03	0.051 a 0.053 a
Mulch						
Sawdust	0.51 b	0.071 b	0.50 b	0.05	0.03	0.05
Weed mat	0.60 a	0.073 a	0.53 a	0.04	0.03	0.05
Significance						
Cultivar(C)	0.0004	0.001	NS	0.001	0.0001	0.0004
Fertilizer(F)	0.0492	0.001	0.0158	NS	NS	NS
Mulch(M)	0.0006	0.004	0.0003	NS	NS	NS

Treatments	N	P	K	Ca	Mg	S
			%			
F x M	NS	NS	NS	0.0001	NS	0.0008
Post Harvest						
Leaves						
Cultivar						
Liberty	1.27 b	0.08 b	0.55	0.60 b	0.16	0.11 b
Duke	1.48 a	0.09 a	0.58	0.63 a	0.18	0.12 a
Fertilizer						
Feather	1.29 b	0.08 b	0.54 b	0.63	0.17	0.11 b
Fish	1.46 a	0.09 a	0.59 a	0.60	0.17	0.12 a
Mulch			Liberty Duke		Liberty Duke	
Sawdust	1.29 b	0.08 b	0.48 b 0.56 ab	0.67 a	0.155 b 0.194 a	0.11 b
Weed mat	1.46 a	0.09 a	0.62 a 0.61 a	0.57 b	0.156 b 0.161 b	0.12 a
Significance						
Cultivar(C)	0.005	0.0004	NS	0.011	NS	0.0002
Fertilizer(F)	0.002	0.0005	0.018	NS	NS	0.033
Mulch(M)	0.0045	0.0001	NS	0.003	NS	0.029
C x M	NS	NS	0.033	NS	0.014	NS
Stems						
Cultivar						
Liberty	0.58 b	0.07 b	0.32 b	0.66 a	0.07	0.05 b
Duke	0.78 a	0.09 a	0.47 a	0.44 b	0.07	0.06 a
Fertilizer	Sawdust Weedmat					
Feather	0.55 b 0.72 a	0.08 b	0.39	0.55	0.07	0.05 b
Fish	0.70 a 0.73 a	0.09 a	0.40	0.55	0.07	0.06 a
Mulch						
Sawdust	0.63	0.08 b	0.37 b	0.59	0.07	0.05 b
Weed mat	0.73	0.09 a	0.42 a	0.51	0.07	0.06 a
Significance						
Cultivar(C)	0.0001	0.008	0.002	0.027	NS	0.0018
Fertilizer(F)	NS	0.019	NS	NS	NS	0.0038
Mulch(M)	NS	0.018	0.007	NS	NS	0.002
F x M	0.0049	NS	NS	NS	NS	NS
Whips						
Cultivar						
Liberty	1.09 b	0.09 b	0.50 b	0.52 a	0.13	0.09
Duke	1.39 a	0.13 a	0.66 a	0.42 b	0.13	0.10
Fertilizer						
Feather	1.19	0.10	0.56	0.48	0.13	0.09
Fish	1.29	0.12	0.60	0.47	0.14	0.10
Mulch						
Sawdust	1.18	0.11	0.57	0.50 a	0.14	0.09
Weed mat	1.30	0.11	0.59	0.44 b	0.13	0.10
Significance						
Cultivar	0.017	0.026	0.011	0.026	NS	NS
Mulch	NS	NS	NS	0.033	NS	NS
Old Wood						
Cultivar						
Liberty	0.50	0.05	0.23	0.28 a	0.04 a	0.05
Duke	0.48	0.07	0.26	0.12 b	0.03 b	0.05
Fertilizer	Sawdust Weedmat					Sawdust Weedmat
Feather	0.41 b 0.57 a	0.06	0.25	0.21	0.03	0.043 b 0.054 a
Fish	0.48 ab 0.50 ab	0.06	0.25	0.20	0.03	0.049 ab 0.050 ab
Mulch						
Sawdust	0.44	0.05	0.24 b	0.20	0.03	0.05
Weed mat	0.54	0.06	0.26 a	0.20	0.03	0.05
Significance						
Cultivar(C)	NS	NS	NS	0.001	0.0176	NS
Fertilizer (F)	NS	NS	NS	NS	NS	NS
Mulch(M)	NS	NS	0.014	NS	NS	NS
F x M	0.025	NS	NS	NS	NS	0.0370
Crown						
Cultivar						
Liberty	0.48	0.12	0.19	0.07 a	0.03	0.06 a
Duke	0.43	0.09	0.18	0.04 b	0.02	0.04 b
Fertilizer						
Feather	0.42 b	0.09 b	0.20 a	0.06	0.03	0.045 b
Fish	0.49 a	0.11 a	0.17 b	0.05	0.03	0.054 a

Treatments	N		P		K		Ca		Mg		S	
							%					
Mulch			Liberty	Duke								
Sawdust	0.40 b		0.10 b	0.09 b	0.18 b		0.05		0.03		0.046 b	
Weed mat	0.51 a		0.13 a	0.09 b	0.19 a		0.05		0.03		0.053 a	
Significance												
Cultivar(C)	NS		NS		NS		0.043		NS		0.003	
Fertilizer(F)	0.027		0.001		0.001		NS		NS		0.0007	
Mulch(M)	0.001		NS		0.036		NS		NS		0.003	
C x M	NS		0.041		NS		NS		NS		NS	
Roots												
Cultivar	Feather	Fish	Feather	Fish	Feather	Fish					Feather	Fish
Liberty	0.66 b	0.98 a	0.13 b	0.18 a	0.25 c	0.24 c	0.18		0.08		0.07 b	0.10 a
Duke	0.86 ab	0.95 a	0.16 ab	0.17 ab	0.29 b	0.35 a	0.16		0.10		0.08 ab	0.09 ab
Fertilizer	Sawdust	Weedmat										
Feather	0.66 b	0.87 a	0.15		0.27		0.17		0.09		0.08	
Fish	0.95 a	0.98 a	0.17		0.30		0.16		0.09		0.10	
Mulch												
Sawdust	0.80		0.16		0.26 b		0.18		0.09		0.08	
Weed mat	0.92		0.16		0.30 a		0.16		0.08		0.09	
Significance												
Cultivar(C)	NS		NS		NS		NS		NS		NS	
Fertilizer(F)	NS		NS		NS		NS		NS		NS	
Mulch(M)	NS		NS		0.0001		NS		NS		NS	
C x F	0.0087		0.017		0.0002		NS		NS		0.0065	
F x M	0.0397		NS		NS		NS		NS		NS	
Senescence												
Leaves												
Cultivar												
Liberty	0.53		0.04 a		0.48		0.75 b		0.17		0.08 b	
Duke	0.60		0.03 b		0.51		0.85 a		0.18		0.09 a	
Fertilizer					Sawdust	Weedmat	Sawdust	Weedmat				
Feather	0.55		0.03		0.35 b	0.54 a	0.939 a	0.760 b	0.18		0.08	
Fish	0.59		0.03		0.54 a	0.55 a	0.751 b	0.748 b	0.17		0.09	
Mulch												
Sawdust	0.53 b		0.03		0.45		0.85		0.18		0.08	
Weed mat	0.60 a		0.03		0.54		0.75		0.17		0.09	
Significance												
Cultivar(C)	NS		0.013		NS		0.032		NS		0.005	
Fertilizer(F)	NS		NS		NS		NS		NS		NS	
Mulch(M)	0.033		NS		NS		NS		NS		NS	
F x M	NS		NS		0.011		0.013		NS		NS	
Dormant												
Stems												
Cultivar	Feather	Fish							Feather	Fish	Feather	Fish
Liberty	1.09 b	1.30 a	0.12		0.34 b		0.93 a		0.10 a	0.10 a	0.086 ab	0.095 a
Duke	1.07 b	1.05 b	0.12		0.41 a		0.46 b		0.08 b	0.07 b	0.082 b	0.077 b
Fertilizer												
Feather	1.08		0.115 b		0.37		0.76 a		0.09		0.08	
Fish	1.18		0.122 a		0.38		0.63 b		0.08		0.09	
Mulch												
Sawdust	1.03 b		0.115 b		0.37 b		0.69		0.08		0.08 b	
Weed mat	1.22 a		0.122 a		0.38 a		0.71		0.09		0.09 a	
Significance												
Cultivar(C)	NS		NS		0.0008		0.0026		NS		NS	
Fertilizer(F)	NS		0.037		NS		0.0091		NS		NS	
Mulch(M)	0.0003		0.032		0.048		NS		NS		0.0005	
C x F	0.0147		NS		NS		NS		0.041		0.0063	
Whips												
Cultivar												
Liberty	0.74		0.09 b		0.42		0.29		0.06		0.06 b	
Duke	0.86		0.11 a		0.44		0.27		0.06		0.07 a	
Fertilizer												
Feather	0.76 b		0.10		0.44		0.29		0.06		0.06	
Fish	0.84 a		0.10		0.42		0.27		0.05		0.06	
Mulch												
Sawdust	0.75 b		0.10		0.42		0.30		0.06		0.06 b	
Weed mat	0.85 a		0.11		0.44		0.26		0.05		0.07 a	

Treatments	N	P	K	Ca	Mg	S
			%			
Significance						
Cultivar	NS	0.018	NS	NS	NS	0.021
Fertilizer	0.021	NS	NS	NS	NS	NS
Mulch	0.011	NS	NS	NS	NS	0.022
Old Wood						
Cultivar						
Liberty	0.78 a	0.08	0.26	0.44 a	0.06 a	0.07 a
Duke	0.65 b	0.07	0.25	0.16 b	0.03 b	0.06 b
Fertilizer	Sawdust / Weedmat					
Feather	0.60 b / 0.78 a	0.07	0.25	0.30	0.05	0.06
Fish	0.72 ab / 0.76 a	0.08	0.26	0.29	0.04	0.06
Mulch						
Sawdust	0.66	0.07	0.25	0.29	0.04	0.06
Weed mat	0.77	0.08	0.26	0.30	0.05	0.07
Significance						
Cultivar(C)	0.004	NS	NS	0.0001	0.0001	0.0015
Fertilizer (F)	NS	NS	NS	NS	NS	NS
Mulch(M)	NS	NS	NS	NS	NS	NS
F x M	0.028	NS	NS	NS	NS	NS
Crown						
Cultivar						
Liberty	0.60	0.11	0.21	0.08	0.04	0.07 a
Duke	0.44	0.09	0.20	0.05	0.03	0.05 b
Fertilizer						
Feather	0.47 b	0.09 b	0.22 a	0.06	0.03	0.05 b
Fish	0.57 a	0.11 a	0.20 b	0.07	0.03	0.06 a
Mulch						
Sawdust	0.48	0.09	0.20 b	0.06	0.03	0.05
Weed mat	0.55	0.11	0.21 a	0.07	0.04	0.06
Significance						
Cultivar	NS	NS	NS	NS	NS	0.010
Fertilizer	0.017	0.012	0.014	NS	NS	0.012
Mulch	NS	NS	0.046	NS	NS	NS
Roots						
Cultivar			Feather / Fish			
Liberty	1.01	0.17	0.26 b / 0.26 b	0.18 a	0.09	0.10
Duke	1.06	0.17	0.28 b / 0.32 a	0.13 b	0.10	0.10
Fertilizer	Sawdust / Weedmat			Sawdust / Weedmat		Sawdust / Weedmat
Feather	0.80 b / 1.12 a	0.15 b	0.27	0.18 a / 0.16 ab	0.10	0.08 b / 0.10 ab
Fish	1.09 a / 1.14 a	0.18 a	0.29	0.13 b / 0.14 b	0.09	0.11 a / 0.11 a
Mulch						
Sawdust	0.95	0.16	0.27 b	0.15	0.09	0.09 b
Weed mat	1.13	0.17	0.29 a	0.15	0.09	0.11 a
Significance						
Cultivar(C)	NS	NS	NS	0.001	NS	NS
Fertilizer(F)	NS	0.022	NS	NS	NS	NS
Mulch(M)	NS	NS	0.006	NS	NS	0.024
C x F	NS	NS	0.011	NS	NS	NS
F x M	0.035	NS	NS	0.044	NS	0.041

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different (P > 0.05).

Table 3-2. Effect of cultivar (‘Duke’, ‘Liberty’), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments on the concentration of micronutrients for various plant parts of mature blueberry grown in a certified organic production system. Plants were destructively harvested on each of three stages (immature green fruit, postharvest, and dormant) in addition to an average of ripe fruit at harvest and leaves at senescence, 2015 (n=5).

Treatments	B		Fe	Mn		Cu		Zn		Al
					ppm					
Developmental Stage:										
Immature Green fruit										
Cultivar								Feather	Fish	
Liberty	19 b[y]		32 b	92 a		5		13 b	14 b	50 b
Duke	29 a		45 a	67 b		9		21 a	20 a	126 a
Fertilizer	Sawdust	Weedmat								
Feather	23 b	22 b	39	72 b		7		17		90
Fish	23 b	28 a	38	87 a		7		17		86
Mulch										
Sawdust	23		38	75		8		17		90
Weed mat	25		40	84		6		17		86
Significance[z]										
Cultivar(C)	0.003		0.040	0.022		NS		NS		0.002
Fertilizer(F)	NS		NS	0.023		NS		NS		NS
C x F	NS		NS	NS		NS		0.047		NS
F x M	0.003		NS	NS		NS		NS		NS
Leaves										
Cultivar						Feather	Fish	Feather	Fish	
Liberty	45		69 a	217 a		4 b	4 ab	13 c	15 bc	78
Duke	56		50 b	165 b		5 a	4 ab	19 a	17 ab	76
Fertilizer						Sawdust	Weedmat			
Feather	47		59	177		5 a	4 ab	16		79
Fish	54		60	205		4 b	4 ab	16		74
Mulch										
Sawdust	43 b		54 b	174		4		16		73
Weed mat	58 a		65 a	208		4		16		81
Significance										
Cultivar(C)	NS		0.0075	0.017		NS		NS		NS
Mulch(M)	0.0016		0.0019	NS		NS		NS		NS
C x F	NS		NS	NS		0.008		0.013		NS
F x M	NS		NS	NS		0.009		NS		NS
Stems										
Cultivar										
Liberty	14 b		33	265 a		8.3 a		43		35
Duke	21 a		36	195 b		7.5 b		45		48
Fertilizer				Sawdust	Weedmat			Sawdust	Weedmat	
Feather	16		35	216 ab	201 b	8		45 ab	44 ab	42
Fish	19		35	229 b	274 a	8		39 b	49 a	41
Mulch								Liberty	Duke	
Sawdust	16 b		34	223		8		39 b	46 ab	43
Weed mat	19 a		36	238		8		48 a	45 ab	40
Significance										
Cultivar(C)	0.015		NS	0.012		0.017		NS		NS
Mulch(M)	0.010		NS	NS		NS		NS		NS
C x M	NS		NS	NS		NS		0.030		NS
F x M	NS		NS	0.041		NS		0.021		NS
Whips										
Cultivar										
Liberty	27 b		65 a	108		4 b		13 b		66
Duke	40 a		45 b	113		6 a		23 a		67
Fertilizer										
Feather	29 b		55	92 b		5 a		19 a		70
Fish	38 a		55	129 a		4 b		17 b		64
Mulch										
Sawdust	30		54	112		5		18		68
Weed mat	37		56	108		5		19		66
Significance										

Treatments	B	Fe	Mn	Cu	Zn	Al
			ppm			
Cultivar	0.031	0.011	NS	0.003	0.0001	NS
Fertilizer	0.026	NS	0.001	0.004	0.029	NS
Old Wood						
Cultivar						
Liberty	8 b	188 a	368 b	23 b	21	190 a
Duke	11 a	59 b	578 a	41 a	25	67 b
Fertilizer						
Feather	10	140	430	31	27	141
Fish	10	107	515	33	20	117
Mulch						
Sawdust	10	116	450	34	23	125
Weed mat	10	131	496	30	23	133
Significance						
Cultivar	0.031	0.008	0.038	0.005	NS	0.010
Crown						
Cultivar			<u>Feather</u> <u>Fish</u>			
Liberty	7	3598	323 b 383 ab	19 a	39	3103
Duke	5	1750	487 a 421 ab	10 b	28	1666
Fertilizer						
Feather	5	2439	405	13	30 b	2208
Fish	6	2909	402	15	37 a	2561
Mulch	<u>Liberty</u> <u>Duke</u>					
Sawdust	5 b 4 b	3584 a	447 a	13	34	3084 a
Weed mat	8 a 5 b	1764 b	360 b	16	33	1685 b
Significance						
Cultivar(C)	NS	NS	NS	0.004	NS	NS
Fertilizer(F)	NS	NS	NS	NS	0.035	NS
Mulch(M)	NS	0.016	0.0007	NS	NS	0.0245
C x F	NS	NS	0.009	NS	NS	NS
C x M	0.0125	NS	NS	NS	NS	NS
Roots						
Cultivar						
Liberty	5	4920	403 b	13	27	4627
Duke	5	3817	581 a	15	25	3457
Fertilizer						
Feather	5	4246	496	10	24	3920
Fish	5	4491	487	11	28	4164
Mulch						
Sawdust	5	4676	504	11	26	4345
Weed mat	5	4061	479	10	26	3739
Significance						
Cultivar	NS	NS	0.0103	NS	NS	NS
<u>Harvest</u>						
Ripe fruit						
Cultivar				<u>Feather</u> <u>Fish</u>		
Liberty	7 b	17	22	1.8 b 2.0 ab	4 b	118
Duke	9 a	16	19	2.6 ab 2.4 ab	6 a	95
Fertilizer						
Feather	8	16	19	2	5	110
Fish	8	16	21	2	5	103
Mulch			<u>Liberty</u> <u>Duke</u>			
Sawdust	7.5 b	16	20 ab 21 ab	2	5	115 a
Weed mat	8.5 a	17	23 a 17 b	2	5	98 b
Significance						
Cultivar(C)	0.003	NS	NS	NS	0.0001	NS
Mulch(M)	0.006	NS	NS	NS	NS	0.042
C x M	NS	NS	0.008	NS	NS	NS
C x F	NS	NS	NS	0.022	NS	NS
<u>Post Harvest</u>						
Leaves						
Cultivar						
Liberty	58	247 a	220 a	2.0 b	10	273 a
Duke	61	182 b	172 b	2.4 a	11	209 b
Fertilizer						

Treatments	B	Fe	Mn	Cu	Zn	Al
			ppm			
Feather	55	206	166 b	2	10	235
Fish	64	223	226 a	2	12	248
Mulch						
Sawdust	57	209	203	2	11	244
Weed mat	62	220	189	2	11	238
Significance						
Cultivar	NS	0.010	0.0055	0.030	NS	0.019
Fertilizer	NS	NS	0.0171	NS	NS	NS
Stems						
Cultivar						
Liberty	14	57 b	304 a	4	22	77
Duke	15	89 a	236 b	6	25	97
Fertilizer						
Feather	14	69	218 b	5	23	81
Fish	15	76	322 a	6	25	93
Mulch						
Sawdust	14	72	277	6	23	90
Weed mat	15	73	263	5	24	84
Significance						
Cultivar	NS	0.034	0.0077	NS	NS	NS
Fertilizer	NS	NS	0.0027	NS	NS	NS
Whips						
Cultivar		Feather Fish				
Liberty	34	157 ab 194 a	154	3	11 b	198
Duke	26	142 b 117 b	103	3	15 a	153
Fertilizer						
Feather	29	150	119	3	12	169
Fish	32	155	139	3	14	182
Mulch						
Sawdust	29	145	135	3	13	166
Weed mat	32	159	123	3	13	185
Significance						
Cultivar(C)	NS	NS	NS	NS	0.031	NS
Fertilizer (F)	NS	NS	NS	NS	NS	NS
C x F	NS	0.017	NS	NS	NS	NS
Old Wood						
Cultivar						
Liberty	13 a	149	501	46 a	28 a	151
Duke	7 b	162	514	19 b	14 b	172
Fertilizer						
Feather	10	172	460 b	32	20	176
Fish	10	139	556 a	33	22	147
Mulch						
Sawdust	9	163	504	33	20	165
Weed mat	10	148	511	32	22	158
Significance						
Cultivar	0.0008	NS	NS	0.011	0.019	NS
Fertilizer	NS	NS	0.0259	NS	NS	NS
Crown						
Cultivar			Feather Fish	Feather Fish		
Liberty	3	291	321 b 302 b	4 ab 6 a	36 a	327
Duke	2	534	493 a 576 a	3 b 3 b	12 b	544
Fertilizer		Sawdust Weedmat				
Feather	3	745 a 241 b	407	4	20 b	503
Fish	3	359 ab 306 ab	439	4	28 a	368
Mulch	Liberty Duke					
Sawdust	3 ab 2 b	552	414	4	22 b	555 a
Weed mat	4 a 2 b	274	432	4	26 a	316 b
Significance						
Cultivar(C)	NS	NS	NS	NS	0.0002	NS
Fertilizer(F)	NS	NS	NS	NS	0.0001	NS
Mulch(M)	NS	NS	NS	NS	0.0222	0.024
C x F	NS	NS	0.017	0.0498	NS	NS
C x M	0.048	NS	NS	NS	NS	NS
F x M	NS	0.048	NS	NS	NS	NS
Roots						
Cultivar						
Liberty	5	2847	307 b	9 a	20	2845

Treatments	B	Fe	Mn	Cu	Zn	Al
			ppm			
Duke	5	2538	499 a	7 b	21	2505
Fertilizer						
Feather	4.5 b	2492	380	7	18 b	2565
Fish	5.2 a	2893	426	9	22 a	2785
Mulch						
Sawdust	4 b	3314	429	8	21	3164
Weed mat	5 a	2071	377	8	20	2186
Significance						
Cultivar	NS	NS	0.023	0.011	NS	NS
Fertilizer	0.024	NS	NS	NS	0.041	NS
Mulch	0.004	NS	NS	NS	NS	NS
Senescence						
Leaves						
Cultivar						
Liberty	68 b	346	311 a	3 b	11	354
Duke	81 a	305	269 b	5 a	15	389
Fertilizer						
Feather	72	316	274	4	14	361
Fish	77	335	307	4	13	382
Mulch					Liberty Duke	
Sawdust	68 b	321	291	4	11 b 17 a	353
Weed mat	81 a	330	289	4	12 b 14 ab	390
Significance						
Cultivar(C)	0.016	NS	0.0296	0.008	NS	NS
Mulch(M)	0.004	NS	NS	NS	NS	NS
C x M	NS	NS	NS	NS	0.045	NS
Dormant						
Stems						
Cultivar					Feather Fish	
Liberty	27 a	73 a	487 a	4 a	30 a 26 b	85 a
Duke	15 b	42 b	277 b	3 b	29 a 25 b	53 b
Fertilizer						
Feather	21	62 a	365	4	27	74 a
Fish	21	53 b	399	3	26	64 b
Mulch						
Sawdust	19 b	53	366	4	25	65
Weed mat	22 a	62	398	4	27	73
Significance						
Cultivar(C)	0.0002	0.001	0.0004	0.010	NS	0.0015
Fertilizer(F)	NS	0.030	NS	NS	NS	0.0258
Mulch(M)	0.021	NS	NS	NS	NS	NS
C x F	NS	NS	NS	NS	0.020	NS
Whips						
Cultivar						
Liberty	9	118	255	3	13 b	131
Duke	8	43	248	3	16 a	59
Fertilizer						
Feather	8	96	241	3	14	109
Fish	8	65	261	3	15	81
Mulch						
Sawdust	8	69	259	3	15	82
Weed mat	8	92	243	3	14	107
Significance						
Cultivar	NS	NS	NS	NS	0.044	NS
Old Wood						
Cultivar						
Liberty	11 a	79 a	555	23	31 a	93 a
Duke	6 b	43 b	479	22	21 b	55 b
Fertilizer						
Feather	8	60	487	21	25	72
Fish	9	62	547	25	27	76
Mulch						
Sawdust	8 b	61	506	23	25	74
Weed mat	9 a	61	528	22	27	74
Significance						

Treatments	B	Fe	Mn	Cu	Zn		Al
			ppm				
Cultivar	0.0001	0.001	NS	NS	0.046		0.0001
Mulch	0.022	NS	NS	NS	NS		NS
Crown							
Cultivar					Feather	Fish	
Liberty	3 a	328 a	406 b	6	49 b	71 a	366 a
Duke	2 b	158 b	537 a	3	17 c	18 c	176 b
Fertilizer							
Feather	3	235	468	4	33.0		258
Fish	3	252	476	5	44.4		284
Mulch					Liberty	Duke	
Sawdust	3	278	465	4 b	50 b	15 c	302
Weed mat	3	208	479	6 a	70 a	19 c	240
Significance							
Cultivar(C)	0.045	0.046	0.018	NS	NS		0.022
Fertilizer (F)	NS	NS	NS	NS	NS		NS
Mulch(M)	NS	NS	NS	0.027	NS		NS
C x F	NS	NS	NS	NS	0.003		NS
C x M	NS	NS	NS	NS	0.022		NS
Roots							
Cultivar							
Liberty	5	2770	339	8	25		2751
Duke	4	2034	432	7	24		2222
Fertilizer							
Feather	5	2714	395	8	23		2761
Fish	4	2089	376	8	25		2212
Mulch							
Sawdust	4 b	2428	392	8	22		2468
Weed mat	5 a	2375	379	8	26		2505
Significance							
Mulch(M)	0.028	NS	NS	NS	NS		NS

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different (P > 0.05).

Table 3-3. Effect of year (2015, 2016), cultivar ('Duke', 'Liberty'), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments on the concentration of macronutrients for various plant parts of mature blueberry grown in a certified organic production system. Plants were destructively harvested in winter, when dormant (n=5).

Treatments	N		P		K		Ca		Mg		S	
						%						
Plant part:												
Stems												
Year	Liberty	Duke	Liberty	Duke			Liberty	Duke	Liberty	Duke		
2015	1.20 a[y]	1.06 ab	0.12 b	0.12 b	0.38		0.93 a	0.46 c	0.10 a	0.07 c	0.08	
2016	0.92 b	1.13 a	0.14 a	0.15 a	0.37		0.69 b	0.41 c	0.09 b	0.07 c	0.09	
Cultivar												
Liberty	1.06		0.13		0.35		0.81		0.10		0.09	
Duke	1.10		0.14		0.40		0.43		0.07		0.08	
Fertilizer												
Feather	1.05		0.13		0.37		0.66		0.08		0.08	
Fish	1.11		0.13		0.38		0.58		0.08		0.09	
Mulch					Liberty	Duke						
Sawdust	0.99		0.13 b		0.330 c	0.404 a	0.63		0.08		0.08 b	
Weed mat	1.16		0.14 a		0.366 b	0.401 ab	0.62		0.09		0.09 a	
Significance[z]												
Year(Y)	NS		NS		NS		NS		NS		NS	
Cultivar(C)	NS		NS		NS		NS		NS		NS	
Mulch(M)	NS		0.0001		NS		NS		NS		0.0001	
Y x C	0.0001		0.0001		NS		0.0036		0.014		NS	
C x M	NS		NS		0.0004		NS		NS		NS	
Whips												
Year												
2015	0.80		0.10 b		0.43 b		0.28		0.055 b		0.06 b	
2016	0.83		0.13 a		0.50 a		0.26		0.061 a		0.07 a	
Cultivar												
Liberty	0.78 b		0.11 b		0.45		0.28		0.056 b		0.06 b	
Duke	0.86 a		0.13 a		0.48		0.26		0.060 a		0.07 a	
Fertilizer												
Feather	0.78 b		0.11		0.46		0.27		0.06		0.066 b	
Fish	0.86 a		0.12		0.46		0.27		0.06		0.070 a	
Mulch												
Sawdust	0.78 b		0.12		0.46		0.28		0.06		0.06 b	
Weed mat	0.85 a		0.12		0.46		0.26		0.06		0.07 a	
Significance												
Year	NS		0.0001		0.0005		NS		0.038		0.0001	
Cultivar	0.032		0.003		NS		NS		0.025		0.031	
Fertilizer	0.019		NS		NS		NS		NS		0.023	
Mulch	0.020		NS		NS		NS		NS		0.001	
Old Wood												
Year	Liberty	Duke					Liberty	Duke	Liberty	Duke	Liberty	Duke
2015	0.78 a	0.65 b	0.07		0.26		0.44 a	0.16 c	0.06 a	0.03 c	0.07 a	0.06 b
2016	0.54 c	0.62 b	0.08		0.25		0.24 b	0.15 c	0.04 b	0.03 c	0.06 b	0.06 b
Cultivar												
Liberty	0.66		0.08		0.26		0.34		0.05		0.07	
Duke	0.63		0.08		0.25		0.15		0.03		0.06	
Fertilizer			2015	2016								
Feather	0.62		0.07 b	0.07 b	0.25		0.25		0.04		0.06	
Fish	0.68		0.08 ab	0.09 a	0.26		0.24		0.04		0.06	
Mulch			2015	2016								
Sawdust	0.62 b		0.07 b	0.07 b	0.25		0.24		0.04		0.06 b	
Weed mat	0.68 a		0.08 ab	0.09 a	0.26		0.25		0.04		0.07 a	
Significance												
Year(Y)	NS		NS		NS		NS		NS		NS	
Cultivar(C)	NS		NS		NS		NS		NS		NS	
Fertilizer(F)	NS		NS		NS		NS		NS		NS	
Mulch(M)	0.010		NS		NS		NS		NS		0.0001	
Y x C	0.0001		NS		NS		0.0001		0.0001		0.002	
Y x F	NS		0.024		NS		NS		NS		NS	

Treatments	N	P	K	Ca	Mg	S
			%			
Y x M	NS	0.039	NS	NS	NS	NS
Crown						
Year						
2015	0.52	0.10 b	0.21	0.06 b	0.03 b	0.055 b
2016	0.57	0.11 a	0.20	0.08 a	0.04 a	0.062 a
Cultivar						
Liberty	0.61	0.12 a	0.21 a	0.08	0.04	0.07 a
Duke	0.48	0.10 b	0.19 b	0.06	0.03	0.05 b
Fertilizer						
Feather	0.51	0.10 b	0.21	0.08	0.04	0.05 b
Fish	0.58	0.12 a	0.19	0.07	0.04	0.06 a
Mulch						
Sawdust	0.52	0.10 b	0.20	0.07	0.03	0.06
Weed mat	0.57	0.11 a	0.21	0.08	0.04	0.06
Significance						
Year	NS	0.023	NS	0.0027	0.006	0.022
Cultivar	NS	0.017	0.0365	NS	NS	0.002
Fertilizer	NS	0.006	NS	NS	NS	0.000
Mulch	NS	0.011	NS	NS	NS	NS
Roots						
Year	Liberty Duke					
2015	1.01 ab 1.06 ab	0.17 b	0.28	0.15 a	0.09 a	0.100
2016	1.20 a 0.85 b	0.19 a	0.26	0.12 b	0.08 b	0.092
Cultivar						
Liberty	1.11	0.18	0.26 b	0.16 a	0.09	0.102 a
Duke	0.95	0.17	0.28 a	0.11 b	0.08	0.091 b
Fertilizer	Sawdust Weedmat					Sawdust Weedmat
Feather	0.83 b 1.09 ab	0.16 b	0.26	0.15 a	0.08	0.08 b 0.10 a
Fish	1.08 ab 1.13 ab	0.19 a	0.28	0.12 b	0.09	0.10 a 0.11 a
Mulch						
Sawdust	0.95	0.17	0.26 b	0.13	0.08	0.088
Weed mat	1.11	0.18	0.28 a	0.14	0.09	0.104
Significance						
Year(Y)	NS	0.009	NS	0.0001	0.032	NS
Cultivar(C)	NS	NS	0.0290	0.0002	NS	0.023
Fertilizer(F)	NS	0.005	NS	0.0022	NS	NS
Mulch(M)	NS	NS	0.0107	NS	NS	NS
Y x C	0.0001	NS	NS	NS	NS	NS
F x M	0.014	NS	NS	NS	NS	0.013

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different (P > 0.05).

Table 3-4. Effect of year (2015, 2016), cultivar (‘Duke’, ‘Liberty’), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments on the concentration of micronutrients for various plant parts of mature blueberry grown in a certified organic production system. Plants were destructively harvested in winter, when dormant (n=5).

Treatments	B		Fe		Mn		Cu	Zn	Al	
					ppm					
Plant part:										
Stems										
Year	Liberty	Duke	Liberty	Duke	Liberty	Duke			Liberty	Duke
2015	27 a[y]	15 c	73 a	42 c	487 a	277 b	4	26	85 a	53 b
2016	22 b	17 c	62 ab	57 b	303 b	199 c	4	26	60 b	62 b
Cultivar										
Liberty	25		67		395		4 a	24 b	72	
Duke	16		49		238		3 b	28 a	57	
Fertilizer										
Feather	20		61		298		4	26	68	
Fish	20		56		334		4	26	62	
Mulch										
Sawdust	19		57		312		3.5 b	24 b	64	
Weed mat	21		60		321		3.8 a	27 a	66	
Significance[z]										
Year(Y)	NS		NS		NS		NS	NS	NS	
Cultivar(C)	NS		NS		NS		0.001	0.005	NS	
Fertilizer(F)	NS		NS		NS		NS	NS	NS	
Mulch(M)	NS		NS		NS		0.046	0.002	NS	
Y x C	0.0001		0.0001		0.0002		NS	NS	0.0001	
C x M	NS		NS		NS		NS	NS	NS	
Whips										
Year			Liberty	Duke						
2015	8		89 a	43 b	251 a		3	15	95 a	
2016	9		34 b	33 b	200 b		3	14	32 b	
Cultivar										
Liberty	9		76		215		3	12	80	
Duke	8		38		236		3	17	46	
Fertilizer										
Feather	8		65		222		3	13	70	
Fish	9		49		229		3	16	57	
Mulch										
Sawdust	9		50		236		3	14	57	
Weed mat	9		64		215		3	15	69	
Significance										
Year(Y)	NS		NS		0.0072		NS	NS	0.0001	
Cultivar(C)	NS		NS		NS		NS	NS	NS	
Fertilizer(F)	NS		NS		NS		NS	NS	NS	
Mulch(M)	NS		NS		NS		NS	NS	NS	
Y x C	NS		0.013		NS		NS	NS	NS	
Old Wood										
Year	Liberty	Duke	Liberty	Duke	Liberty	Duke			Liberty	Duke
2015	11 a	6 b	79 a	43 c	555 a	479 a	23 a	26	93 b	55 b
2016	7 b	6 b	57 b	56 b	340 b	533 a	9 b	30	56 b	52 b
Cultivar										
Liberty	9		68		448		15	29	75	
Duke	6		50		506		17	27	54	
Fertilizer										
Feather	7		61		453		15	29	66	
Fish	8		57		501		16	27	63	
Mulch										
Sawdust	7		60		481		16	27	65	
Weed mat	8		58		473		15	29	63	
Significance										
Year(Y)	NS		NS		NS		0.0001	NS	NS	
Cultivar(C)	NS		NS		NS		NS	NS	NS	
Fertilizer(F)	NS		NS		NS		NS	NS	NS	
Mulch(M)	NS		NS		NS		NS	NS	NS	

Treatments	B	Fe	Mn	Cu	Zn	Al
			ppm			
Y x C	0.0001	0.0001	0.0001	NS	NS	0.0001
Y x F	NS	NS	NS	NS	NS	NS
Y x M	NS	NS	NS	NS	NS	NS
Crown						
Year					Liberty Duke	
2015	2.9 b	243 b	472 a	5 b	60 a 17 c	271 b
2016	3.3 a	1298 a	397 b	7 a	44 b 21 c	1244 a
Cultivar						
Liberty	3	950	362 b	7 a	52	929
Duke	3	591	507 a	4 b	19	586
Fertilizer						
Feather	3	883	443	5	31	854
Fish	3	658	426	6	40	661
Mulch	Liberty Duke				Liberty Duke	
Sawdust	3 b 3 b	826	434	5 b	44 b 18 c	804
Weed mat	4 a 3 b	715	435	7 a	61 a 20 c	711
Significance						
Year(Y)	0.0071	0.0001	0.0004	0.005	NS	0.0001
Cultivar(C)	NS	NS	0.0057	0.015	NS	NS
Fertilizer(F)	NS	NS	NS	NS	NS	NS
Mulch(M)	NS	NS	NS	0.015	NS	NS
Y x C	NS	NS	NS	NS	0.0002	NS
C x M	0.0322	NS	NS	NS	0.004	NS
Roots						
Year				Liberty Duke		
2015	5 a	2402	386	8 a 7 a	24 a	2487
2016	4 b	2065	362	8 a 4 b	19 b	2067
Cultivar						
Liberty	5 a	2800	320 b	8	23	2797
Duke	4 b	1667	428 a	6	20	1757
Fertilizer						
Feather	4	2179	384	7	20	2241
Fish	4	2288	364	7	23	2313
Mulch						
Sawdust	4 b	2110	374	7	19	2141
Weed mat	5 a	2356	374	7	24	2412
Significance						
Year(Y)	0.0206	NS	NS	NS	0.002	NS
Cultivar(C)	0.0389	NS	0.0352	NS	NS	NS
Fertilizer(F)	NS	NS	NS	NS	NS	NS
Mulch(M)	0.0001	NS	NS	NS	NS	NS
Y x C	NS	NS	NS	0.022	NS	NS
F x M	NS	NS	NS	NS	NS	NS

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different (P > 0.05).

Table 3-5. Effect of year (2015, 2016), cultivar ('Duke', 'Liberty'), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments on the concentration of macronutrients in ripe fruit of mature blueberry grown in a certified organic production system. (n=5).

Treatments	N		P		K		Ca		Mg	S	
							%				
2015 - 2016											
Year			Liberty	Duke	Liberty	Duke	Liberty	Duke		Liberty	Duke
2015	0.55 a[y]		0.066 c	0.079 a	0.521 a	0.515ab	0.051 a	0.041 b	0.03	0.048 b	0.055 a
2016	0.49 b		0.067 c	0.074 b	0.504 b	0.516ab	0.050 a	0.049 a	0.03	0.042 c	0.053 a
Cultivar	Feather	Fish									
Liberty	0.38 c	0.39 c	0.07		0.51		0.051		0.028 b	0.04	
Duke	0.61 b	0.69 a	0.08		0.52		0.045		0.035 a	0.05	
Fertilizer	Sawdust	Weedmat					Sawdust	Weedmat		Sawdust	Weedmat
Feather	0.44 b	0.54 a	0.070 b		0.51 b		0.061 a	0.043 b	0.03	0.046 c	0.051 ab
Fish	0.53 a	0.56 a	0.073 a		0.52 a		0.045 b	0.042 b	0.03	0.049 b	0.051 a
Mulch			2015	2016	2015	2016					
Sawdust	0.49		0.071ab	0.071ab	0.50 b	0.514ab	0.053		0.032 a	0.05	
Weed mat	0.55		0.073 a	0.070 b	0.531 a	0.507 b	0.043		0.031 b	0.05	
Significance[z]											
Year(Y)	0.0233		NS		NS		NS		NS	NS	
Cultivar (C)	NS		NS		NS		NS		0.0001	NS	
Fertilizer(F)	NS		0.0011		0.0020		NS		NS	NS	
Mulch(M)	NS		NS		NS		NS		0.0461	NS	
Y x C	NS		0.0136		0.0252		0.0038		NS	0.0094	
Y x M	NS		0.0095		0.0003		NS		NS	NS	
C x F	0.0492		NS		NS		NS		NS	NS	
C x M	NS		NS		NS		NS		NS	NS	
F x M	0.0220		NS		NS		0.0001		NS	0.0115	

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different (P > 0.05).

Table 3-6. Effect of year (2015, 2016), cultivar (‘Duke’, ‘Liberty’), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments on the concentration of micronutrients in ripe fruit of mature blueberry grown in a certified organic production system. (n=5).

Treatments	B		Fe		Mn		Cu	Zn		Al
					ppm					
2015 - 2016										
Year	Liberty	Duke	Liberty	Duke						
2015	6.8 c[y]	9.2 b	17 b	16 b	20		2	5 b		106
2016	11.3 a	8.5 bc	23 a	17 b	18		2	6 a		105
Cultivar	Sawdust	Weedmat			Sawdust	Weedmat		Sawdust	Weedmat	
Liberty	9 b	10 a	20		19 ab	21 a	2.0 b	4 b	5 b	119 a
Duke	9 b	9 b	16		21 a	16 b	2.3 a	6 a	6 a	92 b
Fertilizer										
Feather	9		18		19		2	5		107
Fish	9		18		20		2	5		104
Mulch	2015	2016								
Sawdust	7.5 c	10.0 a	18		20		2	5		111
Weed mat	8.5 b	9.9 a	18		18		2	6		99.7
Significance[z]										
Year(Y)	NS		NS		NS		NS	0.0352		NS
Cultivar (C)	NS		NS		NS		0.0351	NS		0.0102
Fertilizer(F)	NS		NS		NS		NS	NS		NS
Mulch(M)	NS		NS		NS		NS	NS		NS
Y x C	0.0002		0.0200		NS		NS	NS		NS
Y x M	0.0176		NS		NS		NS	NS		NS
C x F	NS		NS		NS		NS	NS		NS
C x M	0.0043		NS		0.0008		NS	0.0455		NS

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different (P > 0.05).

Table 3-7. Effect of year (2015, 2016), harvest (first and second pick in mid- and late-June), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments on the concentration of macronutrients in ripe fruit of mature ‘Duke’ blueberry grown in a certified organic production system. (n=5).

Treatments	N		P		K		Ca	Mg		S	
							%				
Duke											
Year	First	Second	First	Second	First	Second		First	Second	First	Second
2015	0.68 a[y]	0.66 ab	0.09 a	0.07 c	0.53 b	0.50 b	0.04 b	0.034 ab	0.034 ab	0.06 a	0.053 a
2016	0.74 a	0.53 b	0.08 b	0.07 c	0.57 a	0.47 c	0.05 a	0.036 a	0.033 b	0.057 a	0.048 b
Harvest	Feather	First									
First	0.72 a	0.71 a	0.09		0.55		0.05 a	0.04		0.06 a	
Second	0.50 b	0.68 a	0.07		0.49		0.04 b	0.03		0.05 b	
Fertilizer	Sawdust	Weedmat									
Feather	0.55 b	0.67 ab	0.07		0.51 b		0.05 a	0.03		0.052 b	
Fish	0.69 a	0.69 a	0.08		0.53 a		0.04 b	0.03		0.055 a	
Mulch			2015	2016							
Sawdust	0.62		0.077 ab	0.076 ab	0.51		0.05 a	0.04 a		0.05 b	
Weed mat	0.68		0.080 a	0.073 b	0.52		0.04 b	0.03 b		0.06 a	
Significance[z]											
Year(Y)	NS		NS		NS		0.0324	NS		NS	
Harvest (H)	NS		NS		NS		0.0304	NS		0.0002	
Fertilizer(F)	NS		NS		0.0059		0.0018	NS		0.0024	
Mulch(M)	NS		NS		NS		0.0001	0.0293		0.0001	
Y x H	0.0179		0.0085		0.0013		NS	0.0100		0.0058	
Y x M	NS		0.0215		NS		NS	NS		NS	
H x F	0.0022		NS		NS		NS	NS		NS	
F x M	0.0357		NS		NS		NS	NS		NS	

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different (P > 0.05).

Table 3-8. Effect of year (2015, 2016), harvest (first and second pick in mid- and late-June), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments on the concentration of micronutrients in ripe fruit of mature ‘Duke’ blueberry grown in a certified organic production system. (n=5).

Treatments	B	Fe	Mn	Cu		Zn	Al
				ppm			
Duke							
Year				First	Second		
2015	9	16 b[y]	19	2.2 ab	2.8 a	6	95
2016	9	17 a	18	2.3 ab	2.0 b	7	89
Harvest							
First	10 a	16	19	2		7 a	89
Second	8 b	17	18	2		6 b	95
Fertilizer							
Feather	9	16	18	2.4 a		6	90
Fish	9	17	19	2.2 b		7	94
Mulch							
Sawdust	9	17	21 a	2		6	100
Weed mat	9	16	16 b	2		6	84
Significance[z]							
Year(Y)	NS	0.0007	NS	NS		NS	NS
Harvest (H)	0.0003	NS	NS	NS		0.0001	NS
Fertilizer(F)	NS	NS	NS	0.0444		NS	NS
Mulch(M)	NS	NS	0.0003	NS		NS	NS
Y x H	NS	NS	NS	0.0149		NS	NS

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different (P > 0.05).

Table 3-9. Effect of year (2015, 2016), harvest (first, second, and third pick in early-, mid- and late-July), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments on the concentration of macronutrients in ripe fruit of mature ''Liberty' blueberry grown in a certified organic production system. (n=5).

Treatments	N	P	K	Ca	Mg	S
				%		
Liberty						
Year						
2015	0.43	0.07	0.52	0.05	0.03	0.05 a
2016	0.34	0.07	0.50	0.05	0.03	0.04 b
Harvest						
First	0.38	0.07	0.52	0.048 c[y]	0.026 b	0.04
Second	0.40	0.07	0.51	0.054 a	0.028 a	0.04
Third	0.38	0.07	0.51	0.051 b	0.028 a	0.05
Fertilizer					Sawdust Weedmat	Sawdust Weedmat
Feather	0.38	0.065 b	0.51	0.06	0.029 a 0.027 a	0.041 c 0.047 ab
Fish	0.39	0.067 a	0.52	0.05	0.027 a 0.028 a	0.044bc 0.047 a
Mulch	2015 2016		2015 2016			
Sawdust	0.38ab 0.33b	0.065 b	0.50b 0.51b	0.06	0.03	0.04
Weed mat	0.49 a 0.35b	0.067 a	0.54a 0.50b	0.04	0.03	0.05
Significance[z]						
Year(Y)	NS	NS	NS	NS	NS	0.0001
Harvest (H)	NS	NS	NS	0.0094	0.012	NS
Fertilizer(F)	NS	0.0019	NS	NS	NS	NS
Mulch(M)	NS	0.0373	NS	NS	NS	NS
Y x M	0.0304	NS	0.0002	NS	NS	NS
F x M	NS	NS	NS	NS	0.0057	0.0077

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different (P > 0.05).

Table 3-10. Effect of year (2015, 2016), harvest (first, second, and third pick in early-, mid- and late-July), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments on the concentration of micronutrients in ripe fruit of mature ‘’Liberty’ blueberry grown in a certified organic production system. (n=5).

Treatments	B			Fe	Mn		Cu		Zn		Al		
					ppm								
Liberty													
Year	First	Second	Third								First	Second	Third
2015	7 b[y]	6 b	7 b	17 b	22		2		4		105 b	151 b	94 b
2016	8 b	8 b	18 a	23 a	18		2		5		120 ab	112 ab	129 ab
Harvest									Sawdust	Weedmat			
First		7		20	18 b		2		4 b	4 b		113	
Second		7		19	21 a		2		4 b	6 a		132	
Third		12		21	21 a		2		4 b	4 b		113	
Fertilizer							2015	2016					
Feather		9		20	19		2 a	2 a	4			123	
Fish		9		20	21		2 a	2 a	4			115	
Mulch					2015	2016							
Sawdust		9		20	20 ab	19 ab	2		4			123	
Weed mat		10		20	23 a	18 b	2		5			115	
Significance[z]													
Year(Y)		NS		0.0026	NS		NS		NS			NS	
Fertilizer(F)		NS		NS	NS		NS		NS			NS	
Mulch (M)		NS		NS	NS		NS		NS			NS	
Harvest (H)		NS		NS	0.0012		NS		NS			NS	
Y x H		0.0001		NS	NS		NS		NS			0.0053	
Y x F		NS		NS	NS		0.0307		NS			NS	
Y x M		NS		NS	0.004		NS		NS			NS	
H x M		NS		NS	NS		NS		0.0143			NS	

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different (P > 0.05).

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Chapter 4: Organic Production Systems in Northern Highbush Blueberry: Influence of Cultivar, Mulch and Fertilizer Source on Plant Part Biomass, Nutrient Content, Allocation and Losses

Abstract

Little is known about the allocation of nutrients and biomass in mature, organic blueberry systems, which is important for understanding plant requirements for organic fertilizer. Fertilizer source (fish solubles and feather meal at 140 $kg \cdot ha^{-1}$ N), mulch [porous, black propylene ground cover ("weed mat") and sawdust], and cultivar ('Duke' and 'Liberty') were evaluated in mature, certified organic northern highbush blueberry (*Vaccinium corymbosum* L.) for their effect on dry weight (DW) and nutrient content of plant parts (roots, crown, wood, fruit, and leaves) at various stages of development (immature fruit and postharvest in 2015 and dormancy in 2015 and 2016) as well as of ripe fruit and senescent leaves. Treatment effects varied depending on plant part and stage of development. Cultivar had the greatest effect with 'Liberty' having more DW, nutrient content, and losses than 'Duke'. Plants grown with weed mat, on average, had greater DW of senesced leaves than those grown with sawdust and a greater above- to below-ground DW ratio. Plant uptake of N, P, K and B was increased with weed mat compared to sawdust mulch, but the opposite was found for Mg. Weed mat increased N content in green and ripe fruit, in leaves at the postharvest stage, and in dormant stems and old wood. The increased uptake of N with weed mat compared to sawdust was lost in senescent leaves. Mulching with weed mat increased K content in ripe fruit, in leaves and stems at the postharvest stage, and in senescent leaves. Averaged over cultivar and mulch, fertilization with feather meal increased the DW of the roots, green fruit, and the total plant and Ca content of the roots and crown, compared to fish solubles, confirming that feather meal is a good source of Ca for organic blueberry. By contrast,

fertilization with fish increased K uptake compared to feather meal due to the amount of K in the fertilizer (198 kg·ha^{-1} vs. 18 kg·ha^{-1} of K, for fish and feather meal, respectively). Fish fertilization also increased N uptake in whips, compared to feather meal, but this was not found in other plant parts. Fertilizer source had little other impact on nutrient content or losses. The average total estimated losses in harvested fruit, senescent leaves, and pruning wood for the mature planting were 5627 kg·ha^{-1} of DW biomass, 34.8 kg·ha^{-1} of N, 3.5 kg·ha^{-1} of P, 25.2 kg·ha^{-1} of K, 20.7 kg·ha^{-1} of Ca, 4.5 kg·ha^{-1} of Mg, 3.7 kg·ha^{-1} of S, 162 g·ha^{-1} of B, 1038 g·ha^{-1} of Fe, 1336 g·ha^{-1} of Mn, 40 g·ha^{-1} of Cu, and 73 g·ha^{-1} of Zn. If planting management could be modified to recover organic matter and nutrients currently lost in senescent leaves and pruning wood, making them available to the blueberry plants in the row, application of fertilizers could be reduced. Greater nutrient uptake and losses with weed mat, a common mulch used by both conventional and organic blueberry growers, may indicate a need for nutrient management programs specific to this mulch.

Introduction

Certified organic blueberry production has continued to expand in the United States, particularly in the Pacific Northwest (USDA-NASS, 2019; North American Highbush Blueberry Council, unpublished), and the industry has provided strong support for research on specific production systems research (Fernandez-Salvador et al., 2017). Organic production of northern highbush blueberry (*Vaccinium corymbosum* L.) has been studied for more than 15 years in Oregon and has included research on the impacts of different mulch types, fertilizer sources, and cultivars on growth, yield, fruit quality, soil nutrient levels, and nutrient concentration in both young and mature plants (Davis and Strik, 2021; Fernandez-Salvador, Chapter 3; Larco, 2014; Larco et al., 2013a, 2013b; Strik, 2014; Strik et al., 2017a, 2017b, 2019; Strik and Vance, 2017).

Additional studies focused on suitable composts for soil amendments prior to planting and as a surface mulch (Costello, 2011; Costello et al., 2019; Larco et al., 2014; Strik et al., 2017b; Sullivan et al., 2014, 2015). Growers have adopted many new practices based on the aforementioned studies, in particular using weed mat (perforated polypropylene black ground cover) instead of only sawdust as a mulch for most economical weed control and reducing the use or rate of fish solubles as a fertilizer source (Fernandez-Salvador et al., 2017; Strik, 2014, 2016). More recently, some growers are combining weed mat and organic mulch to address issues with decreasing organic matter over time with weed mat over bare soil and reducing the use of fertilizer sources containing high levels of potassium (K), such as fish solubles, when soil and plant levels of K are sufficient (Davis and Strik, 2021).

The impact of fertilizer source, cultivar, mulch type, and irrigation on plant growth and biomass of the total plant or plant parts has been studied for conventional and organic blueberry during establishment (Bañados, 2006; Bañados et al., 2012; Bryla et al., 2012; Burkhard et al., 2009; Larco et al., 2013a; Strik et al., 2020a, 2020b), but little is known about allocation of nutrients and biomass in mature organic blueberry. When weeds were controlled, organic mulches (compost and/or sawdust) often increase aboveground growth in blueberry compared to no mulch or bare ground (Clark and Moore, 1991; Goulart et al., 1997; Pliszka et al., 1993; Savage, 1942; White, 2006). However, Krewer et al. (2009) found more growth with weed mat than with organic mulches in an organic planting of rabbiteye blueberry (*Vaccinium virgatum*) in Georgia. Larco et al. (2013a) reported greater allocation of biomass aboveground than below ground with weed mat than with sawdust mulch during establishment of new planting of organic northern highbush blueberry. By contrast, Strik et al. (2020a) found that conventional blueberry plants had a larger canopy during the growing season and a wider root system and higher crown dry weight (DW) in winter when grown with sawdust mulch than with weed mat over bare soil, depending on year of establishment.

It is generally understood that nutrient uptake in blueberry varies over the course of the growing season, with greater and faster uptake during the main stages of root, shoot, and fruit growth (Bañados, 2006; Bañados et al., 2012; Bryla et al., 2012; Throop and Hanson, 1997). Mobile nutrients are reallocated from the storage tissues (woody stems, crown and roots) to new growth in early spring, and the process is reversed during leaf senescence in autumn (Bañados, 2006; Bañados et al., 2012; Bryla et al., 2012; Fernandez-Salvador, Chapter 3; Strik and Vance, 2015). Fertilizer management can be planned for and adjusted with an understanding of plant nutrient gains and losses (Bryla and Strik, 2015). Nutrient gains in blueberry are related to increases in growth or biomass from one winter to the next, whereas losses include harvested fruit, fallen leaves, and wood removed at pruning. Based on previous studies in blueberry and other berry crops, the nutrient content in pruning material may be affected by weed management techniques, type of mulch, fertilizer source and rate, and cultivar (Bañados, 2006; Bañados et al., 2012; Dixon et al., 2015, 2016; Harkins et al., 2014; Larco et al., 2013a, 2013b, 2014; Spiers and Braswell, 1992; Strik et al., 2020b).

The objective of this study was to determine the impact of cultivar, mulch, and fertilizer source on the allocation of biomass and nutrients at different stages of seasonal development for mature northern highbush blueberry plants grown in a long-term study on different organic management systems. Nutrient removal during fruit harvest, leaf fall, and pruning were also evaluated to help inform possible strategies to recycle biomass and nutrients in fertility management programs.

Materials and Methods

Site and planting design. The study was conducted in 2015 and 2016 as part of a 0.4-ha trial of mature, certified organic blueberry at the North Willamette Research and Extension Center in Aurora, OR (NWREC) [(lat. 45°17’ N, long.122°45’ W; elevation 46 m; USDA hardiness zone 8b (2012)]. The planting was initially certified organic by a USDA-accredited agency (Oregon Tilth Certified Organic, Corvallis, OR) in 2008, and organic certification was continued throughout this study. The soil at the site was a Willamette silt loam (a fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll). For more information on soil properties and nutrient levels and planting establishment practices, refer to Larco et al. (2013a, 2013b) and Strik et al. (2017a, 2019).

The spacing between plants was 0.8 m in the row with 3.0 m between rows (4385 plants/ha). Row aisles were planted with a permanent fescue grass (*Festulolium braunii* K. Richt.) cover, which was mowed during the growing season as necessary. Irrigation was applied through single-line polyethylene drip tubing (Netafim, Fresno, CA) with 2 $L \cdot h^{-1}$ pressure compensating emitters spaced every 0.3 m. Irrigation was adjusted as needed based on the treatment and scheduled based on a target soil water content of 25% to 30% during the growing season. Irrigation was applied from early to mid-May through September in both years (Strik et al., 2017a). Weed control was done by hand, as needed. Planting, pest and disease management, crop harvest, and commercial pruning were performed uniformly in the trial plots, as described by Strik et al. (2017a, 2019).

Treatments. This study involved a subsection of a larger production systems research trial (Strik et al., 2017a). There were eight treatments arranged in 2 x 2 x 2 balanced factorial split-plot design with five replicates. The main plots were fertilized with fish solubles or feather meal, and the subplots included a combination of two cultivars, 'Liberty' and 'Duke', that were mulched with either weed mat or sawdust. Plots were 4.6-m long with six plants in each at establishment. All were planted on raised beds and were fertilized with 140 $kg \cdot ha^{-1}$ of N from 2013–2016 (Strik et al., 2017a, 2019).

Fertilizer source treatments were granular feather meal (11–13% N; California Organic Fertilizers, Phyta Grow Super N, Fresno, CA; Pacific Calcium, Tonasket, WA) and fish by-product liquid solubles with acid-stabilized pH (4–5% N; TRUE Organic Products TRUE 512, Spreckels, CA; California Organic Fertilizers, Phytamin 420, Fresno, CA). The fertilizers used were analyzed and application rates and timings for the season were described by Strik et al. (2019). Feather meal was applied to the plot in-row area in two equal split-applications in March and May of each year. The fertilizer was applied to the surface of the sawdust mulch treatment, while the weed mat was opened (see below) before applying the product on the soil surface. Fish solubles fertilizer was pre-diluted with 10 parts water (v/v) and injected through the drip system (fertigation) in seven equal applications every 2 weeks from mid-April to early July.

Cultivars were chosen to represent industry standards for fruiting season (Fernandez-Salvador, Chapter 3). Sawdust mulch was established with a 9-cm-deep layer of Douglas fir (*Pseudotsuga menziesii*) on top of the raised bed (360 $m^3 \cdot ha^{-1}$ approx.). The weed mat mulch used was a 1.5-m-wide black, permeable, woven polypropylene groundcover with a water infiltration rate of 6.8 $L \cdot m^{-2} \cdot h^{-1}$ and a density of 0.11 $kg \cdot m^{-2}$ (TenCate Protective Fabrics; OBC Northwest Inc., Canby, OR). For this trial, the weed mat was overlapped (zippered) when installed over the beds, allowing the mulch to be opened when fertilizing and checking irrigation functioning (Strik et al., 2017a).

Data collection. In 2015, one plant per plot was dug at each of three stages of development, including the green fruit stage (16 and 30 May for 'Duke' and 'Liberty', respectively), the postharvest stage (after fruit harvest but well before leaf senescence; 1 and 22 Aug. for 'Duke' and 'Liberty', respectively), and dormancy (early winter; 5 and 12 Dec. for 'Duke' and 'Liberty', respectively). In 2016, one plant per plot was dug during dormancy only (3 and 10 Dec. for 'Duke' and 'Liberty', respectively). At each stage, a commercial nursery crew carefully dug up the plants using a shovel, retaining as much of the root system as possible. The plants were separated into green fruit (picked prior to digging), leaves, shoots (current season, excluding leaf blades; these were 1-year-old laterals for the dormant sampling), whips (current season, excluding leaf blades; these were 1-year-old whips for the dormant sampling), old wood (> 1-year old), crown, and roots (carefully washed to remove soil). In addition to complete plant sampling, ripe fruit were hand-picked at the normal harvest time each year (two picks per season for 'Duke' and three for 'Liberty'). Fallen leaves were also collected by placing nets around one plant per plot just prior to leaf senescence. Representative tissue samples were obtained for each plant part and sent for complete nutrient analysis and percent moisture to Brookside Laboratories, Inc. (New Bremen, OH) using methods described in Strik et al. (2019). Each plant part was weighed fresh prior to analysis, and total yield was calculated per plant. The DW of each plant part was calculated based on fresh weight and percent moisture. For fruit, an average nutrient concentration for the season was used (Fernandez-Salvador, Chapter 3). Nutrient content was then calculated by multiplying nutrient concentration by the DW of each plant part. Plants were pruned in winter, just prior to the dormant dig date. Pruning wood was separated into whips and 1-year and older wood and weighed fresh. Above- (all top growth) to belowground (roots and crown) DW ratios were calculated from plants that were harvested destructively at four stages (immature fruit, postharvest, and dormancy in 2015 and 2016). Nutrient losses (fruit, fallen leaves, and pruned wood) were calculated per plant and per hectare. It was not possible to calculate nutrient gains for a full season because plants were first sampled at the green fruit stage.

Statistical analysis. Dry weight (DW) and nutrient content data, as well as total losses (fruit, fallen leaves, and pruning wood) and above- to belowground ratios were analyzed using PROC MIXED for a split-plot with fertilizer source as the main effect and cultivar and mulch as sub-plots (SAS software package version 9.4; SAS Institute, Cary, NC). Plant DW before and after pruning in 2015 and 2016 were analyzed as a split-split plot with year added as the main effect. Means were compared with 5% confidence level using Tukey's Honestly Significant Difference test. Mean comparisons within significant interactions were done using Least Square Means with 5% confidence level.

Results

Treatment effects on biomass are presented for all plant parts and sampling dates in 2015 (Table 4-1) and for total plant DW at the dormant stage in 2015 and 2016 (Table 4-2). Nutrient content is only presented for plant parts sampled in 2015 (Tables 4-1 and 4-3). Nutrient content is not shown for 2016 due to high variability in plant DW. The nutrient concentration of dormant plants in 2016 was similar to that found in 2015 and thus was not presented (Fernandez-Salvador, Chapter 3).

Biomass

There were significant treatment effects on the DW of leaves, stems, whips, crown, and roots at the green fruit stage, ripe fruit, the crown and roots at postharvest stage, senescent leaves, and whips and roots for dormant plants in 2015 (Table 4-1). On average, 'Liberty' had more DW than 'Duke', except in the stems at the immature stage. Furthermore, plants fertilized with feather meal had greater crown and root DW at the immature and postharvest stages and greater root DW at dormancy than plants fertilized with fish emulsion, while plants mulched with weed mat had greater DW in the senesced leaves than those mulched with sawdust.

Total plant DW was higher in 2016 than in 2015, both before and after pruning (Table 4-2). On average, 9% of the total DW in the plants was removed during pruning, and plants fertilized with feather meal had 33% to 36% more total DW than those fertilized with fish solubles.

Each treatment affected the ratio of above- to belowground DW, depending on stage of development. 'Duke' had a higher ratio (1.8) than 'Liberty' (1.3) at the immature stage, but only when fertilized with fish solubles (data not shown). Dormant 'Duke' plants also had a higher ratio than 'Liberty' (1.9 vs. 1.1) in 2016 but not in 2015. Plants fertilized with fish had a greater above- to belowground biomass ratio as compared to feather meal, but only in 'Duke' at the immature stage (1.8 vs. 1.2) and for plants grown with sawdust mulch as compared to weed mat at postharvest stage (1.8 vs. 1.1). Plants mulched with weed mat had a higher ratio at the immature stage (1.5 vs. 1.3) and when dormant in 2015 (1.7 vs. 1.3), compared to sawdust, respectively.

Macronutrients – 2015 Season

Nitrogen. 'Liberty' had a higher N content in the whips and crown at the immature stage and in the senescent leaves (but only with weed mat) than 'Duke'; however, the opposite was found for old wood at immature stage and stems at postharvest stage (Table 4-1). Fertilizer source only affected N content of old wood at postharvest stage with greater levels for feather meal than for fish (only with weed mat), but dormant whips had greater N with fish than with feather. Mulching with weed mat, rather than sawdust, increased N content of green and ripe fruit, leaves at postharvest stage, and dormant stems and old wood. There was a mulch by fertilizer interaction for N content of many plant parts with weed mat having higher levels than sawdust for old wood at immature stage, stems and old wood postharvest, and senescent leaves, but only when fertilized with feather meal.

Phosphorus. ‘Duke’ had higher P content in old wood and stems at immature and postharvest stages, respectively, but a lower content in ripe fruit and in senescent leaves (only with weed mat) than ‘Liberty’ (Table 4-1). At the dormant stage, plant whips had higher P content when fertilized with fish; however, the opposite was found for old wood at the postharvest stage (but only with weed mat). Mulching with weed mat, as compared to sawdust, increased P content of green and ripe fruit, old wood (only with feather meal), leaves and stems at the postharvest stage, and senesced leaves (only with feather meal).

Potassium. ‘Liberty’ had greater K content in leaves and stems (only with feather meal), and whips at immature stage, ripe fruit, stems at postharvest stage, and senescent leaves (Table 4-1). However, the opposite was found for roots at the postharvest stage where ‘Duke’ had higher K content, but only when fertilized with fish. Plants fertilized with feather meal, rather than fish, had greater K content of leaves and stems at immature stage, but only in ‘Liberty’, the crown at immature and postharvest stages, roots at postharvest (only in ‘Liberty’) and the crown at dormancy. Mulching with weed mat increased K content of ripe fruit, leaves and stems at postharvest stage, and senescent leaves.

Calcium. ‘Liberty’ had higher Ca content of stems (only with feather meal) and the crown at immature stage, ripe fruit, old wood at postharvest stage, senescent leaves, and stems, old wood, and the crown at dormant stage (Table 4-1). At immature, postharvest and dormant stages, roots had greater Ca content when fertilized with feather meal than with fish, as did the crown at postharvest and dormant stages. Fertilization with feather meal also increased Ca content of stems at immature, but only for 'Liberty', and ripe fruit when mulched with sawdust. Mulching with sawdust resulted in greater Ca content of roots and whips at immature and dormant stages.

Magnesium. At the immature stage, 'Duke' stems and roots had greater Mg content than 'Liberty', whereas the opposite was found for whips (Table 4-1). The Mg content was higher in ripe fruit, old wood at postharvest stage, senescent leaves, and dormant stems and old wood of 'Liberty' as compared to 'Duke'. Fertilizer source had no effect on Mg content of any plant part at any stage. Crowns at the immature stage had higher Mg content when mulched with sawdust, whereas senescent leaves, and stems at postharvest and dormant stages and had higher Mg content when mulched with weed mat.

Sulfur. 'Liberty' leaves (only with feather meal), whips, and crowns at the immature stage, ripe fruit, crown at postharvest stage, and senescent leaves had greater S content than 'Duke', but the opposite was found for stems at postharvest stage (Table 4-1). Dormant whips had higher S content when plants were fertilized with fish. Plants fertilized with feather meal had higher S content in stems at the immature stage, but only in 'Liberty', as compared to fish. Both green and ripe fruit had greater S content when mulched with weed mat as compared to sawdust, as did old wood at immature stage (only for feather meal), senescent leaves, and stems at postharvest and dormancy stages.

Micronutrients

Boron. 'Duke' had higher B content in stems at the immature stage (only when fertilized with fish) and at immature fruit stage than 'Liberty'. However, 'Liberty' had higher B content than 'Duke in the crown at immature fruit stage, ripe fruit (only with weed mat), old wood and crown at the postharvest stage, senescent leaves (only with weed mat), and dormant stems and old wood (Table 4-3). Roots (at immature and dormant stages) and crowns (postharvest) for plants fertilized with feather meal had greater B content, whereas dormant whips and old wood had higher B content when fertilized with fish. Weed mat mulch increased B content in ripe fruit (only in ‘Liberty’), green fruit, stems (at immature, postharvest and dormant stages), leaves (at immature and postharvest stages), senescent leaves (only in ‘Liberty’), and old wood when dormant compared to sawdust mulch.

Iron. ‘Liberty’ immature leaves and whips, ripe fruit, immature and dormant old wood, stems postharvest (only with fish fertilization), and dormant stems and crowns had higher Fe content than those of ‘Duke’ (Table 4-3). There was no effect of fertilizer source on Fe content of plant parts at any sampling time. Plants mulched with weed mat had higher Fe content of green fruit and dormant stems than sawdust, whereas the opposite occurred in the crown at all sampling stages.

Manganese. ‘Duke’ had greater Mn content in immature fruit, the crown (postharvest), and roots (immature, postharvest stages) than ‘Liberty’, but the opposite was found in ripe fruit, senescent leaves (only with weed mat), and dormant stems (Table 4-3). Plants fertilized with fish had higher Mn content in stems and whips from postharvest and dormant stages, respectively, but the opposite occurred for roots at the immature and dormant stages, and for the crown at postharvest stage. Plants mulched with weed mat had higher Mn content of old wood at immature stage (only with feather meal), ripe fruit and senescent leaves (only for ‘Liberty’), and dormant stems as compared to sawdust, but the opposite was found for the crown at immature stage.

Copper. ‘Liberty’ plants had greater Cu content than ‘Duke’ for stems at immature and dormant stages, the crown at immature stage, ripe fruit (only with fish), and in old wood and roots at postharvest stage, whereas the opposite was found for old wood at immature stage (Table

4-3). Fertilization with feather meal increased Cu content of leaves at immature stage, as compared to fish. There was no effect of mulch on Cu content of plant parts at any sampling stage.

Zinc. ‘Liberty’ crowns [at immature and postharvest stages and dormant (only with weed mat)] and old wood (at postharvest and dormant) had greater Zn content, whereas ‘Duke’ had more Zn in whips at postharvest stage (Table 4-3). Fertilization with fish increased the Zn content of dormant whips, as compared to fertilization with feather meal. Mulching with weed mat increased Zn content of senescent leaves as compared to sawdust, but only in ‘Liberty’, whereas the opposite was found for whips at dormant stage.

Aluminum. Immature fruit had greater Al content for ‘Duke’ than ‘Liberty’, whereas the opposite was found for ripe fruit (Table 4-3). ‘Liberty’ had greater Al content of old wood (at immature and dormant stages), leaves (immature stage), and stems and crowns at dormant stage, as compared to ‘Duke’. Mulching with sawdust increased Al levels in the crown at immature stage, whereas the opposite was found for whips and stems at the postharvest and dormant stages, respectively.

Losses of biomass and nutrients

The plants produced an average of 2,268 $kg{\cdot}ha^{-1}$ of ripe fruit in 2015 and lost an average of 1,750 $kg{\cdot}ha^{-1}$ DW during leaf fall and 1,610 $kg{\cdot}ha^{-1}$ DW during pruning (Table 4-4). ‘Liberty’ produced more fruit and leaves than ‘Duke’, while the use of weed mat produced more leaves and wood than the use of sawdust mulch.

Losses of N, P, K, Ca, Mg, and S averaged 12.0, 1.6, 11.0, 1.0, 0.7, and 1.2 $kg{\cdot}ha^{-1}$, respectively, during fruit harvest, 10.0, 0.6, 8.9, 13.5, 3.0, and 1.4 $kg{\cdot}ha^{-1}$, respectively, during leaf fall, and 12.8, 1.3, 4.5, 6.1, 0.9, and 1.1 $kg{\cdot}ha^{-1}$, respectively, during pruning (Table 4-4).

‘Liberty’ lost more P, K, Ca, Mg, S, Cu (only with fish solubles), and Al during fruit harvest, more K, Ca, Mg, and S during leaf fall, and more N (only with fish), Ca, Mg, S (only with fish), B, Fe, Mn (only with fish), Cu, Zn, and Al (only with fish) during pruning than ‘Duke’ (Tables 4-4 and 4-5).

Fertilization with feather meal increased losses of Ca in harvested fruit, but only when the plants were mulched with sawdust. Fertilizer source had no main effect on losses of macro- and micronutrients in senesced leaves or pruned wood (Tables 4-4 and 4-5).

More N, P, K, S, and B and Mn (only in ‘Liberty’) was lost during fruit harvest when the plants were mulched with weed mat than when they were mulched with sawdust. Weed mat also resulted in a greater loss of K, Mg, S, and Fe during leaf fall than sawdust in both cultivars, as well as a greater loss of N, P, B, Mn, and Zn in ‘Liberty’. In pruned wood, weed mat increased losses of N, K, Ca, Mg, S, B (only in ‘Liberty’), Fe, Mn, Zn and Al (Tables 4-4 and 4-5).

Discussion

Biomass

Mature ‘Liberty’ plants had more DW in most plant parts than ‘Duke’, confirming findings for young plants in this same planting after the first and second growing seasons (Larco et al., 2013a), depending on fertilizer and mulch treatments.

Total plant DW increased from winter 2015 to 2016, when measured before and after pruning, confirming findings in mature ‘Elliott’ blueberry (Nemeth, 2013) that mature plants with a stable yield continue to grow and produce more biomass. Larco et al. (2013a) reported that young plants fertilized with fish had greater total DW after the first growing season, but feather meal led to greater growth in the second year when it was applied earlier in the season, which increased the availability of N and other nutrients. Likewise, in our study, plants fertilized with feather meal had greater total DW than those fertilized with fish.

The impact of fertilizer source on plant growth has been consistent when comparing the mature plants in the present study to those sampled during establishment (Larco et al., 2013a). Fertilization with feather meal increased root DW at all plant sampling stages in 2015 and total plant DW during dormancy when averaged over both years of the study. Long-term use of fish fertilizer reduced yield compared to feather meal, especially when applied at the higher rate used in this study (Davis and Strik, 2021; Strik et al., 2017a). During establishment, N was likely less available from feather meal than from fish solubles, which had a negative impact on plant DW (Larco et al., 2013a). However, this effect may have been reversed over time once the N released from the soil organic matter was more stable (Larco et al., 2013a; Sullivan et al., 2015), the blueberry plant canopies in our study were more established, thus reducing variability in soil temperature in the row, and timing of fertilizer application was adjusted for feather meal (Strik et. el, 2019). Nitrogen release can vary widely with the C:N of mulch, affecting plant-available N release from organic inputs (Gaskell et al., 2006; Sullivan et. al, 2010). High K in the fish solubles also led to excessive K in the soil and leaves, reducing plant yield (Davis and Strik, 2021; Strik et al., 2017a).

Strik et al. (2017a) noted that plants mulched with weed mat required more irrigation than those mulched with sawdust, likely because of a larger canopy size. We confirmed that weed mat increased DW of leaves at senescence, although no effect was found at other sampling times. During establishment, plants grown on raised beds and fertilized with fish had a lower total plant DW when grown with weed mat than with sawdust, whereas there was little effect when using feather meal (Larco et al., 2013a). In conventionally-grown blueberry, Strik et al. (2020a) reported that sawdust-mulched plants had greater DW of some plant parts than with weed mat in 'Duke'.

The ratio of above- to belowground plant parts in our mature planting was greater for weed mat than for sawdust at immature and dormant stages in 2015, despite no significant effects of mulch on the individual DW of crown and roots at these stages. Larco et al. (2013a) also reported a greater above- to belowground DW ratio with weed mat for dormant plants after the second growing season, but only when the plants were fertilized with the high rate of fish; however, they found no mulch effect with feather meal. In these mature plants, fish fertilizer increased the above- to belowground DW ratio, but only with sawdust. The negative impact of fish fertilization, particularly at the high rate, on root growth relative to feather meal (Larco et al., 2013a) was mitigated over time, particularly with weed mat mulch, as found in our study. Higher soil temperatures under weed mat likely accounted for less root growth observed in the establishing plants (Strik et al., 2017a; 2020a). The larger plant canopies found with weed mat during establishment likely led to more shade, reducing soil temperature variation when compared to sawdust as the plants matured (Strik et al., 2017a).

The largest loss of biomass in these mature plants was in the harvested fruit, followed by senesced leaves, and pruning wood. Pruning removed an average of 9% of total plant DW in this study.

Nutrient content and allocation

Nutrient content varied by plant part and sampling time, as found in young blueberry plants (Bañados et al., 2012; Bryla et al., 2012). Despite 'Duke' having a higher concentration of many nutrients in the fruit (Fernandez-Salvador, Chapter 3), 'Liberty' had a higher content of most nutrients due to greater fruit DW. ‘Liberty’ also had higher nutrient content in many other plant parts than ‘Duke’ due to greater vigor or plant biomass.

Fertilizer source had little effect on the N content of most plant parts during the sampling periods in 2015. However, application of fish solubles increased N content of whips in dormant plants compared to feather meal, and considering whips also had a higher %N (Fernandez-Salvador, Chapter 3), plant uptake of N in vigorously growing whips was higher with this fertilizer source. No such effect was seen for leaves, fruit, or other plant parts, likely because of differences in DW. On average, plants mulched with weed mat had higher N content than those with sawdust for green and ripe fruit, leaves at the postharvest stage, and dormant stems and old wood. The N concentration being higher in leaves at all stages and dormant stems (Fernandez-Salvador, Chapter 3), coupled with increased DW of senescent leaves with weed mat indicates greater N uptake in this mulch as compared to sawdust, particularly after fruit harvest. Some of the N in the fertilizers may have been immobilized by the sawdust mulch (Larco et al., 2014; Sullivan et al., 2015). Furthermore, greater canopy growth (Strik et al., 2017a) and higher ratios of above- to belowground biomass may have led to greater N uptake by plants with weed mat than those with sawdust.

In organic blackberry (*Rubus* sp.), weed mat mulch increased plant N uptake but decreased soil organic matter as compared to bare soil (Dixon et al., 2016) with the possibility of creating an organic matter and nutrient imbalance overtime. In a continuation study in the organic blueberry planting, Davis and Strik (2021) found topping the sawdust mulch with weed mat to create a combined mulch increased yield, likely due to improved soil organic matter compared to continued weed mat over bare soil; the impact of this on plant N content was not studied.

Considering the importance of stored N in crown, roots, and old wood for new growth in spring (Bañados, 2006; Bañados et al., 2012), there was little mulch or fertilizer treatment effect on N content in these dormant plant parts in our study, except for weed mat, which resulted in higher N content in old wood and stems than sawdust. While it is unlikely that N at the high rate was a limiting factor to growth or yield in any of the treatment combinations studied (Strik et al., 2017a), we found no evidence of luxury uptake of N being stored over winter. Most of the excess N taken up by plants may have been lost during leaf fall, as noted previously in young blueberry and strawberry (*Fragaria* x *ananassa* Duch.) plants (Bañados et al., 2012; Strik et al., 2004).

On average, P content and concentration (Fernandez-Salvador, Chapter 3) increased with weed mat mulch as compared to sawdust for ripe fruit, leaves and stems at the postharvest stage, and dormant stems, despite no effect of these treatments on DW, indicating greater plant uptake of P. By contrast, Strik et al. (2020b) reported no difference in P uptake in the first and second growing season when comparing sawdust and weed mat in 'Duke'. Weed mat increased annual P accumulation and losses aboveground in organic trailing blackberry compared to hand-weeded, bare soil (Dixon et al., 2016). In our study, P content of old wood and senesced leaves was also higher with weed mat than with sawdust, but only for plants fertilized with feather meal. Higher uptake of P with feather meal, despite applying about one-tenth of the P than with fish solubles (14 vs. 107 $kg \cdot ha^{-1}$; Strik et al., 2019), may have been related to higher soil temperatures under the weed mat earlier in the season as a new leaf canopy develops, increasing availability of P from feather meal (Strik et al., 2017a). While application of fish solubles increased the concentration of P in ripe fruit and stems, crown, and roots of dormant plants (Fernandez-Salvador, Chapter 3), there was no evidence that there was greater uptake as P content was not significantly affected by fertilizer source.

‘Liberty’ had greater content of K in most plant parts during the season, except for roots at postharvest sampling where ‘Duke’ fertilized with fish had higher K content than ‘Liberty’. Despite ‘Duke’ having a higher %K in almost all plant parts at all sample dates (Fernandez-Salvador, Chapter 3), the greater DW of these parts for ‘Liberty’ led to greater K content. ‘Duke’ roots had greater %K at postharvest and dormant stages than ‘Liberty’ (Fernandez-Salvador, Chapter 3). The more than ten-fold higher rate of K applied with fish (198 $kg \cdot ha^{-1}$) than with feather meal (18 $kg \cdot ha^{-1}$), due to the complexity of these organic fertilizers (Strik et al., 2019), increased uptake of K in most plant parts. Strik et al. (2019) reported that fertilization with fish solubles increased leaf %K compared to feather meal, and in some cases led to levels greater than the upper end of the sufficiency range (Hart et al., 2006). In our study, leaf %K was also higher with fish fertilization than with feather meal for leaves sampled at all stages during the growing season (only with sawdust mulch at senescence), even though values were an average of leaves on the whole plant rather than the selective sampling of most recent fully-expanded leaves when collecting for tissue testing (Fernandez-Salvador, Chapter 3; Hart et al., 2006). However, the impact of DW on K content led to inconsistent effects of fertilizer source with use of feather meal having greater K in some plant parts (e.g. crown at postharvest and dormant stages for ‘Liberty’) due to the negative impact of fish solubles on growth and yield (Strik et al., 2017a). When fertilization with K was ceased in this planting from 2017 onwards soil and leaf tissue K levels declined with a concomitant increase in yield (Davis and Strik, 2021).

Use of weed mat mulch increased K content in ripe fruit, leaves and stems at the postharvest sampling stage and for senescent leaves compared to sawdust. However, weed mat increased K concentration in most plant parts at all sampling times (Fernandez-Salvador, Chapter

3). Clearly, plant uptake of K was increased with weed mat mulch, perhaps a result of higher soil levels of K under weed mat than sawdust, averaged over fertilizer source (Strik et al., 2019).

‘Liberty’ had greater Ca content in multiple plant parts and stages than ‘Duke’. Fertilization with feather meal, on average, increased Ca content of roots at all sampling stages and the crown at postharvest and dormant stages. Feather meal did increase %Ca of green and ripe fruit, stems at immature stage, senescent leaves, and leaves postharvest, and stems and roots at dormant stage (but only with sawdust mulch) as compared to fish solubles (Fernandez-Salvador, Chapter 3). Strik et al. (2019) found that feather meal was a good source of Ca for increasing leaf %Ca compared to fish solubles. The impact of feather meal on increased %Ca of many plant parts and on growth or DW led to much greater Ca content as compared to fish solubles.

‘Liberty’ had greater Mg content in multiple plant parts and stages than ‘Duke’. Fertilizer source had no significant effect on Mg content of plant parts at any stage, even though fertilization with feather meal increased %Mg of green fruit (with sawdust only) and fish solubles increased %Mg of whips at the immature stage (Fernandez-Salvador, Chapter 3). Use of sawdust mulch increased Mg content and concentration (Fernandez-Salvador, Chapter 3) of the crown at the immature stage (averaged over cultivar and fertilizer source). It is not clear why Mg uptake or allocation to the crown would be greater with sawdust than weed mat at this stage of growth, especially because soil Mg levels were greater under weed mat than under sawdust mulch (Strik et al., 2019).

Cultivar had an effect on both concentration (Fernandez-Salvador, Chapter 3) and content of B, Mn, Fe and Cu through the 2015 season. These micronutrients were greater in green fruit of ‘Duke’ than ‘Liberty’, whereas the opposite was found in old wood at the post-harvest stage and stems and old wood at the dormant stage. The pattern of change in parts and through the season for most micronutrients, other than B, was inconsistent based on mulch and fertilizer source and sampling time.

Plants grown with weed mat had greater B content in green fruit, stems at each sampling time, dormant old wood, and leaves at each sampling time except only for ‘Liberty’ for senescent leaves, as compared to sawdust. Boron concentration was also greater with weed mat than sawdust for the aforementioned parts in addition to the crown at immature stage (only for ‘Liberty’), ripe fruit, and roots at the postharvest and dormant stages (Fernandez-Salvador, Chapter 3). Higher concentrations of B coupled with DW increases caused by mulching with weed mat rather than sawdust, increased B uptake. Root uptake of B in plants is closely related to soil factors such as pH, moisture, temperature, organic matter, and salinity (Shireen et al., 2018). Increased soil temperature under weed mat (Strik et al., 2017a; Strik et al., 2020a) may have improved root uptake of B and allocation to multiple plant parts. Although higher soil temperature under black weed mat has been shown to reduce soil organic matter (Atucha et al., 2011; Choi et al., 2011; Davis and Strik, 2021; Strik et al., 2019), this may also improve B uptake indirectly.

While fertilizer source had some limited effect on B concentration of green fruit (only with weed mat), whips at immature stage, and roots at postharvest stage, with levels higher when fertilized with fish (Fernandez-Salvador, Chapter 3), there was no fertilizer source effect on B content. Strik et al. (2019) found little effect of fertilizer source on leaf B concentration over their long-term study.

Nutrient Losses

On average, the total estimated losses of nutrients from the planting were 35 kg·ha^{-1} of N, 3.5 kg·ha^{-1} of P, 25 kg·ha^{-1} of K, 21 kg·ha^{-1} of Ca, 4.5 kg·ha^{-1} of Mg, 3.7 kg·ha^{-1} of S, 162 g·ha^{-1} of B, 1038 g·ha^{-1} of Fe, 1336 g·ha^{-1} of Mn, 40 g·ha^{-1} of Cu, and 73 g·ha^{-1} of Zn.

Nutrient losses were greater overall in 'Liberty' than in 'Duke' for fruit (P, K, Ca, Mg), senesced leaves (K, Ca, Mg, S), and pruned wood (N, for fish only, Ca, Mg, B and most micronutrients), similar to what was reported for young plants in this trial (Larco et al., 2013b). In young blueberry plants, relative nutrient losses for N was greatest in senesced leaves, followed by pruned wood and harvested fruit (Strik et al., 2020b) or fruit, senesced leaves, and pruned wood (Bryla et al., 2012). Losses of P and K, on the other hand, were least in pruned wood and highest in the fruit (Bryla et al., 2012) or senesced leaves (Strik et al., 2020b), and both studies agreed that the highest losses of Ca, Mg, and S occurred in senesced leaves. In our study, we found the greatest loss of K in the fruit (11.8 kg·ha^{-1}), similar losses of N and P in fruit and pruning wood (12.0 and 12.8 kg·ha^{-1} of N and 1.6 and 1.3 kg·ha^{-1} of P, respectively), and the highest loss of Ca (13.5 kg·ha^{-1}) and Mg (3.0 kg·ha^{-1}) in the leaves. There was a high level of macronutrients in the senesced leaves, providing opportunity for nutrient recovery in the blueberry field, particularly in an organic system that encourages such practices. The bulk of the senesced leaves dropped during a 2- to 3-week period each autumn. Just prior to leaf senescence, weed mat mulch could be opened as is commonly done by growers to apply organic matter and fertilizer amendments (Davis and Strik, 2021; Strik, 2016; Strik et al., 2017a). A larger proportion of senesced leaves would then drop to the in-row area and stick to the soil or any organic mulch normally underneath the weed mat. The weed mat could then be closed thereafter, promoting recycling of nutrients into the in-row soil area where blueberry roots are present.

On average, losses of N, P, K, Ca, and Mg in pruning wood were 12.8, 1.3, 4.5, 6.2 and 0.9 $kg \cdot ha^{-1}$, respectively. In raspberry (*Rubus idaeus* L.), N in chopped pruning wood left in the aisles, where crops roots are located, was taken up by the raspberry plant within 1.5 years (Strik et al., 2006). In blueberry, roots are only present within the in-row area and growers normally remove prunings from the field. However, prunings could be chopped (flailed) in the aisles and applied to the in-row area along with any senesced leaves using a side discharge on the mower. These sources of organic matter and otherwise lost nutrients could be added to the in-row area before the weed mat mulch is closed in late winter. Small and large-scale organic farmers already use these practices in other crops, mainly with green manure and cover crops as a mow and blow. However, such a system could also serve as the basis for improving recovery of biomass and nutrients currently lost in blueberry fields, especially from pruning wood. Adding sawdust to the in-row area under weed mat has been shown to improve yield relative to weed mat over bare soil (Davis and Strik, 2021). Research would be needed to assess the possible benefit to reducing fertilizer application when returning more nutrients to the field. Considering the relatively high cost of organic fertilizers (Strik et al., 2017a), savings in product cost could offset any increased costs of pruning wood management.

There was little effect of fertilizer source on nutrient loss. However, use of weed mat mulch increased loss of N, P, K, S, and B and Mn (‘Liberty’ only) in fruit and N, P, K, Ca, Mg, S, B (‘Liberty’), Mn, Fe, Zn, and Al in pruning wood. By contrast, Strik et al. (2020b) found no difference between black weed mat over bare soil and sawdust for nutrient losses in ‘Duke’ during establishment.

Conclusions

The effects of cultivar, mulch, and fertilizer source on the allocation of biomass and nutrients among plant parts at different stages of development in 2015 varied widely depending on plant part. Plants continued to increase in DW from one winter to the next as expected in a mature planting, with 'Liberty' having a greater overall biomass than 'Duke'. The greater DW of many plant parts at various sampling stages for 'Liberty' than 'Duke' led to 'Liberty' having greater nutrient content, despite sometimes having a lower concentration (Fernandez-Salvador, Chapter 3).

Averaged over cultivar and mulch, fertilization with feather meal increased DW (roots, green fruit, and total) and Ca content of roots and crown, compared to fish solubles, confirming feather meal was a good source of Ca (Strik et al., 2019). By contrast, fertilization with fish increased K uptake compared to feather meal, due to the high rate of K applied with this fertilizer source (Strik et al., 2019). Fish fertilization also increased N uptake in whips, compared to feather meal, but this was not found in other plant parts. Fertilizer source had little other impact on nutrient content or losses.

Weed mat, on average, increased DW of senescent leaves and the ratio of above- to below-ground biomass. Mulching with weed mat increased N content of many plant parts, compared to sawdust, but the excess N taken up was lost in leaves at senescence – no treatment effects on stored N in dormant plants was found. Uptake of P, K and B was increased with weed mat compared to sawdust, but the opposite was found for Mg. Greater soil temperature and availability of K under weed mat (Strik et al., 2017a, 2019) coupled with increased canopy size likely increased uptake of N, P, and K. Root acquisition of B is more related to soil moisture and temperature, among other factors such as pH and soil organic matter. The increase in moisture (due to increased irrigation needed) and soil temperature under weed mat (Strik et al., 2017a), may have indirectly improved plant B uptake, meriting further research.

Weed mat has become the most common mulch used by blueberry growers in the region (Strik, 2016) because of reduced weed management costs relative to sawdust mulch (Strik and Vance, 2017). While we report advantages of increased nutrient uptake with weed mat, compared to sawdust, reports of reduced soil organic matter with long-term use of this mulch are concerning (Strik et al., 2019). Davis and Strik (2021) confirmed that a combined mulch of sawdust topped with weed mat in this same planting increased yield compared to continued use of weed mat over bare soil. Considering the high nutrient losses in senescent leaves and pruning wood found in this study, finding ways to re-direct this organic matter to the in-row area, would allow for plant recovery of these nutrients and mitigate the decline in organic matter.

Our findings of weed mat, on average, increasing plant uptake of K are of note because fish solubles, high in K, is still commonly used as a fertilizer source by organic growers (Strik, 2016). Strik et al. (2019) reported the negative effect of high uptake of K with fish solubles, in soils already sufficient, leading to reduced yield of 'Duke'. In a follow up study, Davis and Strik (2021) confirmed that ceasing fertilization with K increased yield. Growers who use weed mat mulch, must thus be very cautious in choosing fertilizer sources without any K if soil and tissue levels of K are already adequate.

While we were not able to estimate nutrient gains in this study, measured nutrient losses do provide ideas on possible improvements in nutrient management. The greatest losses happened for K in fruit and were similar for N and P in fruit and pruning wood. Losses of Ca and Mg were greatest in senescent leaves. Weed mat increased losses of these nutrients compared to sawdust. Recovery of nutrients in senescent leaves and prunings could be increased in both mulches with a system where prunings are flailed (chopped) and these, along with leaves, are moved into the in-row area (under the weed mat, if present). Recovery of even a fraction of the nutrients lost in senescent leaves and pruning wood, 22.8, 1.9, 13.4, 19.6 and 3.9 $kg \cdot ha^{-1}$ of N, P, K, Ca, and Mg, respectively, may have a large impact on fertilizer requirement. Research would be needed to determine if this new practice would lead to nutrients being available when needed for plant growth and thus reduce fertilizer requirement.

Tables

Table 4-1. Effect of cultivar ('Duke', 'Liberty'), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments on dry tissue biomass and the content of macronutrients for various plant parts of mature blueberry grown in a certified organic production system. Plants were destructively harvested on each of three stages (immature green fruit, postharvest, and dormant) in addition to an average of ripe fruit at harvest and leaves at senescence, 2015 (n=5).

Treatments	Dry Biomass		N	P	K		Ca		Mg	S	
					g/plant						
Developmental Stage:											
Immature											
Green fruit											
Cultivar											
Liberty	266		3.24	0.35	1.86		0.39		0.20	0.23	
Duke	218		3.29	0.36	1.60		0.31		0.19	0.23	
Fertilizer											
Feather	256		3.39	0.37	1.82		0.39		0.21	0.24	
Fish	227		3.14	0.33	1.64		0.31		0.18	0.22	
Mulch											
Sawdust	213		2.77 b[y]	0.31 b	1.51		0.33		0.17	0.20 b	
Weed mat	271		3.76 a	0.40 a	1.96		0.37		0.22	0.26 a	
Significance[z]											
Mulch	NS		0.017	0.046	NS		NS		NS	0.038	
Leaves											
Cultivar	Feather	Fish			Feather	Fish				Feather	Fish
Liberty	444 a	299ab	7.56	0.48	2.67 a	1.84 b	1.53		0.51	0.59 a	0.42 b
Duke	260 b	267 b	5.96	0.50	1.83 b	1.94ab	1.19		0.39	0.43 b	0.45 ab
Fertilizer											
Feather	352		7.25	0.52	2.25		1.52		0.48	0.51	
Fish	283		6.28	0.45	1.89		1.21		0.41	0.43	
Mulch											
Sawdust	310		6.31	0.47	1.94		1.35		0.43	0.45	
Weed mat	324		7.21	0.51	2.20		1.37		0.46	0.50	
Significance											
Cultivar (C)	NS		NS	NS	NS		NS		NS	NS	
Fertilizer (F)	NS		NS	NS	NS		NS		NS	NS	
C x F	0.025		NS	NS	0.030		NS		NS	0.045	
Stems											
Cultivar					Feather	Fish	Feather	Fish		Feather	Fish
Liberty	55 b		0.69	0.08	0.61 a	0.41 b	0.37 a	0.21 b	0.07 b	0.061 a	0.039 b
Duke	70 a		0.72	0.10	0.43 b	0.47 b	0.25 b	0.27 b	0.09 a	0.053 ab	0.059 ab
Fertilizer											
Feather	69		0.75	0.10	0.52		0.31		0.08	0.06	
Fish	56		0.66	0.09	0.44		0.24		0.07	0.05	
Mulch											
Sawdust	60		0.65	0.09	0.45		0.27		0.07	0.05	
Weed mat	66		0.75	0.10	0.51		0.28		0.08	0.06	
Significance											
Cultivar(C)	0.047		NS	NS	NS		NS		0.031	NS	
Fertilizer (F)	NS		NS	NS	NS		NS		NS	NS	
C x F	NS		NS	NS	0.042		0.010		NS	0.031	
Whips											
Cultivar											
Liberty	25 a		0.50 a	0.04	0.17 a		0.07		0.03 a	0.03 a	
Duke	13 b		0.31 b	0.03	0.10 b		0.05		0.02 b	0.02 b	
Fertilizer											
Feather	20		0.43	0.04	0.14		0.06		0.02	0.03	
Fish	18		0.38	0.03	0.12		0.06		0.02	0.02	
Mulch											
Sawdust	18		0.36	0.03	0.13		0.06		0.02	0.02	
Weed mat	20		0.45	0.04	0.14		0.06		0.02	0.03	
Significance											
Cultivar	0.023		0.033	NS	0.024		NS		0.025	0.047	

Treatments	Dry Biomass	N	P	K	Ca	Mg	S
				g/plant			
Old Wood							
Cultivar							
Liberty	2196	8.58 b	1.13 b	4.97	2.72	0.58	1.09
Duke	2316	12.46 a	1.47 a	6.67	3.46	0.66	1.26
Fertilizer		Sawdust Weedmat					Sawdust Weedmat
Feather	2429	7.73 b 13.63 a	1.27	6.26	3.44	0.66	0.94 b 1.50 a
Fish	2084	10.42 ab 10.31 ab	1.34	5.38	2.74	0.58	1.20 ab 1.06 ab
Mulch							
Sawdust	2126	9.07	1.20	5.41	2.94	0.56	1.07
Weed mat	2387	11.97	1.40	6.23	3.24	0.68	1.28
Significance							
Cultivar(C)	NS	0.038	0.024	NS	NS	NS	NS
Fertilizer (F)	NS	NS	NS	NS	NS	NS	NS
Mulch (M)	NS	NS	NS	NS	NS	NS	NS
F x M	NS	0.037	NS	NS	NS	NS	0.026
Crown							
Cultivar							
Liberty	1073	5.85 a	1.14	1.93	1.52 a	0.81	0.71 a
Duke	751	4.04 b	0.82	1.49	0.79 b	0.35	0.43 b
Fertilizer							
Feather	1023 a	4.91	0.95	1.95 a	1.20	0.63	0.55
Fish	800 b	4.99	1.02	1.47 b	1.10	0.53	0.58
Mulch							
Sawdust	949	5.04	1.05	1.73	1.25	0.76 a	0.58
Weed mat	874	4.86	0.92	1.69	1.06	0.40 b	0.56
Significance							
Cultivar	NS	0.004	NS	NS	0.001	NS	0.011
Fertilizer	0.037	NS	NS	0.017	NS	NS	NS
Mulch	NS	NS	NS	NS	NS	0.043	NS
Roots							
Cultivar							
Liberty	1103	8.36	1.70	2.86	1.94	1.11 b	1.04
Duke	1283	10.55	2.18	3.90	1.93	1.35 a	1.15
Fertilizer							
Feather	1430 a	10.13	2.18	3.89	2.29 a	1.42	1.17
Fish	956 b	8.78	1.71	2.88	1.58 b	1.05	1.01
Mulch							
Sawdust	1236	8.92	1.97	3.52	2.22 a	1.37	1.05
Weed mat	1150	9.98	1.92	3.24	1.64 b	1.10	1.13
Significance							
Cultivar	NS	NS	NS	NS	NS	0.025	NS
Fertilizer	0.011	NS	NS	NS	0.016	NS	NS
Mulch	NS	NS	NS	NS	0.042	NS	NS
Harvest							
Fruit							
Cultivar							
Liberty	636 a	2.79	0.42 a	3.32 a	0.32 a	0.18 a	0.31 a
Duke	417 b	2.78	0.33 b	2.15 b	0.17 b	0.14 b	0.23 b
Fertilizer					Sawdust Weedmat		
Feather	522	2.68	0.36	2.67	0.30 a 0.24 ab	0.16	0.26
Fish	531	2.90	0.38	2.79	0.21 b 0.24 ab	0.16	0.27
Mulch							
Sawdust	495	2.36 b	0.34 b	2.49 b	0.25	0.15	0.24 b
Weed mat	558	3.22 a	0.40 a	2.97 a	0.24	0.17	0.30 a
Significance							
Cultivar(C)	0.011	NS	0.010	0.002	0.0001	0.008	0.007
Fertilizer(F)	NS	NS	NS	NS	0.023	NS	NS
Mulch(M)	NS	0.004	0.042	0.019	NS	NS	0.009
F x M	NS	NS	NS	NS	0.029	NS	NS

Treatments	Dry Biomass	N	P	K	Ca	Mg	S
				g/plant			
Postharvest							
Leaves							
Cultivar							
Liberty	497	6.1	0.40	2.75	2.90	0.74	0.51
Duke	506	7.6	0.47	2.99	3.16	0.88	0.61
Fertilizer							
Feather	513	6.7	0.43	2.82	3.20	0.83	0.56
Fish	490	7.0	0.44	2.93	2.86	0.79	0.56
Mulch							
Sawdust	462	5.91 b	0.38 b	2.42 b	2.97	0.77	0.50
Weed mat	541	7.79 a	0.49 a	3.32 a	3.08	0.85	0.63
Significance							
Mulch	NS	0.041	0.046	0.034	NS	NS	NS
Stems							
Cultivar							
Liberty	184	1.05 b	0.13 b	0.59 b	1.17	0.13	0.09 b
Duke	212	1.65 a	0.19 a	1.02 a	0.91	0.14	0.13 a
Fertilizer		Sawdust Weedmat					
Feather	192	0.76 b 1.75 a	0.15	0.76	1.03	0.14	0.10
Fish	204	1.42 ab 1.47 ab	0.18	0.84	1.05	0.14	0.12
Mulch							
Sawdust	174	1.09	0.14 b	0.66 b	1.0	0.1 b	0.09 b
Weed mat	222	1.61	0.19 a	0.94 a	1.1	0.2 a	0.13 a
Significance							
Cultivar(C)	NS	0.008	0.007	0.003	NS	NS	0.018
Fertilizer(F)	NS	NS	NS	NS	NS	NS	NS
Mulch(M)	NS	NS	0.037	0.030	NS	0.046	0.021
F x M	NS	0.013	NS	NS	NS	NS	NS
Whips							
Old Wood							
Cultivar							
Liberty	2190	10.58	1.08	5.21	6.15 a	0.81 a	1.06
Duke	2167	10.48	1.43	5.72	2.66 b	0.62 b	1.05
Fertilizer		Sawdust Weedmat	Sawdust Weedmat				
Feather	2375	8.50 b 14.49 a	0.99 b 1.72 a	5.93	4.95	0.78	1.15
Fish	1982	9.92 b 9.20 b	1.21 b 1.10 b	5.00	3.86	0.66	0.96
Mulch							
Sawdust	2101	9.21	1.10	4.96	4.24	0.69	0.95
Weed mat	2256	11.85	1.41	5.97	4.57	0.75	1.16
Significance							
Cultivar(C)	NS	NS	NS	NS	0.005	0.001	NS
Fertilizer(F)	NS	NS	NS	NS	NS	NS	NS
Mulch(M)	NS	NS	NS	NS	NS	NS	NS
F x M	NS	0.016	0.030	NS	NS	NS	NS
Crown							
Cultivar							
Liberty	1001	4.58	1.11	1.96	0.62	0.30	0.56 a
Duke	1062	4.40	0.95	1.93	0.49	0.26	0.43 b
Fertilizer							
Feather	1203 a	4.95	1.12	2.38 a	0.70 a	0.33	0.54
Fish	860 b	4.03	0.95	1.51 b	0.41 b	0.22	0.45
Mulch							
Sawdust	1092	4.29	1.01	1.98	0.58	0.30	0.49
Weed mat	972	4.69	1.05	1.91	0.52	0.26	0.50
Significance							
Cultivar	NS	NS	NS	NS	NS	NS	0.005
Fertilizer	0.026	NS	NS	0.005	0.007	NS	NS

Treatments	Dry Biomass	N	P	K	Ca	Mg	S
				g/plant			
Roots							
Cultivar				Feather / Fish			
Liberty	1005	7.43	1.49	3.12 a / 1.70 b	1.78	0.83	0.79
Duke	996	9.01	1.62	3.06 a / 3.20 a	1.54	0.91	0.86
Fertilizer							
Feather	1182 a	8.73	1.70	3.09	2.04 a	0.98	0.88
Fish	819 b	7.70	1.41	2.45	1.28 b	0.77	0.77
Mulch							
Sawdust	1026	7.51	1.56	2.65	1.81	0.94	0.79
Weed mat	975	8.93	1.55	2.89	1.50	0.81	0.86
Significance							
Cultivar(C)	NS	NS	NS	NS	NS	NS	NS
Fertilizer(F)	0.007	NS	NS	NS	0.001	NS	NS
C x F	NS	NS	NS	0.038	NS	NS	NS
Senescence Leaves							
Cultivar							
Liberty	517 a	2.75	0.18	2.55 a	3.83 a	0.88 a	0.40 a
Duke	295 b	1.81	0.08	1.59 b	2.44 b	0.52 b	0.26 b
Fertilizer		Sawdust / Weedmat	Sawdust / Weedmat				
Feather	401	1.51 b / 2.86 a	0.10 b / 0.18 a	1.87	3.24	0.72	0.31
Fish	411	2.32 ab / 2.43 ab	0.12 ab / 0.14 ab	2.27	3.03	0.68	0.35
Mulch		Liberty / Duke	Liberty / Duke				
Sawdust	355 b	2.09 b / 1.74 b	0.14 b / 0.08 b	1.61 b	2.92	0.61 b	0.28 b
Weed mat	457 a	3.42 a / 1.87 b	0.23 a / 0.09 b	2.53 a	3.35	0.79 a	0.38 a
Significance							
Cultivar(C)	0.006	NS	NS	0.032	0.007	0.005	0.026
Fertilizer (F)	NS	NS	NS	NS	NS	NS	NS
Mulch(M)	0.029	NS	NS	0.003	NS	0.023	0.012
C x M	NS	0.029	0.013	NS	NS	NS	NS
F x M	NS	0.025	0.038	NS	NS	NS	NS
Dormant Stems							
Cultivar							
Liberty	188	2.24	0.22	0.65	1.77 a	0.19 a	0.17
Duke	188	1.98	0.22	0.77	0.85 b	0.13 b	0.15
Fertilizer							
Feather	188	2.04	0.22	0.70	1.41	0.17	0.16
Fish	188	2.19	0.23	0.72	1.21	0.16	0.16
Mulch							
Sawdust	169	1.72 b	0.19	0.62	1.10	0.14 b	0.13 b
Weed mat	207	2.51 a	0.25	0.80	1.52	0.19 a	0.19 a
Significance							
Cultivar	NS	NS	NS	NS	0.013	0.047	NS
Mulch	NS	0.013	NS	NS	NS	0.040	0.026
Whips							
Cultivar							
Liberty	14	0.11	0.01	0.06	0.05	0.01	0.01
Duke	32	0.27	0.03	0.14	0.08	0.02	0.02
Fertilizer							
Feather	17 b	0.13 b	0.02 b	0.07	0.05	0.01	0.01 b
Fish	29 a	0.25 a	0.03 a	0.12	0.08	0.02	0.02 a
Mulch							
Sawdust	28	0.22	0.03	0.11	0.08 a	0.02	0.02
Weed mat	18	0.16	0.02	0.08	0.05 b	0.01	0.01
Significance							
Fertilizer	0.041	0.018	0.033	NS	NS	NS	0.031
Mulch	NS	NS	NS	NS	0.029	NS	NS

Treatments	Dry Biomass	N	P	K	Ca	Mg	S
				g/plant			
Old Wood							
Cultivar							
Liberty	2121	16.09	1.59	5.51	9.27 a	1.20 a	1.47
Duke	2171	14.22	1.57	5.50	3.26 b	0.69 b	1.24
Fertilizer							
Feather	2253	15.30	1.61	5.75	6.46	0.97	1.38
Fish	2039	15.02	1.55	5.26	6.08	0.92	1.32
Mulch							
Sawdust	1971	12.78 b	1.40	4.94	5.64	0.84	1.20
Weed mat	2321	17.54 a	1.76	6.07	6.89	1.04	1.51
Significance							
Cultivar	NS	NS	NS	NS	0.009	0.025	NS
Mulch	NS	0.016	NS	NS	NS	NS	NS
Crown							
Cultivar							
Liberty	843	4.62	0.90	1.78	0.59 a	0.29	0.52
Duke	797	3.48	0.71	1.58	0.40 b	0.20	0.36
Fertilizer							
Feather	903	4.13	0.80	1.92 a	0.56 a	0.28	0.45
Fish	736	3.97	0.81	1.44 b	0.43 b	0.21	0.43
Mulch							
Sawdust	903	4.20	0.83	1.78	0.50	0.24	0.46
Weed mat	736	3.90	0.78	1.58	0.49	0.25	0.42
Significance							
Cultivar	NS	NS	NS	NS	0.020	NS	NS
Fertilizer	NS	NS	NS	0.020	0.028	NS	NS
Roots							
Cultivar							
Liberty	785	7.12	1.27	1.98	1.50	0.82	0.73
Duke	1079	11.14	1.75	3.13	1.38	1.01	1.03
Fertilizer							
Feather	1144 a	10.33	1.74	3.02	1.91 a	1.13	1.00
Fish	720 b	7.92	1.28	2.10	0.98 b	0.70	0.76
Mulch							
Sawdust	934	8.47	1.50	2.45	1.49	0.91	0.84
Weed mat	930	9.79	1.51	2.67	1.39	0.92	0.92
Significance							
Fertilizer	0.032	NS	NS	NS	0.010	NS	NS

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different ($P > 0.05$).

Table 4-2. Effect of year, cultivar (‘Duke’, ‘Liberty’), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments on total plant dry biomass of mature blueberry plants grown in a certified organic production system. Plants were destructively harvested during dormancy in December 2015 and 2016 (n=5).

Treatments	Dry biomass (kg/plant)	
	Before pruning	After pruning
Year		
2015	4.1 b[y]	3.7 b
2016	5.1 a	4.8 a
Cultivar		
Liberty	4.6	4.2
Duke	4.6	4.3
Fertilizer		
Feather	5.3 a	4.9 a
Fish	4.0 b	3.6 b
Mulch		
Sawdust	4.4	4.1
Weed mat	4.8	4.4
Significance[z]		
Year	0.034	0.034
Fertilizer	0.002	0.002

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different ($P > 0.05$).

Table 4-3. Effect of cultivar (‘Duke’, ‘Liberty’), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments on the content of micronutrients for various plant parts of mature blueberry grown in a certified organic production system. Plants were destructively harvested on each of three stages (immature green fruit, postharvest, and dormant) in addition to an average of ripe fruit at harvest and leaves at senescence, 2015 (n=5).

Treatments	B	Fe	Mn	Cu	Zn	Al
			mg/plant			
Developmental Stage:						
Immature						
Green fruit						
Cultivar						
Liberty	5 b[y]	9	24 a	1	3	13 b
Duke	6 a	10	15 b	2	4	26 a
Fertilizer						
Feather	6	10	19	2	4	21
Fish	6	8	20	2	4	19
Mulch						
Sawdust	5 b	8 b	17	1	3	18
Weed mat	6 a	10 a	22	2	4	22
Significance[z]						
Cultivar	0.020	NS	0.021	NS	NS	0.002
Mulch	0.033	0.027	NS	NS	NS	NS
Leaves						
Cultivar						
Liberty	16	26 a	79 a	1	5	30 a
Duke	15	13 b	45 b	1	5	20 b
Fertilizer						
Feather	16	22	64	1.5 a	5	28
Fish	15	18	60	1.1 b	5	22
Mulch						
Sawdust	13 b	17	56	1	5	23
Weed mat	18 a	22	68	1	5	27
Significance						
Cultivar	NS	0.012	0.010	NS	NS	0.029
Fertilizer	NS	NS	NS	0.047	NS	NS
Mulch	0.034	NS	NS	NS	NS	NS
Stems						
Cultivar	Feather / Fish					
Liberty	1.2 ab / 0.8 b	2	18 a	0.6 a	3	2
Duke	1.0 ab / 1.3 a	2	11 b	0.4 b	2	3
Fertilizer						
Feather	1	2	15	1	3	3
Fish	1	2	14	0	2	2
Mulch						
Sawdust	0.9 b	2	13	0	2	3
Weed mat	1.2 a	2	15	0	3	3
Significance						
Cultivar(C)	NS	NS	0.002	0.021	NS	NS
Fertilizer(F)	NS	NS	NS	NS	NS	NS
Mulch(M)	0.033	NS	NS	NS	NS	NS
C x F	0.015	NS	NS	NS	NS	NS
Whips						
Cultivar						
Liberty	1	2 a	3 a	0	0	2
Duke	1	1 b	1 b	0	0	1
Fertilizer						
Feather	1	1	2	0	0	1
Fish	1	1	2	0	0	1
Mulch						
Sawdust	1	1	2	0	0	1
Weed mat	1	1	2	0	0	1
Significance						
Cultivar	NS	0.007	0.030	NS	NS	NS

Treatments	B	Fe	Mn	Cu	Zn	Al
			mg/plant			
Old Wood						
Cultivar						
Liberty	18	467 a	785 b	51 b	48	464 a
Duke	26	131 b	1317 a	94 a	53	150 b
Fertilizer			Sawdust Weedmat			
Feather	23	376	804 b 1253 a	71	64	373
Fish	20	222	1175 ab 971 b	73	38	242
Mulch						
Sawdust	20	255	990	73	46	276
Weed mat	23	343	1112	71	56	339
Significance						
Cultivar(C)	NS	0.007	0.0004	0.005	NS	0.008
Fertilizer(F)	NS	NS	NS	NS	NS	NS
Mulch(M)	NS	NS	NS	NS	NS	NS
F x M	NS	NS	0.024	NS	NS	NS
Crown						
Cultivar						
Liberty	7 a	4207	382	20 a	42 a	3608
Duke	3 b	1305	339	7 b	19 b	1215
Fertilizer						
Feather	6	2902	401	14	31	2534
Fish	5	2610	320	12	29	2289
Mulch						
Sawdust	5	4046 a	425 a	13	33	3453 a
Weed mat	6	1466 b	296 b	13	27	1370 b
Significance						
Cultivar	0.024	NS	NS	0.005	0.015	NS
Mulch	NS	0.023	0.026	NS	NS	0.029
Roots						
Cultivar						
Liberty	5	5158	433 b	13	28	4862
Duke	7	4916	742 a	12	31	4451
Fertilizer						
Feather	7 a	5715	698 b	14	33	5309
Fish	5 b	4359	477 a	11	27	4004
Mulch						
Sawdust	6	5480	620	13	31	5119
Weed mat	6	4594	554	11	28	4193
Significance						
Cultivar	NS	NS	0.003	NS	NS	NS
Fertilizer	0.018	NS	0.022	NS	NS	NS
Harvest						
Ripe Fruit						
Cultivar				Feather Fish		
Liberty	4	11	14	1.1 ab 1.4 a	3	75 a
Duke	4	6	8	1.2 ab 0.9 b	3	39 b
Fertilizer						
Feather	4	9	10	1	3	58
Fish	4	9	11	1	3	56
Mulch	Liberty Duke	Liberty Duke	Liberty Duke			
Sawdust	4 b 4 b	9 ab 6 c	12 b 8 c	1	2	58
Weed mat	5 a 4 b	12 a 7 bc	16 a 7 c	1	3	57
Significance						
Cultivar(C)	NS	NS	NS	NS	NS	0.001
Fertilizer(F)	NS	NS	NS	NS	NS	NS
Mulch(M)	NS	NS	NS	NS	NS	NS
C x F	NS	NS	NS	0.013	NS	NS
C x M	0.021	0.049	0.001	NS	NS	NS

Treatments	B	Fe	Mn	Cu	Zn	Al
			mg/plant			
Post Harvest						
Leaves						
Cultivar						
Liberty	27	120	96	1	5	133
Duke	30	91	85	1	6	103
Fertilizer						
Feather	28	106	84	1	5	120
Fish	29	104	97	1	6	116
Mulch						
Sawdust	25 b	96	83	1	5	111
Weed mat	33 a	114	98	1	6	125
Significance						
Mulch	0.025	NS	NS	NS	NS	NS
Stems						
Cultivar		Feather / Fish				
Liberty	3	11 b / 9 b	49	1	4	14
Duke	3	15 ab / 21 a	50	1	5	20
Fertilizer						
Feather	3	13	41 b	1	4	15
Fish	3	15	57 a	1	5	18
Mulch						
Sawdust	2 b	12	43	1	4 b	16
Weed mat	3 a	16	56	1	5 a	18
Significance						
Cultivar(C)	NS	NS	NS	NS	NS	NS
Fertilizer(F)	NS	NS	0.014	NS	NS	NS
Mulch(M)	0.026	NS	NS	NS	0.026	NS
C x F	NS	0.037	NS	NS	NS	NS
Whips						
Cultivar						
Liberty	1	7	5	0	0 b	7
Duke	1	6	4	0	1 a	7
Fertilizer						
Feather	1	6	4	0	0	6
Fish	1	7	5	0	1	8
Mulch						
Sawdust	1	5	4	0	0	5 b
Weed mat	2	8	6	0	1	9 a
Significance						
Cultivar	NS	NS	NS	NS	0.035	NS
Mulch	NS	NS	NS	NS	NS	0.038
Old Wood						
Cultivar						
Liberty	28 a	326	1034	96 a	59 a	329
Duke	15 b	335	1110	43 b	30 b	356
Fertilizer						
Feather	24	386	1067	75	45	395
Fish	19	275	1077	63	44	290
Mulch						
Sawdust	20	340	1026	70	43	346
Weed mat	23	321	1118	68	46	340
Significance						
Cultivar	0.005	NS	NS	0.016	0.015	NS
Crown						
Cultivar						
Liberty	3.1 a	323	305 b	4	34 a	351
Duke	2.5 b	693	550 a	3	13 b	690
Fertilizer						
Feather	3 a	724	490 a	5	23	721
Fish	2 b	292	365 b	3	24	320
Mulch						
Sawdust	3	769 a	445	5	23	753
Weed mat	3	247 b	409	3	24	288
Significance						
Cultivar	0.012	NS	0.003	NS	0.001	NS
Fertilizer	0.038	NS	0.035	NS	NS	NS
Mulch	NS	0.047	NS	NS	NS	NS

Treatments	B		Fe	Mn		Cu	Zn		Al
				mg/plant					
Roots									
Cultivar									
Liberty	5		3102	316 b		9 a	19		3051
Duke	5		2175	472 a		6 b	20		2242
Fertilizer									
Feather	5		2926	439		8	21		3003
Fish	4		2352	349		7	18		2290
Mulch									
Sawdust	4		3295	416		8	20		3177
Weed mat	5		1982	372		7	19		2116
Significance									
Cultivar	NS		NS	0.046		0.040	NS		NS
Senescence Leaves									
Cultivar									
Liberty	36		328	160		2	6		323
Duke	23		90	78		2	4		114
Fertilizer									
Feather	29		282	115		2	5		283
Fish	30		136	123		2	5		154
Mulch	Liberty	Duke		Liberty	Duke		Liberty	Duke	
Sawdust	26 b	21 b	121	125 b	77 b	1	5 b	5 ab	126
Weed mat	45 a	26 b	297	196 a	78 b	2	7 a	4 ab	311
Significance									
Cultivar(C)	NS		NS	NS		NS	NS		NS
Mulch(M)	NS		NS	NS		NS	NS		NS
C x M	0.039		NS	0.016		NS	0.037		NS
Dormant Stems									
Cultivar									
Liberty	5 a		13 a	89 a		0.8 a	5		16 a
Duke	3 b		8 b	51 b		0.6 b	5		10 b
Fertilizer									
Feather	4		11	67		1	5		14
Fish	4		9.7	73		1	5		12
Mulch									
Sawdust	3 b		9 b	58 b		1	4		11 b
Weed mat	5 a		12 a	82 a		1	5		15 a
Significance									
Cultivar	0.007		0.023	0.020		0.028	NS		0.025
Mulch	0.018		0.022	0.025		NS	NS		0.035
Whips									
Cultivar									
Liberty	0		2	4		0	0		2
Duke	0		1	8		0	1		2
Fertilizer									
Feather	0.1 b		2	4 b		0	0.3 b		2
Fish	0.2 a		1	8 a		0	0.5 a		2
Mulch									
Sawdust	0		2	7		0	0.5 a		2
Weed mat	0		2	5		0	0.3 b		2
Significance									
Fertilizer	0.033		NS	0.032		NS	0.023		NS
Mulch	NS		NS	NS		NS	0.045		NS
Old Wood									
Cultivar									
Liberty	24 a		164 a	1110		48	61 a		195 a
Duke	13 b		94 b	1053		45	42 b		119 b
Fertilizer									
Feather	18.1 b		131	1058		46	52		157
Fish	18.4 a		128	1105		47	51		157
Mulch									
Sawdust	16 b		117	960		45	45		144
Weed mat	21 a		141	1203		48	57		170
Significance									

Treatments	B	Fe	Mn	Cu	Zn	Al
			mg/plant			
Cultivar	0.018	0.024	NS	NS	0.036	0.026
Mulch	0.036	NS	NS	NS	NS	NS
Crown						
Cultivar						
Liberty	3	260 a	320	5	49	290 a
Duke	2	135 b	422	3	13	148 b
Fertilizer						
Feather	2	227	413	4	30	246
Fish	2	167	328	3	33	191
Mulch					Liberty Duke	
Sawdust	2	248 a	417	3	41 ab 14 b	269
Weed mat	2	146 b	325	4	58 a 12 b	169
Significance						
Cultivar(C)	NS	0.018	NS	NS	NS	0.008
Mulch(M)	NS	0.044	NS	NS	NS	NS
C x M	NS	NS	NS	NS	0.036	NS
Roots						
Cultivar						
Liberty	4	3130	313	7	21	2938
Duke	4	2115	437	8	24	2336
Fertilizer						
Feather	5 a	3428	462 a	9	26	3405
Fish	3 b	1817	288 b	6	18	1869
Mulch						
Sawdust	4	2643	390	7	21	2609
Weed mat	4	2603	360	8	23	2665
Significance						
Fertilizer	0.022	NS	0.047	NS	NS	NS

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different ($P > 0.05$).

Table 4-4. Biomass and macronutrient losses as affected by cultivar ('Duke', 'Liberty'), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments of mature blueberry grown in a certified organic production system. Losses include harvested fruit, senesced leaves, and wood removed during pruning in winter, 2015 (n=5).

Treatments	Biomass Loss	N		P		K	Ca		Mg	S	
						kg·ha^{-1}					
Loss stages											
Harvested fruit											
Cultivar											
Liberty	2741 a[y]	12.0		1.8 a		14 a	1.4 a		0.8 a	1.3 a	
Duke	1795 b	12.0		1.4 b		9.3 b	0.7 b		0.6 b	1.0 b	
Fertilizer							Sawdust	Weedmat			
Feather	2250	11.5		1.6		11.5	1.3 a	1.0 ab	0.7	1.1	
Fish	2285	12.5		1.6		12.0	0.9 b	1.0 ab	0.7	1.2	
Mulch											
Sawdust	2131	10.2 b		1.5 b		11 b	1.1		0.6	1.0 b	
Weed mat	2404	13.9 a		1.7 a		13 a	1.0		0.7	1.3 a	
Significance[z]											
Cultivar(C)	0.011	NS		0.010		0.002	0.0001		0.008	0.007	
Fertilizer (F)	NS	NS		NS		NS	NS		NS	NS	
Mulch(M)	NS	0.004		0.042		0.019	NS		NS	0.009	
F x M	NS	NS		NS		NS	0.029		NS	NS	
Senesced Leaves											
Cultivar											
Liberty	2229 a	11.9		0.8		11.0 a	16.5 a		3.8 a	1.7 a	
Duke	1270 b	7.8		0.4		6.8 b	10.5 b		2.2 b	1.1 b	
Fertilizer		Sawdust	Weedmat	Sawdust	Weedmat						
Feather	1729	6.5 b	12.3 a	0.4 b	0.8 a	8.1	13.9		3.1	1.3	
Fish	1769	10.0 ab	10.5 ab	0.5 ab	0.6 ab	9.8	13.1		2.9	1.5	
Mulch		Liberty	Duke	Liberty	Duke						
Sawdust	1530 b	9.0 b	7.5 b	0.6 b	0.3 b	7.0 b	12.6		2.6 b	1.2 b	
Weed mat	1969 a	14.7 a	8.1 b	1.0 a	0.4 b	10.9 a	14.4		3.4 a	1.6 a	
Significance											
Cultivar(C)	0.006	NS		NS		0.032	0.007		0.005	0.026	
Fertilizer (F)	NS	NS		NS		NS	NS		NS	NS	
Mulch(M)	0.029	NS		NS		0.003	NS		0.023	0.012	
C x M	NS	0.029		0.013		NS	NS		NS	NS	
F x M	NS	0.025		0.038		NS	NS		NS	NS	
Pruned Wood											
Cultivar		Feather	Fish							Feather	Fish
Liberty	1824	13.0 ab	17.6 a	1.5		5.0	9.4 a		1.2 a	1.2 ab	1.5 a
Duke	1397	11.6 ab	9.05 b	1.1		4.0	2.8 b		0.5 b	1.0 ab	0.7 b
Fertilizer											
Feather	1626	12.3		1.3		4.5	6.1		0.8	1.1	
Fish	1595	13.3		1.4		4.5	6.2		0.9	1.1	
Mulch											
Sawdust	1368 b	10.0 b		1.1 b		3.8 b	5.1 b		0.7 b	0.9 b	
Weed mat	1853 a	15.6 a		1.5 a		5.2 a	7.1 a		1.0 a	1.3 a	
Significance											
Cultivar(C)	NS	NS		NS		NS	0.005		0.010	NS	
Fertilizer (F)	NS	NS		NS		NS	NS		NS	NS	
Mulch(M)	0.022	0.001		0.007		0.016	0.010		0.005	0.004	
C x F	NS	0.031		NS		NS	NS		NS	0.025	

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different (P > 0.05).

Table 4-5. Micronutrient losses as affected by cultivar (‘Duke’, ‘Liberty’), fertilizer source (fish solubles, feather meal), and mulch (sawdust, weed mat) treatments of mature blueberry grown in a certified organic production system. Losses include harvested fruit, senesced leaves, and wood removed during pruning in 2015 (n=5).

Treatments	B		Fe		Mn		Cu		Zn		Al	
							$g\cdot ha^{-1}$					
Developmental Stage:												
Harvested fruit												
Cultivar							Feather	Fish				
Liberty	19		47		60		5 ab[y]	6 a	11		324 a	
Duke	16		28		33		5 ab	4 b	11		169 b	
Fertilizer												
Feather	17		38		44		5		11		251	
Fish	18		37		49		5		11		242	
Mulch	Liberty	Duke	Liberty	Duke	Liberty	Duke						
Sawdust	15 b	16 b	40 ab	27 c	50 b	36 c	5		10		250	
Weed mat	22 a	17 b	54 a	28 bc	69 a	31 c	5		12		244	
Significance[z]												
Cultivar(C)	NS		NS		NS		NS		NS		0.001	
C x F	NS		NS		NS		0.013		NS		NS	
C x M	0.021		0.049		0.001		NS		NS		NS	
Senesced Leaves												
Cultivar												
Liberty	154		1412		691		7		25		1393	
Duke	100		389		335		7		19		490	
Fertilizer												
Feather	124		1213		496		7		23		1218	
Fish	131		587		531		7		22		665	
Mulch	Liberty	Duke			Liberty	Duke			Liberty	Duke		
Sawdust	113 b	90 b	523		540 b	333 b	6		19.5 b	19.7 ab	543	
Weed mat	195 a	110 b	1278		842 a	337 b	8		30.8 a	18.7 ab	1340	
Significance												
C x M	0.039		NS		0.016		NS		0.037		NS	
Pruned Wood												
Cultivar					Feather	Fish					Feather	Fish
Liberty	25 a		142 a		788 ab	1116 a	35 a		51 a		147 ab	189.a
Duke	10 b		59 b		673 ab	529 b	23 b		28 b		86 b	64.b
Fertilizer												
Feather	17		97		731		27		38		117	
Fish	19		104		822		32		41		127	
Mulch	Liberty	Duke										
Sawdust	19 b	8 c	83 b		631 b		25		33 b		102 b	
Weed mat	31 a	12 bc	117 a		922 a		34		47 a		142 a	
Significance												
Cultivar(C)	0.006		0.006		NS		0.029		0.010		0.009	
Mulch(M)	0.001		0.010		0.003		NS		0.003		0.012	
C x F	NS		NS		0.012		NS		NS		0.041	
C x M	0.048		NS		NS		NS		NS		NS	

[z]NS = nonsignificant.
[y]Means followed by the same letter within treatment or the interaction are not significantly different (P > 0.05).

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Chapter 5: General Conclusions

Our survey in 2015, found a great diversity in size, production practices and needs for the organic blueberry industry in Oregon, depending mostly on the grower's approach and management philosophy. Additional research with grower input will be needed to continue to serve the organic industry and keep Oregon at the forefront of organic blueberry development.

There were significant effects of cultivar on the nutrient concentration of various plant parts throughout the growing season, confirming likely differences in cultivar fertilizer uptake or requirements. Seasonal differences in nutrient concentrations for various plant parts occurred. Fertilizing with fish solubles as compared to feather meal, increased the concentration of N and P, in general, in the roots, crown, and fruit, and sometimes in the leaves and stems indicating these nutrients in the fish product were readily available to the plants. The K in fish solubles led to increased %K in fruit and leaves but decreased levels in the roots and crown compared to feather meal, depending on cultivar. Feather meal was a good source for Ca leading to increased concentrations in the fruit and roots at dormancy, depending on mulch. We confirmed an impact of mulch on nutrient concentration, with higher levels of N, P, K, and B and lower Ca and Mg in various plant parts through the season, with weed mat than with sawdust, depending on cultivar.

The effects of cultivar, mulch, and fertilizer source on the allocation of biomass and nutrients at different stages of development in 2015 varied widely depending on plant part. Plants continued to increase in DW from one winter to the next as expected in a mature planting, with 'Liberty' having a greater overall biomass than 'Duke'.

Fish fertilization increased N uptake in whips, compared to feather meal, but this was not found in other plant parts. fertilization with fish also increased K uptake compared to feather meal, due to the high rate of K applied (198 $kg \cdot ha^{-1}$ vs. 18 $kg \cdot ha^{-1}$ of K, for fish and feather, respectively). Averaged over cultivar and mulch, fertilization with feather meal increased DW (roots, green fruit, and total) and Ca content of roots and crown, compared to fish solubles, confirming feather meal was a good source of Ca. Fertilizer source had little other impact on nutrient content or losses.

Weed mat, on average, increased DW of senescent leaves and the ratio of above- to below-ground biomass. Mulching with weed mat increased N content of many plant parts, compared to sawdust, but the excess N taken up was lost in leaves at senescence – no treatment effects on stored N in dormant plants was found. Uptake of P, K and B was increased with weed mat compared to sawdust, but the opposite was found for Mg. While we report advantages of increased nutrient uptake with weed mat, compared to sawdust, reports of reduced soil organic matter with long-term use of this mulch are concerning.

While we were not able to estimate nutrient gains in this study, measured nutrient losses do provide ideas on possible improvements in nutrient management. The greatest losses happened for K in fruit and were similar for N and P in fruit and pruning wood. Losses of Ca and Mg were greatest in senescent leaves. Weed mat increased losses of these nutrients compared to sawdust. Recovery of nutrients in senescent leaves and prunings could be increased in both mulches with a system where prunings are flailed (chopped) and these, along with leaves, are moved into the in-row area (under the weed mat, if present). Recovery of even a fraction of the nutrients lost in senescent leaves and pruning wood, 22.8, 1.9, 13.4, 19.6 and 3.9 $kg \cdot ha^{-1}$ of N, P, K, Ca, and Mg, respectively, may have a large impact on fertilizer requirement of organic plantings. Considering the high nutrient losses in senescent leaves and pruning wood found, re-directing this organic matter to the in-row area, would allow for plant recovery of these nutrients and mitigate the decline in organic matter. Research would be needed to determine if this new practice would lead to nutrients being available when needed for plant growth and thus reduce fertilizer requirement.

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Appendix

Appendix 1. 2015 Survey questionnaire

GENERAL ORGANIC FARM INFORMATION

2.1 Is your farm (or a certain part of the land) currently certified organic? (Only if the land is certified by the date of the interview the farm will be considered organic).

a. No

2.1.a.b If no, are you currently:

i. Transitioning your land to organic (in the 3y conversion period). If transitioning then treat the rest of the survey as if it were organic but it will count for the transitional acreage results only. Skip to 2.3
ii. Conventional but thinking about beginning transition. If selected, continue survey as if transitional but do not use data for analysis, use just as reference. Skip to 2.3
iii. Applied for certification but certificate not obtained yet by the date the interview was conducted.
iv. Following organic practices but have no intention of getting certified. This survey does not apply to you. Finish interview.
v. Conventional only. This survey does not apply to you. Finish interview.

b. Yes

2.1.b.a. If yes, does it have any other certifications or status?

i. No
ii. Biodynamic
iii. Salmon Safe
iv. GAP
v. Food Alliance
vi. Fair trade/Social Justice
vii. Other

2.2 Is your farm:

a. Organic only (100% of the land is certified organic - only organic crops grown at the farm).Skip to 2.3
b. Split (different crops grown organic and conventional at the farm), go to next question.
c. Parallel (same organic and non-organic crops grown at the farm), go to next question.

2.2.bc.a If split or parallel, <u>what is your **total** acreage (all crops, organic and conventional)</u>?
________Total acres

2.3 <u>What is your total and certified organic acreage</u>?
________Total Acres ; ________Certified Acres

REASONS FOR BEING ORGANIC

3.1 Is your reason for being organic:

a. Philosophical? 0) None 1) Low 2) Intermediate 3) High
b. Environmental impact? 0) None 1) Low 2) Intermediate 3) High
c. Health of family / workers? 0) None 1) Low 2) Intermediate 3) High
d. Market premium / business opportunity? 0) None 1) Low 2) Intermediate 3) High
e. Fashion trend? 0) None 1) Low 2) Intermediate 3) High
f. Synthetic pesticide reduction/ awareness? 0) None 1) Low 2) Intermediate 3) High
g. Others ___________________________

BLUEBERRY CROP ACREAGE AND CULTIVAR INFORMATION

<u>**If the producer grows blueberries only in his farm SKIP TO 4.4**</u>

4.1 Of your organic acreage, what is your total organic blueberry acreage?
________Acres

4.2 Do you grow conventional and organic blueberries?

a. Yes

b. No, if no skip to 4.4

4.3 What is your total conventional blueberry acreage?
________Acres
4.4 What is your organic blueberry acreage, if possible by cultivar? (use table below to complete)

IN PRODUCTION			
Cultivar	Acreage	Year Planted (crop age)	Certified (Y/N) or transition
PLANTED BUT NOT OF PRODUCTION AGE YET			
Cultivar	Acreage	Year Planted (crop age)	Certified (Y/N) or transition

4.5 Do you have plans to increase organic blueberry acreage?
a. No → Skip to 5.1
b. Yes, go to next question.

4.5.b.a To what, if possible by cultivar? (use table below to complete)

ACREAGE PLANNED FOR THE FUTURE (NEXT YEAR)			
Cultivar	Acreage	Expected planting year	Plan for certification? (Y/N) or transition

BLUEBERRY PRODUCTION SYSTEM
5.1 Do you test your soil pH pre-planting /before beginning management of the blueberry crop?
a. Yes
b. No

5.2 What was your pre-planting/before beginning management of the blueberry crop pH (on average)?
a. _____ (enter value)
b. Didn't test
c. Don't know

5.3 Did you modify your soil pre-planting pH/before beginning management of the blueberry crop?

a. No → Skip to 5.4
b. Yes, go to next question.

5.3.b.a to what?
i. ______(value, tested or estimated)
ii. Didn't retest

5.4 What input did you use to modify your pre-planting/before beginning management of the blueberry crop pH?
a. Lime
b. sulfur
c. other _____________
5.5 Do/have you replenish such amendments over time/or have later decided to add an amendment?
a. No
b. Yes.

5.5.a.b if No Why? → Skip to 5.10
5.5.b.a If Yes Which?
i. Lime ($CaCO_3$/Dolomite)
ii. sulfur
iii. other _____________

BLUEBERRY ROW/AISLE MANAGEMENT.
5.6 Did you incorporate any inputs (soil amendments) in the blueberry row prior to planting?
a. No → Skip to 5.10
b. Yes, go to next question.

5.7 Compost?
a. No
b. Yes
c. Why? ___________________
5.8 Gypsum?
a. No
b. Yes
c. Why? ___________________

5.9 Other (non nutrient, for OM or Carbon)? ___________________
a. No
b. Yes ____________________
c. Why? ___________________

5.10 What planting row management system do you use?
a. Flat ground (planted on leveled soil)
b. Raised beds
c. Combination (both systems at the same farm)
d. other (describe) ___________________

5.11 Do you use any type of mulch (natural or synthetic/inert)?
a. No → Skip to 5.12
b. Yes, go to next question.

5.11.b.a If Yes, which? (If different systems in separate fields then circle both, if different systems in the same field(s) the circle combination and describe which)

i. sawdust
ii. weed mat / landscape fabric
iii. compost
iv. combination ________________; _________________ and _________________
v. Other (describe mulch system) _________________

For combinations, include the percentage of each for the total organic acreage:

i. Sawdust ____________%
ii. weed mat / landscape fabric ____________%
iii. compost ____________%
iv. Other (describe mulch system) ____________%

5.12 Do you replenish your mulch (on top after planting)?

a. No → Skip to 5.13
b. Yes, go to next question.

5.12.b.a If yes, what, and how often?

i. sawdust. How often? _____________
ii. weed mat. How often? _____________
iii. compost. How often? _____________
iv. combinations. How often? _____________
v. Other (describe mulch system) ___________________________________

5.13 What is your between-row (aisle) management?

a. Grass planting
b. Mow and blow/or flail sometimes (circle one or both) Write explanation if needed
   ____
c. Cover crop Write explanation if needed
   ____
d. Bare soil
e. Crop (aisle intercropping)
f. Other (describe system) ____________________

5.14 Do you do intercrop in the row?

a. No → Skip to 5.15
b. Yes, go to next question.

5.14.b.a If yes, with what?

i. Cover crop _____________
ii. Crop _____________
iii. Other _____________

IRRIGATION

5.15 Which irrigation system do you use for your blueberry production?

a. Overhead: sprinklers/conventional overhead OR micro sprinklers (circle one or both for combination)
b. Drip
c. Both (overhead and drip)
d. Other (Describe your irrigation system: not irrigating, flooding, etc.) ___________________

CROPPING YEAR

5.16 In general what is your first cropping year for the blueberries after planting?

a. Year zero (planting year) spring planting?_______________________
b. First crop in year 1 (the first growing season) spring or fall planting?_______________________
c. First crop in year 2 (the second growing season) spring or fall planting?______________
d. First crop in year 3 (third growing season) spring or fall planting?______________
e. Continuous cropping since managing blue berries
f. Other ________________________

5.17 In what year do you consider your organic blueberry crop to be mature or in full production?
Year _______________ after planting year (zero being the planting year)

PRUNING

5.18 Do you prune your blueberries?

a. Yes
b. No

5.18.a.b If yes, how often do you prune (Month and Year)? _____________

5.19 Describe your pruning program?

a. Light pruning. When (frequency)? ______________
b. Hard pruning taking out big canes and non-fruitful or twiggy growth at top of bush
c. Speed pruning (making only big cuts lower on bush)
d. Renewal pruning
e. Other _______________

5.20 What is your average time to prune mature acreage? (Hours per acre and number of people, man hours)
_______________________hours _________________ people.

BLUEBERRY NUTRITION

6.1 How often do you sample your soil and submit soil samples for analysis?

a. Never (skip to 6.3)
b. Once a year
c. Twice a year
d. Every other year (every 2 years)
e. Other _______________

6.2 When during the calendar year do you take your soil samples?

a. Fall
b. Spring
c. Both
d. Other ___________________

6.3 How often do you sample leaves for tissue analysis?

a. Never (skip to 6.5)
b. Once a year
c. Twice a year
d. Every other year (every 2 years)
e. Other _______________

6.4 When during the calendar year do you conduct your tissue test?

a. Late-July to early-August
b. In Spring
c. After fruit harvest, depending on cultivar

d. Other __________________

6.5 Which resources do you use to decide on nutrient management techniques?

a. Fertilizer guide / publication (describe)________________
b. Field representative/consultant _____________
c. Internet resources (describe) ______________
d. Personal experience
e. Other ___________________

NITROGEN MANAGEMENT

6.6 What sources of N fertilizer do you use?

a. Animal based. what?_________________
b. Plant based. what?_________________
c. Mixed. what?_________________
d. Other. what?_________________

6.7 What total rate of N fertilizer do you apply, by age? (Rate of actual N per year and source):

Plant age (or Year Planted)	Rate of N (total per acre concentrated in row)	Fertility method (granular broadcast in row/liquid, by hand/fertigate/other):

6.8 When do you do your N application (give range in months)? _______ ___________

6.9 When do you expect the N from the fertilizer application to be available? (give range in months)?________________

6.10 Do you vary fertilizer application time by the fertilizer source used?

a. No → Skip to 6.11
b. Yes, go to next question.

6.10.b.a If yes, please explain how? ____________________________

6.11 Do you apply any N sources through the drip (fertigation)?

a. Yes, If yes, what? ____________________________
b. No

6.12 Have you had any problems with emitter performance?

a. Yes
b. No

6.13 Do you flush your drip fertigation system?

a. No → Skip to 6.15
b. Yes, go to next question.

6.13.b.a If yes, how often? Please explain ______________

6.13 Do you use any irrigation line cleaning products?

a. No → Skip to 6.15
b. Yes, what?
   i. Chlorine (bleach)?_________________
   ii. Acid (vinegar-acetic/other)?_________________
   iii. Peroxide?_________________
   iv. Ozone? ___________
   v. Alcohol? _______________
   vi. Other. what?_________________

OTHER NUTRIENTS AND AMMENDMENTS

6.15 Do you consider or regularly apply nutrients other than N in your fertility management program?

a. Yes
b. No

6.16 Which other nutrients?

a. Phosphorus (P). Source? ________________. Solid or liquid?
b. Potassium (K). Source? ________________. Solid________ or liquid________?
c. Boron (B). Source? ________________. Solid________ or liquid________?
d. Magnesium (Mg). Source? ________________. Solid________ or liquid________?
e. Other micronutrients? _______________ Source? ________________. Solid or liquid?
f. other ___Mb_________________

6.17 P and K are included with most organic N fertilizers; do you consider P and K accumulation over time? (is it or could it be an issue or problem that you could consider in the future)?

a. Yes
b. No
c. comments ____________________

6.18 Do you use any other soil inputs (conditioners/amendments) on established plantings? (e.g. humic acids, kelp, azomite, green sand, bentonite, biochar)

a. humic acids
b. kelp
c. azomite
d. green sand
e. bentonite
f. biochar
g. Other __________

WEED, DISEASE, AND INSECT MANAGEMENT:

7.1 What weed control methods do you use WITHIN the blueberry row (IN ROW)?

a. No weed control
b. Hand weeding/pulling
c. Hoeing
d. Weed whacker (weed trimmer) motorized.
e. Weed mat/other mulch_____________
f. Organic herbicide
g. Propane torch
h. Other ___________

7.2 Does the mulch you use help with weed control? (asked about mulch before but does it help with weed control)

a. Yes
b. No
c. Other ______________

7.3 Do you replenish your mulch for weed control purposes?

a. Yes
b. No
c. Don't mulch

7.4 What weed control methods do you use BETWEEN the blueberry rows?

a. No weed control
b. Mow a permanent grass/cover crop planting
c. Hand weeding/pulling
d. Organic herbicide
e. Flaming
f. Other: ____________

7.5 Do you scout for diseases or hire a consultant to do it for you? (circle you or hired consultant)

a. Yes
b. No

7.6 What are your main diseases?

a. Mummy berry
b. Blueberry Shock Virus
c. Phytophthora root rot
d. Pseudomonas?
e. Other __________

7.7 Do you practice any disease management strategies?

a. No → Skip to 7.8
b. Yes, go to next question.

7.7.b.a If yes, What are they? ______________________________

7.8 Do you scout for insect problems or hire a consultant to do it for you? (circle you or hired consultant)

a. Yes
b. No

7.9 What are your main insect problems?

a. Spotted Wing Drosophila (SWD)
b. Brown Marmorated Stink Bug
c. Root weevil
d. Aphids
e. Other __________

7.10 Do you practice any insect management control/strategies?

a. No → Skip to 7.13
b. Yes, go to next question.

7.10.b.a If yes, What are they (control mechanism)? ______________________

7.11 What are your vertebrate problems?

a. Voles
b. Deer
c. Birds
d. Other __________

7.12 Do you practice any vertebrate management control/strategies?

c. No → Skip to 7.13
d. Yes, go to next question.

7.12.b.a If yes, What are they? ______________________________

BLUEBERRY HARVEST – POSTHARVEST (ORGANIC FRUIT ONLY)

8.1 What is your harvesting method?

a. Machine harvest only
b. Hand pick only
c. Use both hand and machine harvest
d. other ________________________

8.2 Do you harvest your berries in buckets/ other bulk containers to be further repackaged in a separate packing house / post-harvest facility?

a. Yes
b. No

8.2.a.b If yes, what kind of package do you use?

i. Clamshells
ii. Hallocks
iii. Bulk
iv. other container __________________

8.3 Do you harvest your fruit into the final package in the field ("field pack")?

a. No → Skip to 8.4
b. Yes, go to next question.

8.3.b.a If yes, what kind of package do you use?

v. Clamshells
vi. Hallocks
vii. Bulk
viii. other container __________________

8.4 What was the average yield for your blueberries in 2014 (please specify units) if possible by cultivar? (use table below to complete)

Cultivar	Year Planted	Yield (tons/acre)

BLUEBERRY MARKETING SALES (ORGANIC FRUIT ONLY)

9.1 Do you grow blueberries for fresh market sales?

a. No
b. Yes

9.2 Do you grow blueberries for processing sales?

a. No
b. Yes

9.3 What percentage of your entire fruit yield is sold for processing or fresh market?

Fresh ___________%
Processed ___________%

9.4 What is the market of your fruit by percentage?

Type	Percentage
Direct sales (directly to final consumer)	
Processing (sold to be processed by the buyer)	
fresh wholesale (sold bulk to a packer buyer)	

Retail (sold packaged to a direct retailer)	

9.5 What are the main outlets for your direct sales?

a. Farmers Market
b. CSA
c. U-pick/farm stand (circle one or both)
d. Other ________________________

9.6 Last year (2014 season), what was the average price you received for your blueberries during the harvest season?

Fresh market retail		
Early	Mid	Late
Fresh market wholesale		
Early	Mid	Late

Processing wholesale		
Early	Mid	Late

Other (please explain) _______________________

FEEDBACK ON RESEARCH CONDUCTED - BLUEBERRY RESEARCH IMPACT

10.1 What are the greatest challenges to your organic blueberry production?

1) ___________________________
2) ___________________________
3) ___________________________

10.2 Are you aware of any OSU research on organic blueberries?

a. Yes
b. No

10.3 Have you used any of the available information from OSU for organic blueberries?

a. Yes
b. No

10.4 What can OSU extension do to support your success?

1) ___________________________
2) ___________________________
3) ___________________________

10.5 What ideas do you have for additional blueberry research that would support your success?

1) ___________________________
2) ___________________________
3) ___________________________

10.6 Would you be open to adopting new production methods if research results from OSU showed their usefulness?

a. Yes
b. No

10.7 Do you do any on-farm research?

a. Yes
b. No