The following projects meet Objective 1: *Develop small fruit germplasm through cooperative breeding and evaluation programs.*

Blueberry:

USDA-ARS Blueberry breeding program.

Claire Luby, Research Geneticist, and Ted Mackey, Biological Science Technician, USDA-ARS-HCRU, Corvallis, OR. In collaboration with B. Strik, Oregon State University, Corvallis OR; P. Jones, Oregon State University, D. Mollov, USDA-ARS-HCRU, Corvallis OR, and C. Finn (deceased), USDA-ARS-HCRU, Corvallis OR.

Claire Luby has started as the new blueberry breeder and geneticist at the USDA-ARS Horticultural Crops Research Unit (HCRU) in Corvallis, OR. In this position, she is continuing to make crosses, and evaluate seedlings and advanced selections in the ongoing blueberry trial at Oregon State University's North Willamette Research and Extension Center (OSU NWREC) as part of the cooperative USDA-ARS/OSU breeding program. Yield, fruit size, and fruit quality data is taken on advanced selections planted at OSU NWREC). We are also beginning to take firmness and drop test measurements to assess potential for machine harvestability for fresh market, disease resistance, and fresh market cold storage potential in promising selections. Heat and cold tolerance are also important characteristics to assess. This past summer, we had an extreme heat event across the Pacific Northwest and our OSU NWREC trial saw temperatures reach 115°F for two days in a row with high nighttime temperatures and low relative humidity. We saw significant heat damage to plants and fruit, but also noticed differences among selections that will inform future breeding efforts for heat tolerance.

USDA Breeding Insights Initiative – Blueberry (study in progress)

C. Luby, N. Bassil, M.A. Hardigan. USDA-ARS; D. Zhao, M. Sheehan, Cornell University, Department of Plant Biology; A. Hulse-Kemp, USDA-ARS; J. Humann, Dorrie Main, Washington State University, Department of Horticulture.

The small fruit breeders at the USDA-ARS Horticultural Crops Research Unit (HCRL) are actively engaging with the USDA-ARS Breeding Insights initiative, a program encompassing multiple small fruit crop species, whose goal is to develop genetic tools and resources to enable molecular breeding applications for public breeding programs. The scope of this project with respect to the USDA-ARS-HCRU blueberry breeding program includes collecting data from existing blueberry seedling populations to be used for genomic selection and prediction in conjunction with a new blueberry DNA marker panel being developed by the Breeding Insights bioinformatics team at Cornell University (Ithaca, NY). We are in the process of collecting data on traits including seasonality (flowering and ripening time) and fruit quality (firmness, sugars, acidity) in the Northwest-adapted USDA-ARS-HCRU blueberry population. Upon completion of phenotypic data collection and availability of genetic marker data, our goal will be to evaluate the ability of this genetic marker screening platform to accurately predict seasonality and fruit quality phenotypes in our Northwest blueberry germplasm.

Vaccinium CAP Project- Discover DNA markers and fruit characteristics that maximize industry profitability and match consumer preferences in blueberry (ongoing)

C. Luby, N. Bassil, T. Mackey, USDA ARS Corvallis, OR; Marti Pottorff, Massimo Iorizzo, Penelope Perkins-Veazie, Plants for Human Health Institute, North Carolina State University, Kannapolis, NC.

We are part of the large Vaccinium CAP project, primarily working on the team that is identifying DNA markers associated with fruit characteristics and subcomponents that reduce fruit bruising, contribute to an extension of fruit shelf life, and match consumer preferences. We are collecting genotypic and phenotypic data from our Northern Highbush blueberry breeding program. This information will be used to complete a GWAS study and to evaluate which fruit characteristics contribute to the three major indicators of blueberry fruit quality- improved shelf life, matching consumer preferences, and reduction of fruit damage from mechanical harvest. In 2020 and 2021, we harvested ripe blueberry fruit from 196 seedlings for the 'Draper' x 'Jewel' population, 200 accessions from the NCGR Field collection, and 960 northern highbush blueberry accessions (GenStudy) from the 2016 and 2017 USDA-ARS-HCRL breeding program. Data is collected on a Texture Analyzer to simultaneously evaluate blueberry texture, stem scar diameter, scar tear, fruit weight. We are also collecting information on shelf life indicators such as wrinkle/shrivel, mold, and leakage at harvest time and six weeks post-harvest (stored at 4 °C). Fruit samples have been sent to our partner laboratories for volatile and non-volatile chemistry analysis. Preliminary analyses indicated a wide range of variation for most of the traits and parameters. We have used the phenotypic information to make selections and crosses for various fruit characteristics.

Evaluating Vaccinium germplasm for heat tolerance, drought tolerance, and cold tolerance.

Todd Anderson, Nahla Bassil, Kim Hummer USDA ARS NCGR-Corvallis, OR; Scott Orr, Dave Bryla, Claire Luby, Michael Hardigan, USDA ARS HCRU, Corvallis, OR

During 2021, staff of the USDA in Corvallis working with those at Oregon State University Department of Horticulture, visited four blueberry plots containing 15 hybrid blueberry families to assess horticultural and chemical traits. A singular heat-dome effect

(111 F) occurred at Corvallis in late June. Blueberry fruits are being evaluated for firmness, color, and sugar acid chemistry, after that event and at four other sites in Oregon and Washington with drought and high temperature conditions. Assessment of heritability of desirable traits will be determined through parentage analysis of the crossing families.

Blackberry and Raspberry:

Michael Hardigan is the USDA-ARS lead on the USDA-ARS & OSU Cooperative Caneberry Breeding Program, USDA-ARS-HCRU, Corvallis.

Blackberry breeding is the greatest focus of the USDA-ARS-HCRU caneberry breeding program. Through our historic cooperation with Oregon State University's Department of Horticulture, we are able to conduct advanced selection trials and screening at the Oregon State University North Willamette Research and Extension Center (OSU-NWREC). We are developing thornless, machine harvestable blackberry cultivars for PNW growers, which have historically included trailing blackberry varieties that are genetically distinct from eastern US types. Our current objective is to identify selections with better firmness and machine harvestable yield and fruit quality than 'Black Diamond', 'Columbia Star', and 'Marion'. Building on the work of Chad Finn, we are continuing efforts to adapt eastern US semierect and primocane blackberry material to the PNW, and experimenting with incorporating their genetics into PNW trailing types. Our objective is to develop varieties with improved hardiness and fresh quality, while maintaining the exceptional flavor of traditional Northwest trailing varieties. We are preparing to release ORUS 4222-1, a thornless trailing type for machine harvest and processing that can compete with 'Black Diamond', ORUS 4670-1, a thornless semierect type with yield comparable to industry standard 'Chester Thornless' and significantly improved flavor, and ORUS 4999-2, an erect primocane-fruiting type with exceptional plant vigor and yield for fresh market.

We are actively breeding floricane-fruiting red raspberry selections for machine harvest and processing, and primocane-fruiting selections for handpick and fresh market. We support the broader PNW raspberry industry by providing an additional environment in OR for germplasm development and testing, teaming up with the Washington State University (WSU; Wendy Hoashi-Erhardt) and British Columbia (Michael Dossett) breeding programs and including a significant number of their advanced selections in our annual machine harvest trials at OSU-NWREC. Our efforts help to identify machine harvestable selections with high yield and fruit quality in multiple environments, and we generate new crosses using these selections that are in turn screened in WA for cold hardiness (Lynden, WA) and for root rot tolerance (Puyallup, WA). With regard to fresh market varieties, we are waiting for approval to patent and release the primocane-fruiting selection ORUS 4716-1, which has shown excellent yields and fresh fruit quality.

Though a niche crop, we are currently maintaining our black raspberry ("blackcap") breeding efforts, which include developing higher yielding and less thorny selections with improved eating quality and pairing with OSU Food Science to identify superior processing-oriented selections. Cooperating with the USDA-ARS NCGR lab (Nahla Bassil), we have incorporated marker-assisted selection for multiple aphid resistance genes as a key component of this program in order to focus on selections with a reduced likelihood of harboring aphid-vectored viruses, a major problem for blackcaps growers in OR. Along with traditional black raspberry selections, we are attempting to develop "purple raspberry" hybrids incorporating both red and black raspberry genetics, as well as the wild species *Rubus coreanus*. Early seedlings derived from these crosses have demonstrated some improvements over traditional blackcaps, including improved vigor and yield, reduced thorniness, and better flavor.

Selections Pending Patent Approval:

- **ORUS 4222-1** – A thornless and high yielding selection. In multiple trial years it has shown similar, sometimes greater yield potential than 'Columbia Star'. Compared with 'Columbia Star', ORUS 4222-1 produces larger numbers of smaller 'Marion'-sized fruit, with a notably uniform conical shape, and good firmness to support machine harvest. The fruit are sweet, with higher soluble solids than trailing cultivars 'Columbia Star', 'Black Diamond', and 'Hall's Beauty'. Ripens one week later than 'Columbia Star'.
- **ORUS 4670-1** – This thornless semierect blackberry selection had similar or greater yields to 'Chester Thornless' in 2018-19, and significantly greater yields than 'Chester Thornless' in 2020. Ripens 10-14 days ahead of 'Chester Thornless', closer to 'Triple Crown', but harvest season extends 14 d beyond 'Triple Crown'. It has similar fruit size and firmness to 'Chester Thornless', but much better flavor. The fruit showed at least as good post-harvest quality as 'Chester Thornless'.
- **ORUS 4999-2** – An early-ripening, high-yielding primocane-fruiting blackberry. The plants are vigorous and productive, with fruit that ripen with or earlier than 'Prime-Ark® 45'. Yields on two-year-old plots were twice as high as three-year-old plots of 'Prime-Ark® 45' in 2019, and 44% higher than 'Prime-Ark® 45' in 2021 (2019 trial). The fruit are medium sized for a primocane type, firm, tough-skinned, with good sweetness. The canes are vigorous and establish quickly, with the potential to produce a year-one 'baby crop' competitive with 2nd-year yields of other selections. Ranked highest for flavor among all primocane samples in the most recent OSU Food Science fruit cutting.
- **ORUS 4716-1** – A primocane-fruiting selection with good firmness and flavor. The fruit can be picked at a range of colors from light pink to full red and still have sweetness and a good flavor. The season starts at about the same time as 'Heritage' but it peaks and finishes about 7d later than 'Heritage'.

Future Variety Releases:

- **ORUS 4535-1** – A dwarf, thornless trailing blackberry for homeowner market. While a floricane type, it has short internodes, and its 0.60-0.75 m (2-2.5 ft.) long canes will cascade out of containers. The fruit quality is fine but not exceptional.
- **ORUS 4928-1** – A sterile, ornamental pink flowering semi-erect blackberry that is of interest to cut flower growers.
- **ORUS 3381-3** – A late season variety, as late as 'MacBlack' but with better fruit size and quality. Yield comparable to or slightly less than 'Munger' but starts ripening 12 d later. Targeted for fresh market.

Strawberry:

USDA-ARS Strawberry breeding program.
Claire Luby, USDA-ARS-HCRU, Corvallis. In collaboration with B. Strik, Oregon State University, Corvallis OR; M. Hardigan, USDA-ARS-HCRU, Corvallis OR; T. Mackey, USDA-ARS, Corvallis OR; P. Jones, Oregon State University, and C. Finn (deceased), USDA-ARS-HCRU, Corvallis OR.

We are continuing to evaluate selections from the USDA-ARS/OSU cooperative strawberry breeding program at Oregon State University's North Willamette Research and Extension Center. The primary goals of this breeding program have been to develop June-bearing strawberry cultivars that are suitable for processing and that are adapted to the Pacific Northwest. We are also collaborating with Washington State University and Agri-Foods Canada to that are either June-bearing or day-neutral and are suited for fresh market. We also work to collect, evaluate and incorporate new *Fragaria* germplasm.

Development of Polyploid Tools and Resources for Octoploid Strawberry Breeding. 2020-2021. (Study in progress)

M.A. Hardigan, M.J. Feldmann, P.P. Edger, S.J. Knapp. University of California Davis and USDA-ARS.

Michael Hardigan (USDA-ARS) has continued working with collaborators at the University of California Davis to develop genomic tools and resources for octoploid strawberry breeding and genetics research, including the development of an improved gold-standard reference genome of heterozygous day-neutral cultivar 'Royal Royce' and low-cost, high-throughput marker genotyping panels able to interrogate subgenome-specific DNA polymorphisms. This improved genome assembly 'FaRR1' is completely subgenome-resolved, haplotype-phased, and contains numerous single-molecule chromosome assemblies without information gaps, and contains both the short-day and day-neutral flowering alleles in its respective parental-derived haplotypes. It is currently being made publicly available on Phytozome (https://phytozome-next.jgi.doe.gov/) and the Rosaceae Genomics Database (https://www.rosaceae.org). In addition, an octoploid strawberry DArTag genetic marker panel has been designed with the company Diversity Arrays Technology using the same marker technology being utilized by the USDA Breeding Insights initiative for other small fruit crop species. The genetic markers on the DArTag panel are physically anchored to the new 'FaRR1' strawberry genome, and are intended to provide a resource for genomic selection, prediction, and trait mapping in public strawberry breeding programs. These tools will be made freely available to public researchers beginning Fall-Winter of 2021.

The following projects meet Objective 2 and Objective 4.
Objective 2 - *Develop practices for small fruit production tailored for climatic and market needs of growers*.
And
Objective 4 – *Identify opportunities and collaborate on the development of extension resources for multistate, regional, national, and/or international audiences.*

Horticulture, David Bryla (https://www.ars.usda.gov/pacific-west-area/corvallis-or/horticultural-crops-research/people/bryla-david/)

Blueberry:

Effects of fertigation and granular application of phosphorus fertilizers on mineral nutrition and root colonization by mycorrhizal fungi in northern highbush blueberry.
Oregon Blueberry Commission. 2017-2020.
David Leon (graduate student), Oregon State University, Corvallis, OR; David Bryla and Carolyn Scagel, USDA-ARS HCRU, Corvallis, OR; Bernadine Strik, Oregon State University, Corvallis, OR.
Dissemination of results: 2020 Oregon Blueberry Conference, ISHS XII International Vaccinium Symposium, UMaine Wild Blueberry Conference, 2020 LMHIA Horticultural Growers Short Course (Canada), 4th Conference on Crop Fertigation (Mexico), 4th Chilean Berry Conference.
Plans for next reporting period: None.

Our previous studies indicated that fertigating with N was more effective than using granular N fertilizers in northern highbush blueberry. The objective of the present study was to build on these findings and determine whether fertigation was also an effective method for applying P. The trial was located in western Oregon and conducted in a mature planting of 'Duke' and 'Bluecrop' blueberry. Treatments were applied for 2 years to both cultivars and included no P, a single application of P fertilizer in the spring (early April) using granular monoammonium phosphate (MAP) at the highest recommended rate of 67 $kg \cdot ha^{-1}$ P_2O_5, and weekly fertigation from mid-April to late-July with liquid ammonium polyphosphate at a total rate of 34 or 67 $kg \cdot ha^{-1}$ P_2O_5 per year. Each treatment was also fertilized with 224 $kg \cdot ha^{-1}$ N and 1.5 $kg \cdot ha^{-1}$ B per year. In the year prior to applying the P treatments, the concentration of P in recently expanded leaves was low in both cultivars (0.08-0.09%) and below the recommended level for blueberry in the region (> 0.10%). Fertigation and granular applications of P fertilizer increased the concentration of P in soil solution within the root zone, but neither had any effect on yield, berry weight, or berry firmness during the study in either cultivar. These treatments also had no effect on leaf P. In fact, the concentration of P in the leaves was no different than it was prior to applying any P to the plants. The soil at the site was high in clay (Malabon series) and likely bound much of the P applied as fertilizer. Similar results were found in grower fields in Oregon. Questions remain on whether blueberry requires less P than recommended or if alternative sources or rates of P fertilizer are needed.

Comparison of methods for applying boron fertilizers in northern highbush blueberry. Oregon Blueberry Commission. 2017-2020.
David Leon (graduate student), Oregon State University, Corvallis, OR; David Bryla and Carolyn Scagel, USDA-ARS HCRU, Corvallis, OR; Bernadine Strik, Oregon State University, Corvallis, OR.
Dissemination of results: 2020 Oregon Blueberry Conference, 2021 ASHS Conference, ISHS XII International Vaccinium Symposium, UMaine Wild Blueberry Conference, 2020 LMHIA Horticultural Growers Short Course (Canada), 4th Conference on Crop Fertigation (Mexico), 4th Chilean Berry Conference.
Plans for next reporting period: None.

While blueberry fields are often fertilized with B through the soil and foliage, some growers have expressed interest in applying B by fertigation through the drip system. We tested the efficiency of B fertigation in two cultivars of northern highbush blueberry, ‘Earliblue’ and ‘Aurora’, and compared it to traditional methods of applying B fertilizers to the soil or the leaves. The plants were mature, irrigated by drip, and located in western Oregon. Treatments included: 1) no B fertilizer; 2) soil application in the spring with sodium borate; 3) bloom or post-bloom foliar applications of boric acid; and 4) weekly fertigation from mid-April to late-July with boric acid. Each B fertilizer was applied at a total rate of 1.5 $kg \cdot ha^{-1}$ B per year. The treatments were initiated in spring 2018 and continued for two consecutive growing seasons. The plants were also fertigated with ammonium sulfate in each treatment at a total rate of 224 $kg \cdot ha^{-1}$ N per year. In year 1, leaf B in ‘Earliblue’ was greater with than without B fertilizer and was highest when we applied B as a foliar fertilizer. However, foliar applications were accidentally applied at five times the intended rate to both cultivars, and as a result, leaf B was slightly above the recommended range (i.e., 30–80 ppm) with this treatment in ‘Earliblue’. In contrast, fertigation with B increased leaf B to within range in both cultivars and resulted in higher concentrations than applying it to the soil. In fact, leaf B was below range when we applied B to the soil in both cultivars and was no different from the treatment with no B in ‘Aurora’. We noticed that sodium borate dissolved slowly on the soil, despite the fact that we applied it a time of year with frequent rainfall. By the following season, leaf B in ‘Earliblue’ was below range again with no B but within or above range with any of the B fertilizers, including when it was applied to the soil. However, leaf B in ‘Aurora’ remained deficient with soil applications or no B and was within range when B was applied by fertigation or as a foliar fertilizer. Fertigation and foliar B also resulted in higher concentrations of B in the fruit. The results of this research may vary with timing of the fertilizer applications but will likely apply to most regions where blueberry is grown.

Comprehensive Management Strategies for Use of Biostimulants in Blueberry. Northwest Center for Small Fruits Research/Oregon Blueberry Commission. 2015-2021.
David Bryla, USDA-ARS HCRU, Corvallis, OR; Oscar Vargas (former graduate student), Dole SA, Santiago, Chile; Alex Gregory (graduate student), Oregon State University, Corvallis, OR

Dissemination of results: 2020 Oregon Blueberry Conference, ISHS XII International Vaccinium Symposium, 4th Conference on Crop Fertigation (Mexico), 4th Chilean Berry Conference.
Plans for next reporting period: Continue field and greenhouse experiments (2022).

Many growers are using biostimulants such as humic substances and natural extracts from seaweed in an effort to improve plant growth and production in their crops. These products are used typically as foliar sprays or soil supplements and often work best when applied with fertilizers. Initially, we discovered that application of humic substances (humic and fulvic acids) increased plant growth during the first 2 years after planting in 'Draper' blueberry. The effects of the humic substances on root growth were particularly apparent and resulted in 49-52% more dry root biomass than either conventional fertigation or a control treatment that lacked humic substances but contained exactly the same nutrients as the treatment with humic substances. We then conducted a trial in a mature planting of 'Bluecrop'. In this case, humic substances increased root growth and the availability of P and Zn in the soil relative to controls with fertilizer only, but after 3 years, they had no effect on shoot growth, yield, or fruit quality. Next, we tested several biostimulants, including humic substances, extracts from *Ascophyllum* seaweed, and a mix of N-fixing bacteria (*Azorhizobium caulinodans*, *Azoarcus indigens*, and *Azospirillium brasiliense*), on potted plants of 'Draper'. Fertigating with humic substances or seaweed extract increased growth of the plants relative to using the bacterial mix or nutrients only; however, the response was quite different between the two products. Plants grown with humic substances were greener and contained more N than those in the other treatments, while those grown with seaweed extract tended to be taller and more upright. Finally, a fourth trial was conducted in a hydroponic system in order to avoid soil interactions with the humic substances and to carefully examine root development. Six cultivars were chosen for the study, including 'Duke', 'Draper', 'Top Shelf', 'Cargo', 'Legacy', and 'Last Call'. Each cultivar was grown in a complete nutrient solution with four rates of humic acids, including 0, 100, 250, and 500 $mg \cdot L^{-1}$ of active ingredient (a.i.). The solutions were adjusted daily to maintain a pH of 5.0 in each treatment. The plants were harvested destructively after 8 weeks. Humic acids had a similar effect on each cultivar and increased shoot dry weight by an average 33% and 38% when plants were grown with 250 and 500 $mg \cdot L^{-1}$ a.i., respectively; however; they had no effect on shoot dry weight at the lower rate of 100 $mg \cdot L^{-1}$ or on root dry weight at any of the rates. Our next step is to determine if, with more time, humic acids will elicit a response in the roots. Clearly, the use of these products can be beneficial during establishment of highbush blueberry, but more research is needed to determine exactly how they work and whether they are useful under all circumstances.

Tools and practices for mitigating heat damage in blueberries. Oregon and Washington Blueberry Commissions, 2015-2021.
Joy Yang (former graduate student), Sierra Cascade Nursery, Ballico, CA; David Bryla, USDA-ARS HCRU, Corvallis, OR; Bernadine Strik, Oregon State University, Corvallis, OR; Troy Peters, Washington State University, Irrigated Agriculture Research and Extension Center, Prosser, WA.

Dissemination of results: 2021 ASHS Conference.
Plans for next reporting period: TBD.

Heat damage is a persistent problem in blueberries and results in millions of dollars of fruit loss each year. Growers in the Pacific Northwest commonly report sunburn, softening, and discoloration of the berries when daytime air temperatures exceed 32-35 °C (90-95 °F). Recently, we developed a simple climatological model to predict blueberry fruit temperatures based on local weather data and to simulate the effects of using over-canopy sprinklers for cooling the fruit. Predictions of fruit temperature on sunny days were strongly correlated with the actual values ($R^2 = 0.91$) and had a root-mean-square error of approximately 2 °C. Among the parameters tested, ambient air temperature and light intensity had the greatest impact on fruit temperature, while wind speed and fruit size had less impact, and relative humidity had no impact. Cooling efficiency was successfully estimated under different sprinkler cooling intervals by incorporating a water application factor that was calculated based on the amount of water applied and the time required for water to evaporate from the fruit surface between the intervals. The results indicated that water temperature and nozzle flow rate affected the extent to which cooling with sprinklers reduced fruit temperature. However, prolonging the runtime of the sprinklers did not guarantee lower temperatures during cooling, since cooling efficiency declined as temperature of the fruit approached the temperature of the irrigation water. The outcome of this study provides increased understanding of how fruit temperature changes under various conditions in northern highbush blueberry and presents a useful means for evaluating feasible cooling practices and making cooling decisions according to local weather conditions.

Use of biochar as an alternative soil amendment for conventional and organic production of northern highbush blueberry. Northwest Center for Small Fruits Research/USDA NIFA Organic Transition program. 2015-2022.
Bryan Sales (former graduate student), University of North Carolina, Pembroke, NC; David Bryla, Jerry Weiland, and Carolyn Scagel, USDA-ARS HCRU, Corvallis, OR; Kristin Trippe, USDA-ARS FSCRU, Corvallis, OR; Shikha Singh (postdoc), Scott Lukas, Oregon State University Hermiston Agricultural Research & Extension Center, Hermiston, WA; Bernadine Strik and Dan Sullivan, Oregon State University, Corvallis, OR.
Dissemination of results: 2021 ASHS Conference.
Plans for next reporting period: Continue to evaluate the use of biochar in organic blueberry systems (year 2).

Biochar is a highly porous, carbon-rich residue produced by thermochemical conversion (pyrolysis) of plant biomass and carbonaceous organic materials under oxygen-controlled conditions. Chars produced by this process tend to have high ion-exchange capacities and, when added to soil, increase retention of water and nutrients and improve soil aggregation, porosity, and aeration. Productivity has been shown to respond positively to biochar addition in several crops, including northern highbush blueberry; however, the cost is expensive, and benefits vary depending on the source, pyrolysis conditions, and feedstock of the biochar. A controlled experiment was conducted in a greenhouse to evaluate potential feedstocks for producing a suitable and cost-effective biochar for blueberry. Biochars were individually produced from three locally available feedstocks (apple, blueberry, and grape prunings) at different pyrolysis temperatures (350 and 700 °C) and a control (nonpyrolyzed), and were either used "as is" or were co-composted for 6 weeks with grape pomace. Each treatment was mixed at 20%, by volume, with Atkins sandy loam soil and planted in 4-L pots with 'Duke' blueberry. Additional treatments included soil with no amendments or 20% compost only. The plants were watered as needed and fertilized weekly using a dilute solution of organic nitrogen, phosphorus, and boron fertilizers. The pH of leachate collected from the pots averaged 4.5-5.5 in each treatment, which is the recommended range for highbush blueberry; however, electrical conductivity of the leachate was 15-45% higher than recommended (< 2 dS/m) when soil was amended with biochar only. Consequently, plants grew better with co-composted biochar than with biochar alone. Overall, plants grown with co-composted apple biochar produced at 350 °C had greater leaf area and 20% to 80% more total dry weight than plants grown with any other treatment, including those with no amendment or compost only.

Maintaining optimal root temperatures in highbush blueberry.
Rui Machado, University of Évora, Évora, Portugal; David Bryla, USDA-ARS HCRU, Corvallis, OR.
Dissemination of results: ISHS XII International Vaccinium Symposium.
Plans for next reporting period: none.

Blueberry roots are sensitive to high temperatures and tend to grow poorly in warm soils or warm soilless media. Three experiments were conducted to evaluate strategies for reducing temperatures in the root zone in Évora, Portugal, where soil can reach temperatures > 45 °C. The first experiment was conducted in a small planting of 'Ozarkblue' blueberry. Treatments included bare soil, a 10-cm-deep layer of aged pine bark mulch, and black, green, and white geotextile landscape fabric. Bark mulch and green landscape fabric resulted in the lowest mid-day soil temperatures among the treatments, which improved canopy development and survival of the plants during establishment. White geotextile fabric also reduced soil temperature but resulted in a considerable amount of weed growth under the fabric. The second experiment was likewise conducted on 'Ozarkblue', but, in this case, the plants were grown in 40-L pots filled with a soilless mix of three parts peat, two parts pine bark, and one part humus, by volume. Treatments included black pots and black pots covered with white geotextile landscape fabric. After a year, canopy volume of the plants was greater in black pots than in white pots; however, yield was not affected by pot color. The third experiment was conducted in a 2-year-old planting of 'Legacy' blueberry. Treatments included no shade and 60% green shade netting. The netting had no effect on soil temperature in the root zone as a result of the fact that 1) the canopy of plants intercepted the majority of the radiation at midday and 2) frequent irrigation mitigated changes in soil temperature. Based on these results, bark mulch and green landscape fabric appear to be the best options for reducing temperatures in the root zone of blueberry in warm climates.

Strategies for dealing with drought in blueberry. Oregon Blueberry Commission, 2020-2022.

David Bryla and Scott Orr, USDA-ARS HCRU, Corvallis, OR; Khalid Almutairi (former graduate student), King Saud University, Riyadh, Saudi Arabia; Bernadine Strik, Oregon State University, Corvallis, OR.

Dissemination of results: ISHS XII International Vaccinium Symposium, 4th Chilean Berry Conference, XIV International Seminar on Fruit Trees (Chile).

Plans for next reporting period: Install weighing lysimeters to develop better crop coefficients (year 1); evaluate the use of pulsed drip irrigation in sandy soils (year 2); application of small unmanned aerial systems (drones) for spatial and temporal assessment of plant water deficits and irrigation needs (on going).

Many blueberry growers in western US are facing serious water limitations and must cut back irrigation during drier years. To identify the most critical periods for irrigation, we evaluated the effects of soil water deficits during various stages of fruit development on different cultivars of northern highbush blueberry. The study was conducted for 2 years in western Oregon and included two early season cultivars, ‘Earliblue’ and ‘Duke’, a mid-season cultivar, ‘Bluecrop’, and two late-season cultivars, ‘Elliott’ and ‘Aurora’. Volumetric soil water content and stem water potentials declined within a week or two with no rain or irrigation in each cultivar and were lowest during the later stages of fruit development. Water deficits reduced berry weight by 10% to 15% in ‘Earliblue’ and ‘Elliott’ when irrigation was withheld in the second year during early or late stages of fruit development and by 6% to 9% in ‘Aurora’ when irrigation was withheld in either year during the final stages of fruit development. However, water deficits only reduced yield significantly in ‘Aurora’, which produced 0.8–0.9 kg/plant less fruit per year when irrigation was withheld during fruit coloring. In many cases, water deficits also reduced fruit firmness and increased the concentration of soluble solids in the berries but had inconsistent effects on titratable acidity and sugar-to-acid ratios. As a rule, water deficits were most detrimental during later stages of fruit development, particularly in mid- and late-season cultivars, which ripened in July and August during the warmest and driest months of the year.

Ion-specific limitations of various salts in highbush blueberry.

David Bryla and Carolyn Scagel, USDA-ARS HCRU, Corvallis, OR; Scott Lukas, Oregon State University Hermiston Agricultural Research & Extension Center, Hermiston, WA; Dan Sullivan, Oregon State University, Corvallis, OR; John Yeo (former graduate student), Fall Creek Farm & Nursery, Lowell, OR.

Dissemination of results: 4th Chilean Berry Conference, XIV International Seminar on Fruit Trees (Chile).

Plans for next reporting period: Examine the salinity effects of using high rates of $CaSO_4$ (gypsum) in blueberry.

Excess salinity is becoming a prevalent problem for production of highbush blueberry, but information on how and when it affects the plants is needed. Two experiments, including one on the northern highbush cultivar, Bluecrop, and another on the southern highbush cultivar, Springhigh, were conducted to investigate their response to salinity and assess whether any suppression in growth was ion specific or due primarily to osmotic stress. In both cases, the plants were grown in soilless media (calcined clay) and fertigated using a complete nutrient solution containing four levels of salinity [none (control), low (0.7–1.3 $mmol \cdot d^{-1}$), medium (1.4–3.4 $mmol \cdot d^{-1}$), and high (2.8–6.7 $mmol \cdot d^{-1}$)] from either NaCl or $CaCl_2$. Drainage was minimized in each treatment except for periodic determination of electrical conductivity (EC) using the pour-through method, which, depending on the experiment, reached levels as high as 3.2–6.3 $dS \cdot m^{-1}$ with NaCl and 7.8–9.5 $dS\ m^{-1}$ with $CaCl_2$. Total dry weight of the plants was negatively correlated to EC and, depending on source and duration of the salinity treatment, decreased linearly at a rate of 1.6–7.4 g per $dS \cdot m^{-1}$ in 'Bluecrop' and 0.4–12.5 g per $dS \cdot m^{-1}$ in 'Springhigh'. Reductions in total dry weight were initially similar between the two salinity sources; however, by the end of the study, which occurred at 125 d in 'Bluecrop' and at 111 d in 'Springhigh', dry weight declined more so with NaCl than with $CaCl_2$ in each part of the plant, including in the leaves, stems, and roots. The percentage of root length colonized by mycorrhizal fungi also declined with increasing levels of salinity in 'Bluecrop' and was lower in both cultivars when the plants were treated with NaCl than with $CaCl_2$. However, leaf damage, which included tip burn and marginal necrosis, was greater with $CaCl_2$ than with NaCl. In general, $CaCl_2$ had no effect on uptake or concentration of Na in the plant tissues, while NaCl reduced Ca uptake in both cultivars and reduced the concentration of Ca in the leaves and stems of 'Bluecrop' and in each part of the plant in 'Springhigh'. Salinity from NaCl also resulted in higher concentrations of Cl and lower concentrations of K in the plant tissues than $CaCl_2$ in both cultivars. The concentration of other nutrients in the plants, including N, P, Mg, S, B, Cu, Fe, Mn, and Zn, was also affected by salinity, but in most cases, the response was similar between the two salts. These results point to ion specific effects of different salts on the plants and indicate that source is an important consideration when managing salinity in highbush blueberry.

Irrigation and Cost and Benefits of Substrate Production of Blueberries in Oregon.
Oregon Blueberry Commission, 2021-2022.
David Bryla and Scott Orr, USDA-ARS HCRU, Corvallis, OR; Cora Bobo-Shisler and Lloyd Nackley, Oregon State University, North Willamette Research and Extension Center, Aurora, OR.
Dissemination of results: N/A.
Plans for next reporting period: Continue the trial (year 2).

Production of blueberries in substrate could become a good niche market for conventional and organic growers in the Pacific Northwest, but research is needed to develop efficient systems and practices as well as determine the economic costs and benefits. The goal of this project is to evaluate methods for regulating moisture and nutrients in the containers in which the plants are grown and develop economic enterprise budgets for production of blueberries in substrate (coir and perlite). Specifically, we are testing different drip emitter configurations, including a new emitter designed to apply water uniformly over the surface of the growing medium and prevent formation of dry spots in the pots. The study will be conducted for three years in a Cravo using 'Legacy' blueberry. We will also evaluate different growing media with various amounts of peat, coir, and perlite that are either mixed homogenously throughout the pot or are layered with different ratios of each component to alter substrate moisture and drainage from the pots. In each case, irrigation will be triggered at a matrix potential of -1 or -5 kPa and applied using either a single continuous pulse of up to 10 minutes or a series of short 1-minute pulses every 5 minutes. The study will provide new information on the best irrigation system for growing blueberry in substrate and determine the optimum time and frequency to apply water in order to maximize plant growth and production. We will also produce an enterprise budget for substrate production and an interactive spreadsheet that will help growers to understand their long-run costs and revenues, as well as financial- and price-risk implications of decisions made when setting up a system for growing blueberries in pots.

Fertigation Practices for Increasing Calcium Content and Improving Fruit Quality and Shelf Life of Conventional and Organic Blueberries. Oregon and Washington Blueberry Commissions. 2021-2022.
David Bryla, USDA-ARS HCRU, Corvallis, OR; Wei Yang, Oregon State University, North Willamette Research and Extension Center, Aurora, OR; Lisa DeVetter, Washington State University, Mt. Vernon NW Washington Research and Extension Center, Mount Vernon, WA.
Dissemination of results: 4th Conference on Crop Fertigation (Mexico), 4th Chilean Berry Conference.
Plans for next reporting period: Repeat study for a second season.

Calcium (Ca) is a key component of fruit quality and is known to increase berry firmness and shelf life in blueberries. Usually, Ca is applied by adding gypsum or lime to the soil or by using foliar sprays. However, these materials tend to be ineffective for increasing Ca in the fruit. Recently, we discovered that nearly all Ca in the fruit is taken up during the short period between the early green and late green stages of berry development. Therefore, maintaining a high concentration of Ca in the root zone during these stages may facilitate uptake of the nutrient into the fruit. One potential way of doing this is to inject Ca fertilizer into the drip irrigation system and apply it by fertigation. Currently, there are a number of Ca products that can be used for fertigation, including micronized solution grade gypsum (which is certified organic), Ca thiosulfate, and Ca polysulfide. In the present study, we are testing fertigation with gypsum and comparing it to soil application of gypsum, foliar application of calcium chloride, and a control treatment with no Ca fertilizer. Each treatment is applied to three cultivars, including 'Duke, 'Bluecrop', and 'Aurora'. Measurements include the concentration of Ca in the soil solution, leaves, and fruit, yield, fruit quality (Brix, firmness, TA), and shelf life of the berries in cold storage. We are testing fertigation with gypsum and Ca thiosulfate and comparing it to soil application of gypsum and no Ca fertilizer in 'Earliblue' and 'Elliott'. This work directly addresses industry research priorities on plant nutritional/fertilizer needs and cultural aspects to improve quality, firmness, and storability of blueberry fruit.

Blackberry and Raspberry:

Pulsed drip irrigation increases growth and fruit production of red raspberry. WA Specialty Crop Block Grant Program. 2018-2020.
Jesse Carroll (graduate student), Oregon State University, Corvallis, OR; David Bryla and Scott Orr, USDA-ARS HCRU, Corvallis, OR; Chris Benedict, Washington State University, Bellingham, WA; Lisa DeVetter, Washington State University Northwestern Washington Research & Extension Center, Mt. Vernon, WA.
Dissemination of results: 2021 LMHIA Horticultural Growers Short Course, 2021 NARBA Conference, 2021 ASHS Conference.
Plans for next reporting period: Conduct pulsed drip irrigation studies in blueberry.

Pulsed drip irrigation is the practice of applying water in a series of small intervals each day, until the total amount of water required by the crop is added. When managed properly, pulsing can reduce deep percolation and runoff and supply water and nutrients at an optimum rate for plant uptake, increasing growth and production relative to applying the same amount of water in a single continuous application. The objective of the present study was to determine whether pulsed water applications by drip was beneficial in red raspberry. The trial was conducted at a commercial site located in Lynden, WA in a well-established field of 'Wakefield' raspberry. Soil at the site was a sandy loam. Treatments were applied for three growing seasons (2018–2020) and included pulsed and standard continuous irrigation. In both cases, irrigation was applied using a single lateral of drip tubing per row. The tubing had 1 $L \cdot h^{-1}$ emitters every 0.5 m and was suspended from a trellis wire in the middle of the row at ≈0.3 m above the soil surface. Pulsing was programmed to operate for 30 min every 2 h, up to eight times per day, as needed, while continuous irrigation was applied once a day for up to 4 h using approximately the same amount of water as applied to the pulsed treatment. Fruit were machine-harvested every few days over a period of 6 weeks (July–August) and analyzed for yield and fruit quality. Remote images were also collected periodically using an unmanned aerial system and analyzed for changes in canopy cover. Pulsed drip increased soil water availability relative to conventional irrigation and, by the second year, increased total production by 7%, or 1230 $kg \cdot ha^{-1}$. Production followed a similar trend in the following year and increased by 1209 $kg \cdot ha^{-1}$ with pulsing. Based on recent market prices for processed raspberries (2015–2019), the increase in production with pulsed drip was equivalent to $2460/ha per year. Much of this increase occurred during the latter 3-4 weeks of the harvest season and was primarily due to larger fruit size with pulsing in year 2 and to more berries per plant in year 3. Pulsed drip also increased canopy cover by nearly 12% in year 2 and resulted in larger and more floricanes per plant in year 3. Based on these results, pulsed drip irrigation appears to be a promising method for improving production of red raspberries.

Developing new crop coefficients for irrigating trailing blackberry. Northwest Center for Small Fruits Research. 2018-2021.
Jesse Carroll (graduate student), Oregon State University, Corvallis, OR; David Bryla and Scott Orr, USDA-ARS HCRU, Corvallis, OR; Amanda Davis, Oregon State

University, North Willamette Research and Extension Center, Aurora, OR; Bernadine Strik, Oregon State University, Corvallis, OR.
Dissemination of results: 2020 Northwest Center for Small Fruits Research Conference, 2021 NARBA Conference, 2021 ASHS Conference.
Plans for next reporting period: Continue lysimeter measurements (year 3) and initiate postharvest deficit treatments in rows adjacent to the lysimeters. Also initiate lysimeter study in blueberry.

Growers and researchers use crop coefficients to estimate crop water use and accurately schedule irrigations. Large, precision weighing lysimeters are expensive but invaluable tools for developing accurate crop coefficients (K_c). We installed two of these lysimeters at Oregon State University's North Willamette Research and Extension Center in Aurora, OR. Each lysimeter was constructed from steel and includes an inner tank (1.0-m wide x 1.5-m long x 1.5-m deep) that rests within an outer tank on four sealed, shear beam load cells. We planted the lysimeters (and surrounding field) with 'Columbia Star' trailing blackberry and are using them to measure crop evapotranspiration (ET_c) and calculate K_c on a daily basis. Last year was the first growing season. Canopy cover, which was monitored using a drone equipped with a multispectral camera, increased from 6% in June to 11% in September. Daily ET_c was highest in July and August, where it ranged from 0.13 to 0.25 mm, or 6-12 L/plant per day. The K_c values, calculated by dividing ET_c by potential evapotranspiration (ET_o) obtained from a nearby AgriMet weather station, increased linearly with canopy development and reached 0.4 by the end of growing season. This past summer, we collected data during the first year of fruit production and will continue the project until the plants reach full production. Once the project is completed, we will have a full set of K_c values for both young and mature plantings and will integrate the results into online irrigation management systems and an easy-to-use mobile irrigation app called *Irrigation Scheduler*. We are also using plants outside of the lysimeters for water deficit treatments to identify strategies to reduce irrigation water use after harvest.

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