Project Summary

Title: Evaluating the Role of Boron in Enhancing Fruit Set of Highbush Blueberry

Year Initiated: 2014 **Current Year**: 2016 **Terminating Year:** 2016

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Objectives:
The main objective of this project was to test the hypothesis that foliar-applied B could increase fruit set and resultant yield of highbush blueberry. Specific sub-objectives were to: 1) evaluate the effects of foliar-applied B on measured yield components when applied at low or high rates in the spring or fall, and 2) measure the effects of B application on pollen germination, tube growth, and fertilization of ovules. We proposed to expand the main objectives to include testing of foliar applications of calcium (Ca), either applied alone or in combination with B, in 2016.

Project Report:
In 2014, we began this project with Experiment 1, which was conducted with established 'Duke' plants at the Washington State University Mount Vernon Research and Extension Center (WSU REC). These plants were heavily infected with blueberry shock virus (BlShV) in 2015, which negatively impacted the collection of fruit set and yield data. In 2015, Mr. Matthew Arrington began his PhD program in DeVetter's program and initiated a series of related trials that we would like to include in this progress report as Experiment 2. Further description about the two experiments are below.

Experiment 1. Established 'Duke' plants located at the WSU-REC were used for this experiment. Tissue samples were collected in Aug. 2014 and detected nutrient deficiencies were corrected, including B. Soil samples were also collected in Fall 2014. Results from the preliminary tissue and soil sampling are presented in Tables 1 and 2.

Treatments were applied to individual plots consisting of three plants per plot. A total of three blocks with treatments in a randomized order within a block provided the experimental design. A buffer of two plants from the perimeter of the planting and one plant in between adjacent plots was established. Five treatments were applied and varied based on rate and timing of B application. These treatments include: 1) untreated control (no additional B); 2) fall applied B at 8 oz/acre; 3) spring applied B at 8 oz/acre; 4) fall applied B at 32 oz/acre; and 5) spring applied B at 32 oz/acre. The foliar product used for the experiment was BioGro NUE Boron 10% (derived from boric acid). Fall and spring applications corresponded to postharvest/prior leaf senescence and pre-bloom, respectively. The first cycle of treatment applications began in the fall of 2014 and was carried through in the spring of 2015. The second cycle of treatment applications began fall 2015 and was carried through in the spring of 2016. Foliar nutrient, soil chemistry, fruit set, estimated yield, and fruit firmness data were collected and are presented below.

Foliar and soil test results are presented in Tables 3 and 4. Foliar samples collected across the treatments were within nutrient sufficiency ranges with the exception of sulfur (S) and copper (Cu) in 2015 and iron (Fe) and Cu in 2016 (Table 3). Plants treated in spring 2015 with both high and low concentrations of B were slightly below the sufficiency range for S. We do not believe this difference is significant nor related to our treatments. Also, leaf B concentrations were slightly below sufficiency levels in the fall applied, low concentration treatment in 2016. All treated plants were below the sufficiency range for Cu. However, recently published research in Oregon is proposing to lower the sufficiency standards for this micronutrient (Strik and Vance, 2015). Furthermore, we did not observe any symptoms of Cu deficiency. Soil test results are presented in Table 4. There are differences between soil results from 2014 and 2015 (Tables 2 and 4). Many of these differences can be attributed to our fertility regime, which was newly implemented in 2014 (management prior to 2013 is not known, as DeVetter's research program was not yet established). The most notable difference between the years is the increase in organic matter from 2014 to 2015. Sawdust mulch was applied in 2015 and is likely responsible for the increases in organic matter, particularly if sawdust mulch remained in the soil sample. In addition, we began sending our foliar and soil samples to be tested at a new lab (Brookside Laboratories, Inc.; New Bremen, OH) and differences in testing protocols may result in differences in our results between 2014 and 2015. Soil test results between 2015 and 2016 are comparable, although there is an increase in organic matter content in our control and spring applied, low B treatments plots between years. We attribute this to sample variability. Soil P increased in 2016, which we attribute to our fertility regime and is not correlated to treatments. Soil Ca also decreased and is likewise not associated with our treatments.

Percentage fruit set is presented in Table 5. Overall fruit set was greater than 60% in 2015, with the exception of plants treated with B at a low concentration in the spring of 2015. Fruit set was greater in 2016 compared to 2015, which is attributed to warmer weather that was more conducive for pollination and fruit set. However, fruit set was still depressed in the spring applied, low B treatment in 2016, suggesting there may be some benefit to higher rates of B in the spring. Based on our observations in the field, the reduction in fruit set for plants in this experiment was predominately due to high infection rates of BIShV in 2015. Estimated plant yields were low in both 2015 and 2016 and did not differ due to treatment. We attribute these low yields to poor ripening and fruit development due to BIShV infection and recovery across the years. Berry size and firmness was not different across treatment. Firmness was high and was likely due to reduced berry size.

Experiment 2. This experiment is an expansion of Experiment 1 and was initiated in Spring of 2015 and continued in 2016. Trials occurred in four commercial blueberry fields, with two in Skagit County and two in Whatcom County. Treatments were applied on established 'Draper' and 'Bluecrop' plants beginning at the "early pink bud" stage in 2015 and continued every 7 to 10 days for a total of six applications. Treatments included:

1) Untreated control ("untreated");
2) Solubor® (20.5% B as disodium octaborate tetrahydrate) at 3lbs/acre ("low B");
3) Solubor ® at 6 lbs/acre ("high B");
4) Phyta-Ca QC™ (8% Ca from calcium chloride) at 2 qt/acre ("low Ca");
5) Phyta-Ca QC™ at 4 qt/acre ("high Ca");
6) Phyta-Set QC™ (6% Ca from calcium chloride and 1% B from sodium tetraborate) at 2 qt/acre ("low B+Ca"); and
7) Phyta-Set QC™ at 4 qt/acre ("high B+Ca").

In 2016 the low application rates (2qt/A; "low B" and "low Ca") were removed because they led to no differences in measured variables and were replaced with alternative B and Ca products (MicroLink B+Mn™ and Liberate Ca+™ , refered to as "Alternative B" and "Alterative Ca"; Ca derived from $CaSO_4$). Given no significant treatment effects were found with low B and Ca treatments in 2015, these results will not be presented. All products were applied according to their label rates.

Results from 2015 and 2016 have been shared with grower cooperators in the form of annual grower summaries. Much like Experiment 1, few significant differences were observed. Soil samples collected in Spring 2015 and in the fall of 2016 confirmed soil nutrients were within recommended ranges with no significant differences between treatments (data not presented). There were no statistical differences in fruit set across the sites, so data were combined and are presented by year and cultivar (Figure 1). Estimated yield differed by grower site, but there were no treatment differences within a site regardless of cultivar in 2015 or 2016 (Table 6). Differences in estimated yield across sites is attributed to differences in plant size and corresponding productivity. Berry size and fruit firmness was evaluated and there were no differences across treatments. However, 'Draper' were significantly firmer than 'Bluecrop' in both years.

Foliar tissue analyses indicated that there were no significant differences between nutrient concentrations of untreated and treated plants (Table 7). Additionally, despite our experimental treatment applications, B concentrations were consistency below recommended leaf sufficiency levels in both years of the experiment. These observations suggest spring applications of B alone do not adequately raise B levels in plants that are below sufficiency levels and may need to be combined with fall (only) or spring and fall applications. However, fruit tissue analyses of harvested berries showed up to 60% more B in fruit from plants treated with the high B treatment. Increases in fruit Ca concentrations were modest, being raised by as much as 22% in plants treated with the higher concentration of Ca and with an average increase of ~7% across all sites. Despite the promising increase of B and Ca in fruit tissue nutrient concentrations, which demonstrates that some of these applied nutrients were being taken up by the plant, improved fruit set, yield, and quality was not observed across treatments.

Results from 2015 and 2016, as well as prevailing weather conditions, better inform us about the premature fruit drop periodically observed in 'Draper' grown in western Washington and BC. No fruit drop was observed across treatments and locations in 2015. However, minor-to-moderate drop occurred at both 'Draper' field plots in 2016. Other grower cooperators in Whatcom and Skagit counties were also found to have some level of premature fruit drop in 'Draper', although there were a few exceptions in Whatcom. While the lack of fruit drop in 2015 may be due to increased commercial applications of Ca, which has been suggested to mitigate fruit drop symptoms by research led by Gerbrandt, the fact that we observed no fruit drop in our control treatments (i.e., untreated) indicates that this disorder may not be solely influenced by

Ca. High vigor and imbalances in plant carbon due to overcast conditions may also contribute to premature fruit drop. We are planning follow-up experiments in 2017 to test the role of plant carbon status, as influenced by solar radiation, on premature fruit drop in 'Draper' through use of shade clots. We did however observe encouraging results in 2016 in that fruit number dropped per bush in 'Draper' was reduced by 22-34% with label rate applications of Alternative Ca (Liberate Ca+) and High Ca (Phyta-Set QC^{TM}) (Fig. 2).

In vitro pollen viability was examined in 2016 by collecting pollen from five flower clusters per treatment plot. Pollen was placed on a nutrient agar medium and incubated at 20 °C /68 °F. No differences in pollen germination (over 95% germination across treatments), growth rates, or pollen tube structure were observed (data not presented). Number of large, viable seeds (>1.7 mm) was also determined from a composite sample of 30 berries per plot, which served as a proxy for pollen viability in highbush blueberry (Dogterom et al., 2000). No differences in seed number per berry were observed in 2016 (data not presented).

At this stage of the research, we cannot make a definitive recommendation on the use of B and Ca for improving fruit set, yield, and attributes of berry quality in highbush blueberry. However, under the conditions of our study, B and Ca either alone or in combination did not improve fruit set, yield, or fruit quality characteristics. Under these conditions and also assuming sufficiency in B and Ca status, it appears that the removal of B and Ca products from pre-bloom sprays would not adversely affect key aspects of production and inputs may be reduced by their exclusion. Calcium chloride and, under certain conditions, $CaSO_4$, appear to reduce the premature fruit drop in 'Draper'. Application rate, timing, and form of Ca may affect this relationship and we are learning more from the work being led by Gerbrandt. We have also observed weather conditions, particularly solar radiation, can influence fruit drop. Further research is in this area is recommended and being explored through small experiments.

Anticipated Benefits and Information Transfer:

Information gained from this project suggests foliar applications of B does not improve fruit set, yield, or attributes of berry quality in western Washington blueberry under the conditions of our experiment. These findings suggest applying additional foliar B (assuming plants are sufficient in this micronutrient) has no added benefit of improving fruit set, yield, and berry quality. Follow-up work in 2017 whereby we will compare foliar B applied on the outside (control) and inside (directed spray inside the corolla) of flower blossoms will further test this finding, as it is possible B may not be reaching flower tissues inside the corolla, namely the anthers and stigma. Additionally, it is possible there may be a response with spring and fall B applications combined (not spring or fall only) and this may be worth exploring in future research. We also observed few results with Ca applications, although premature fruit drop in 'Draper' was reduced with high (within label) rates of $CaCl_2$ and $CaSO_4$ in 2016. These results corroborate work being done by Eric Gerbrandt in BC Canada. Fruit quality was not impacted by foliar Ca, which was also found by Strik et al. (2016, *in press*) in 2015. Combined, these findings suggest applications of foliar B can be withheld by growers if plants are sufficient, as determined by tissue nutrient concentrations and/or previous knowledge about the planting. If premature fruit drop in 'Draper' is a concern, high, within label rates of Ca may be applied during bloom, fruit set, and early berry development to mitigate fruit drop. However, vigor should also be managed, as high vigor situations seems to exacerbate premature fruit drop in 'Draper'. Collaborative research being led by Gerbrandt is fine-tuning horticultural management practices in order to reduce premature fruit drop in 'Draper' in western BC and WA. It is also possible fruit drop may be due to low sunlight and reduced internal carbon reserves in plants. Arrington and DeVetter will test this hypothesis in 2017 using shade cloths. Additionally, when applying foliar nutrients, growers should be careful when applying Cl-containing products due to Cl sensitivity and risk of phytoxicity blueberry. Likewise, micronutrients should be applied carefully, as there is a fine line between deficiency and toxicity.

Project information was shared with growers through several mechanisms, including: conference, symposia, and field day presentations, electronic extension newsletters (*WSU Whatcom Ag Monthly*), regional field days, the WSU Small Fruit Horticulture website (http://smallfruits.wsu.edu/), and individual grower cooperator reports. Project information will also be shared through a peer reviewed scientific publication, which will be submitted in 2017. Further details are described below.

- DeVetter, L.W. and M. Arrington. 2015. Application of foliar nutrients for improved fruit set in blueberry: Year 1. Presented at the Washington Small Fruit Conference, Lynden, WA.
- Arrington, M. and L.W. DeVetter. 2016. Improving Highbush Blueberry Fruit Set with Foliar Nutrient Application. International Symposium of Horticulture Science Meeting. Orlando, FL.
- Arrington, M. and L. W. DeVetter. 2016. Improving Highbush Blueberry Fruit Set with Foliar Nutrient Application. Oregon State University Blueberry Field Day. Aurora, OR.

- Arrington, M. and L. W. DeVetter. 2016. Improving Highbush Blueberry Fruit Set with Foliar Nutrient Application Washington State University Northwestern Washington Research and Extension Center Field Day. Mount Vernon, WA.
- Arrington, M. and L.W. DeVetter. 2016. Applications of Foliar Nutrients for Improved Fruit Set In Blueberry: Year 1. WSU Whatcom Ag Monthly. July Edition. Available at: http://whatcom.wsu.edu/WAM/july2016_s1.html
- Grower cooperator progress reports, distributed annually to individual cooperators in 2015 and 2016.
- Arrington, M. and L.W DeVetter. 2016. Foliar Applications of Calcium and Boron for Improved Fruit Set in Blueberry. Presented at the Washington Small Fruit Conference in Lynden, WA.
- Results have been posted on the WSU Small Fruit Horticulture Website and will be updated quarterly (http://smallfruits.wsu.edu/evaluating-the-role-of-boron-in-enhancing-fruit-set-of-highbush-blueberry/)
- Arrington, M. and L.W. DeVetter. 2016. Fruit set improvement of highbush blueberry (*Vaccinium corymbosum*): A review. J. Am. Pom. Soc. 70(3): 124-137.
- Arrington, M. and L.W. DeVetter. 2017. Fruit Set Improvement with Foliar Applied Boron and Calcium in Highbush Blueberry. Presentation at the American Society of Horticulture Science Annual Conference (planned).
- Arrington, M. and L. DeVetter. 2017. Fruit Set Improvement with Foliar Applied Boron and Calcium in Highbush Blueberry. Journal of the American Pomological Society (manuscript in preparation).

References:

Dogterom, M.H., M.L. Winston, A. Mukai. 2000. Effect of pollen load size and source (self, outcross) on seed and fruit production in highbush blueberry cv. 'Bluecrop' (Vaccinium corymbosum; Ericaceae). American Journal of Botany 87:1584-1591.

Hart, J., B. Strik, L. White, and W. Yang. 2006. Nutrient management for blueberries in Oregon. Oregon State University Extension Service. EM 8918.

Strik, B. 2004. Blueberry production and research trends in North America. In VIII International Symposium on Vaccinium Culture 715: 173-184.

Strik, B. and A.J. Vance. 2015. Seasonal variation in leaf nutrient concentration of northern highbush blueberry cultivars grown in conventional and organic production systems. HortScience 50(10): 1453-1466.

Acknowledgements

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Table 1. Foliar nutrient concentrations and sufficiency recommendations. Samples were collected from an experimental plot of 'Duke' blueberry plants located at WSU-REC, Washington. Foliar samples were collected on Aug. 2014.

	(%)						ppm				
	N	P	K	S	Mg	Ca	Fe	Mn	B	Cu	Zn
Treatment plants	2.46	0.2	0.59	0.13	0.16	0.48	64	65	26	3	17
Recommended sufficiency concentrations*	1.76 to 2.00	0.10 to 0.40	0.41 to 0.70	0.11 to 0.16	0.13 to 0.25	0.41 to 0.80	61 to 200	30 to 350	31 to 80	5 to 15	8 to 30

*According to Hart et al. (2006).

Table 2. Soil tests results from a planting of 'Duke' blueberry at WSU-REC, Washington. Samples were collected Sept. 2014.

				ppm						
	pH	Organic Matter (%)	CEC (meq/100 g)	P (Bray P1)	K	Mg	Ca	Na	B	S
Value	5.1	4.4	9.6	65	199	103	909	20	0.4	7
Rating*	S	H	-	H	H	L	L	L	Low	L

*According to interpretations by A&L Laboratories. Symbols: H = "high"; S = "sufficient", and L = "low".

Table 3. Foliar nutrient concentrations of 'Duke' blueberry plants located at WSU-REC, Washington, 2015-2016.

	(%)						ppm				
Treatment	N	P	K	S	Mg	Ca	Fe	Mn	B	Cu	Zn
2015											
Control (no B)	2.4	0.154	1.05	0.148	0.139	0.57	196	252	42.4	6	28.2
Spring applied, low [B]	1.86	0.104	0.92	0.105	0.144	0.67	112	322	56	1.6	9.2
Spring applied, high [B]	1.79	0.105	0.77	0.102	0.141	0.71	112	305	53.9	1.8	8.3
Fall applied, low [B]	1.98	0.115	1.13	0.124	0.159	0.85	106	349	63.3	1.8	9.1
Fall applied, high [B]	1.93	0.11	0.94	0.112	0.152	0.73	92.3	322	58.3	2.1	9.3
2016											
Control (no B)	2.22	0.116	0.63	0.125	0.162	0.55	55.5	187	35.2	2.3	9.7
Spring applied, low [B]	2.02	0.107	0.56	0.115	0.167	0.59	44.4	211	36.4	2.4	9.6
Spring applied, high [B]	2.16	0.107	0.56	0.122	0.166	0.56	44.2	195	33.1	2.1	9.8
Fall applied, low [B]	2.13	0.112	0.64	0.12	0.155	0.5	42	174	29.4	2.1	10.7
Sufficiency ranges*	1.76 to 2.00	0.10 to 0.04	0.41 to 0.70	0.11 to 0.16	0.13 to 0.25	0.41 to 0.80	61 to 200	30 to 350	31 to 80	5 to 15	8 to 30

*According to Hart et al. 2006. Sufficiency ranges for P and Cu are believed to be lower (Strik et al., 2015).

Table 4. Soil test results from a planting of ‘Duke’ blueberry at WSU-Mount Vernon, Washington, 2015-2016.

	pH	Organic Matter (%)	CEC (meq/100 g)	P (Bray P1 in ppm)	mg/kg K	Mg	Ca	Na	B	S
2015										
Control (no B)	4.9	4.7	12.7	92	152	97	887	31	0.39	24
Spring applied, low [B]	4.6	5.9	13.2	115	175	87	770	26	0.44	24
Spring applied, high [B]	4.6	8.8	13.1	96	126	91	777	32	0.33	19
Fall applied, low [B]	4.5	8.9	10.2	86	126	74	535	26	0.34	18
Fall applied, high [B]	4.4	9.4	10.7	97	113	76	527	31	0.32	19
	4.3	9.0	11.0	137	125	71	486	30	0.30	30
2016										
Control (no B)	4.2	9.6	12.1	155	171	70	484	42	0.27	35
Spring applied, low [B]	4.3	9.2	12.7	131	151	78	564	33	0.33	34
Spring applied, high [B]	4.3	8.5	11.8	113	132	71	535	31	0.31	28
Fall applied, low [B]	4.3	9.7	11.4	141	134	72	499	30	0.36	31

Table 5: Fruit set, estimated yield, fruit weight, and fruit firmness in 'Duke' for Experiment 1, 2015-2016.

Treatment	Fruit set (%)	Estimated yield (kg/3 plants)	Fruit weight (g/fruit)	Firmness (g/mm of deflection)
2015				
Control (no B)	86	6	2.04	283.7
Spring applied, low [B]	55	3.2	1.98	283.1
Spring applied, high [B]	68	4.1	1.96	286.4
Fall applied, low [B]	71	4.2	2.04	261.8
Fall applied, high [B]	73	5.9	1.95	272
2016				
Control (no B)	91	3.3	1.97	272.7
Spring applied, low [B]	68	3.1	2.07	288.9
Spring applied, high [B]	89	2.8	2.02	271.4
Fall applied, low [B]	97	2.8	2.08	264.8
Fall applied, high [B]	99	2.7	1.95	260.8
P-value[z]	ND	ND	ND	ND

[z] ND denotes no significant differences due to treatment at $\alpha=0.05$.

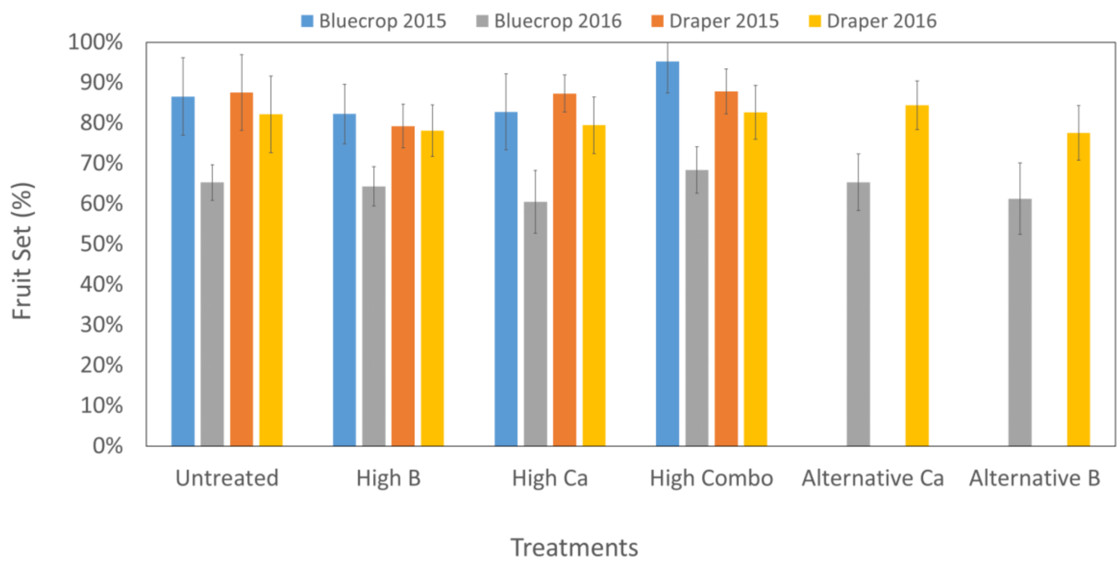

Figure 1. Percent fruit set in 'Bluecrop' and 'Draper' blueberry grown in Northwest Washington in 2015 and 2016. Sites are combined. Alternative treatments (LiberateCa+ and Microlink, or Alternative Ca and Alternative B, respectively) were only tested in 2016.

Table 6. Estimated yield, fruit weight and firmness for Experiment 2. 2015-2016.

Treatment	Estimated yield (kg/3 plants)	Fruit weight (g/fruit)	Fruit firmness (g/mm deflection) Draper	Bluecrop
2015				
Untreated control	11.5	2.04	278.5	169.1
High B	10.3	2.1	277.4	183.4
High Ca	11.4	2.06	287.7	182.2
High B+Ca	12.2	2	272.3	161.1
2016				
Untreated control	13.2	2.52	269.6	184.6
High B	13.6	2.58	288.4	184.9
High Ca	12.6	2.42	281.1	168.2
High B+Ca	13.9	2.51	277.1	183.4
Alternative Ca	14.3	2.6	265.9	178.1
Alternative B	14.7	2.64	279.3	177.5
P-value[z]	ND	ND	ND	ND

[z] ND denotes no significant differences due to treatment at α=0.05.

Table 7. Leaf and fruit nutrient concentrations (boron and calcium) from Experiment 2, 2015-2016.

	Calcium (%)		Boron (ppm)	
	Leaf	Fruit	Leaf	Fruit
2015				
Untreated control	0.45	0.66	7.7	47.6 a
High B	0.48	0.71	14.8	75.7 b
High Ca	0.5	0.74	10.9	60.8 ab
High B+Ca	0.45	0.7	9.25	53 ab
P-value[z]	ND	ND	ND	0.0483
2016				
Untreated control	0.46	0.64	10.23	55.1 a
High B	0.42	0.69	14.3	63.5 ab
High Ca	0.48	0.72	9.8	46.1 a
High B+Ca	0.43	0.67	14.75	63.1 ab
Alternative Ca	0.5	0.8	13.53	52.7 a
Alternative B	0.45	0.64	16.67	91.3 b
P-value	ND	ND	ND	0.0372
Sufficiency[x]	0.41 to 0.80	NA	30 to 80	NA

[z]ND denotes no significant differences due to treatment at α=0.05; numbers with the same letter are not significantly different at α=0.05.

[x]As determined by Hart et al. (2006).

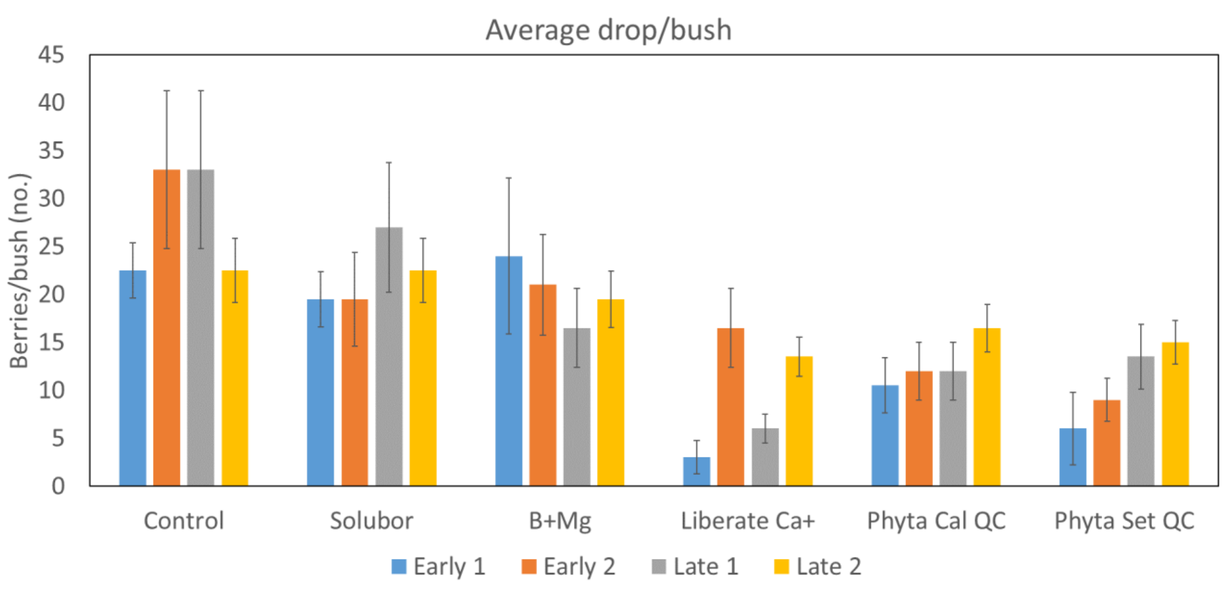

Figure 2. Berries dropped per bush according to treatment in 'Draper' blueberry grown in Whatcom County, WA, 2016. Treatments include: Control = "untreated"; Solubor® = "High B"; B+Mg = "Alternative B"; LiberateCa+ = "Alternative Ca"; Phyta Cal QC™ = "High Ca"; and Phyta Set QC™ = "High B+Ca". Different bars represent different time points when berry drop was assessed. Significant reductions in berries dropped in 'Site 1' for Liberate Ca+ (Alternative Ca) and Phyta Set QC™ (High B+C) treatments and there was a general trend of reduced drop for treatments with high Ca concentrations.