# Controlled and protected environment production of blueberries in the Midwest United States

by

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# Abstract

For a high value crop such as blueberries, managing growth using both controlled and protected environments may allow for extended or year-round production in the Midwest United States. A series of experiments were conducted in Kansas within a high tunnel and a glass greenhouse to evaluate the potential for containerized blueberry production via soilless substrates and/or with slow-release fertilizers in containers.

The first project focused on propagating blueberries in soilless substrates. The second project evaluated plant performance and yield of these plants after they were transplanted into soilless culture. The third project evaluated organic and conventional fertilizers and pH amendments in high tunnel production of blueberries. The half-high *Vaccinium corymbosum* X *angustifolium* ‘Northland’ was used in all three projects, and the lowbush *Vaccinium angustifolium* ‘Brunswick’ was included in some parts of the research.

For the propagation project, rooting success was compared between two cultivars, four substrate types, rooting hormone presence or absence, and cuttings of apical or basal stem sections. The ‘Northland’ cultivar had higher rooting success than ‘Brunswick’. Three-to-one peat: perlite was the best substrate with up to 96% rooting success. Cococoir was similarly effective at 88% rooting success. Both shredded rockwool and rockwool cubes resulted in relatively poor rooting of about 50%. Rooting hormone had no effect on rooting success or root ratings, and apical stem sections rooted about 25% better than cuttings from basal stem sections.

These propagules were transplanted into one of four soilless production systems: 1:1 peat:perlite drip-irrigated bag culture, rockwool slab drip-irrigated system, cococoir containerized sub-irrigation, or leca clay pebble Dutch bucket system. The Dutch bucket system was removed from the study after the first season due to poor plant performance. Each system type was maintained at one of three volumetric water contents (VWC): 15, 25, or 35%. Due to poor pollination, fruit yield was poor but despite significantly smaller plants, those produced in rockwool yielded more berries than those in peat:perlite, albeit at a lower average weight. Plants grown in peat:perlite accumulated nearly six times the biomass of those produced in either rockwool or coir. In peat: perlite, higher VWC was directly correlated to increased biomass accumulation.

High tunnel production of blueberries would have a lower economic barrier to entry than greenhouse production. Blueberries grown with a low or high rate of two fertilizers – one organic and one conventional; and three pH amendments – an organic, conventional, and no application, were compared for yield, growth, and biomass accumulation. Conventional fertilizer yielded healthier plants based on SPAD readings, higher biomass accumulation, and berries with higher soluble solids than the organic fertilizer. The high-rate of both fertilizers also increased growth and overall yield compared to the low-rate. Iron sulfate had no effect on canopy size or fruit yield compared to no pH amendment. Elemental sulfur, when applied at the rate deemed necessary, killed most of the crop and was removed from analyses.

This research demonstrates that blueberries can be produced in Kansas using protected and controlled environment production and can be considered by diversified growing operations.

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# Acknowledgements

During the process of researching blueberries in Kansas, I received help and encouragement from many people along the way.

I would like to begin by thanking my major advisor, Dr. Kimberly Williams. After meeting her at an internship, moving to Kansas, and meeting with her again, we were able to develop a wicked substantial masters project. With Dr. Williams' insight throughout this process, I have become a much better researcher, writer, and teacher. I extend additional appreciation to my committee. The insights from Drs. Kimberly Williams, Jason Griffin, and Jeremy Cowan helped me orient my research towards relevant production issues in addition to innovative research concepts.

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Upon arriving at Kansas State University, I was assigned an office with Michael Brunson. Michael supported me in a fashion he likely did not realize at the time. He happened to have lived in my home state of Maine for a period where he met his lovely wife. Whenever I was feeling a bit homesick after arriving in Kansas, I knew I could discuss a paralleled admiration of "home." Michael also helped me realize my passion for cycling, for which I cannot thank him enough. Shortly after Michael was moved to a group office within his program, he was replaced by Karen Schneck. It is imperative I thank Karen for everything she did to help me, which ranged from tending to my research and watching my animals while I was away at conferences to listening to me drone-on about various irrelevant topics. She endured me while working on her own master’s degree and I am unable thank her enough for the friendship she provided.

The person to whom I would like to extend my final gratitude is my significant other, Letitia Phan. Letitia is the reason I was displaced from Maine to Kansas and was the driving force encouraging and supporting me to pursue a graduate degree while she worked on her DVM. This whole project would not have happened without her urging me forward.

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# Chapter 1 - Asexual propagation by stem cuttings of half-high and low-bush blueberries in soilless substrates: cutting location, rooting hormone, and fertilization

## Abstract

For use in soilless production systems, blueberries would ideally be propagated in compatible substrates. Two experiments were conducted to evaluate rooting of apical (AP) and basal stem (ST) semi-hardwood cuttings of *Vaccinium corymbosum x angustifolium* 'Northland' (NL) in rockwool cubes (RC), shredded rockwool (SR), cococoir (CO) 3 perlite:1 sphagnum peat moss (v/v; PP). In the first experiment, cuttings were treated with 1,000 ppm IBA in 1:1 95% ethyl alcohol: reverse osmosis water (1A), 1,000 ppm K-IBA in reverse osmosis water (1K), 1:1 95% ethyl alcohol: reverse osmosis water (WE), or reverse osmosis water (WC) and were rooted under intermittent mist. In the second experiment, rooting of *Vaccinium angustifolium* 'Brunswick' (BW) was also evaluated. Treatments included weekly fertilizer applications of distilled water, 75 ppm N from 16-4-17 OASIS® hydroponic fertilizer or ChemGro three-bag hydroponic fertilizer, were made; all were adjusted to pH 4.0. Each treatment combination was replicated 6 times with 6 cutting subsamples per experimental unit (e.u.). Rooting percentages were calculated, and rooting quality was assessed using a 6-point visual scale. NL had much higher success than BW. The type of substrate in which the cuttings were rooted had the greatest effect on success with best rooting occurring in PP and CO. Despite this, both rockwool substrates could still be used to root blueberry cuttings when the plants will be transplanted into rockwool-based soilless production systems. AP cuttings had better root ratings than ST (2.7 and 1.9 respectively) as well as better rooting percentages at 80% and 54%, respectively. There was

no increase in rooting when auxin was applied. The fertilizer treatments did not affect the rooting rating; EC across treatments ranged from 0.4 to 0.6 $dS \cdot m^{-1}$. Both RW and SR resulted in higher pH (7.2 and 7.1, respectively) compared to PP and CO (5.5 and 6.2). For best propagation results, use apical stem cuttings of ‘Northland’ in peat:perlite without fertilizer or auxin applications.

## Introduction

Blueberries (*Vaccinium* spp.) are an important small berry for fresh and frozen market production with annual market value of $908.7 million in the U.S. in 2019 (USDA, 2020). Environmental requirements of an acidic soil (~pH 4.5-5.5; Dirr, 2009) and with low salinity (electrical conductivity <3 $dS \cdot m^{-1}$; Bryla and Machado, 2011) limit the regions where they can be commercially produced in unamended soil. As consumer demand for locally produced, extended-season foods increase (Conner et. al. 2009), one option is to produce blueberries in controlled environments with soilless production systems. However, traditional propagation substrates for blueberries include sand, peat moss, perlite, pine bark or some combination thereof (Krewer and Clein, 2003). These substrates are not compatible with closed loop hydroponic systems where loose particles interfere with drip emitters and can damage the recirculating pump. Therefore, propagation directly in substrates such as rockwool that are readily compatible with such production systems requires evaluation.

Protocols for asexual propagation of blueberry by stem cuttings are not well defined. Typically, pencil-diameter, 7.5 cm long, semi-hardwood basal stem cuttings are collected, and cuttings are inserted into a traditional perlite and peat based rooting substrate. No research has been reported to date involving propagation of blueberries in soilless substrates of rockwool or cococoir. The use of rooting hormones varies depending on the propagator. Davies et al. (2018)

recommend 8,000 ppm IBA (indole-3-butyric acid), whereas blueberry producers such as Stokes Blueberry Farm & Nursery (Grand Junction, MI) reported that hormone treatments do not affect rooting. Therefore, they do not use it in their commercial operation (personal communication; March, 2018). The rates applied in this research are based on suggestions from Dr. Dave Creech. He suggested using between 1,000 and 2,500 ppm IBA to hasten and promote uniform rooting of the cuttings (personal communication; March, 2018). One aspects of rooting hormone which may affect rooting quality is alcohol toxicity due to ethyl alcohol in the carrier solution. This has been shown to negatively impact sensitive species (Dirr and Heuser, 2006; Dole and Gibson, 2006) while in other species it may aid the uptake of auxin (Stutter and Burger, 2008).

The objectives of this research were to determine the feasibility of rooting two species of blueberry in soilless substrates of shredded rockwool or rockwool cubes and cococoir versus traditional peat-based rooting media, evaluate the benefit of auxin and related alcohol toxicity from the carrier solution, determine whether a low rate of fertilizer applied after root initials emerge impacts rooting quality, and assess the viability of apical versus basal stem cuttings.

## Materials and Methods

Two experiments were conducted; *V. angustifolium x corymbosum* 'Northland' was used in both and *V. angustifolium* 'Brunswick' was added in the second experiment. In the first experiment, cuttings were stuck on May 18, 2018, and harvested after consistent rooting was established on July 11, 2018 (55 days). The second experiment began on July 26, 2018 and was harvested on September 30, 2018 (67 days).

### *Treatments*

Experiment 1 (Expt. 1) consisted of three rooting substrates, four rooting hormones, and two cutting types (Figure 1.1). Experiment 2 (Expt. 2) consisted of two blueberry species, four rooting substrates, and three fertilizer treatments (Figure 1.2). The two species of blueberry were *V. angustifolium* x *corymbosum* ‘Northland’ (NL) and *V. angustifolium* ‘Brunswick’ (BW).

Cuttings were collected from two year-rooted liners grown in 100% sphagnum peat in 16.5 cm (1,930 $cm^3$) black azalea pots (Pöppelmann Plastics USA LLC, Claremont, NC, USA). These stock plants were maintained in the Throckmorton greenhouse at Kansas State University (Manhattan, KS, USA). Semi-hardwood stems of 30 to 45 cm were removed and held with their base in distilled water. From these stems, experimental cuttings were gleaned maintaining three nodes with a bud in the leaf axil (7 to 10 cm), wounded by removing 1 to 2 cm epidermal tissue at the base of the cutting before dipping in rooting hormone for 5 sec. Cuttings were then stuck vertically in their respective treatment substrates at a depth of 2 to 3 cm.

The experimental design was a completely random design with six cutting subsamples per experimental unit (e.u.) and each e.u. replicated six times. As such, there were 24 treatment combinations with 864 cuttings in each experiment.

### *Substrates*

In Expt. 1 the substrate treatments included rockwool cubes (RC, Bootstrap Farmer, Ernul, NC, USA), shredded rockwool (SR, Growpito, Kansas City, MO, USA), and 1:3 peat (Pro-Moss Sphagnum Peat Moss, Premier Tech Horticulture, Quakertown, PA, USA): perlite (PP; Therm-O-Rock West Inc., Chandler, AZ, USA). Substrates were placed in 0804 cell pack (145 mL per cell) inserts (T.O. Plastics, Clearwater, MN, USA) then laid out in a completely random design on one mist bench. These substrates were then wetted with DI water overhead. Expt. 2 was procedurally the same as Expt. 1 with the addition of cococoir (CO, Planet Coco, Allen, TX, USA; originated from Tamilnadu, India). This coir was soaked in distilled (DI) water overnight to reach saturation. Both rockwool substrates for Expt. 2 were also held in DI water overnight to fully saturate them before placing them into 0804s.

### *Hormone*

In Expt. 1, cuttings were treated with four root promoting hormone treatments. Reverse osmosis water with no IBA (water control; WC), 1:1 95% ethyl alcohol (McCormick Distilling , Weston, MO, USA) : reverse osmosis (RO) water (ethanol control; WE), 1,000 ppm potassium salt indole-3-butyric acid (KIBA; Sigma-Aldrich, St. Louis, MO, USA) in RO water (1K), 1,000 ppm indole-3-butyric acid (IBA; Sigma-Aldrich, St. Louis, MO, USA) in 1:1 reverse osmosis water : 95% ethyl alcohol (1E, same as above). In Expt. 2, all cuttings were treated with 1,000 ppm KIBA.

### *Fertilizer*

In Expt. 2, the fertilizer treatments included DI water, 75 ppm N from 16-4-17 (16N-1.7P-14.1K) Oasis® hydroponic fertilizer(HF; OASIS® Grower Solutions, Kent, OH, USA), or 75 ppm N from 4-18-38 (4N-7.7P-31.5K) (ChemGro Hydro-Gardens, Colorado Springs, CO, USA) with $Ca(NO_3)_2$ (Yara North America, Tampa, FL, USA) and $MgSO_4$ (PQ Corp., Valley Forge, PA, USA). The cuttings were fertigated with one of the three treatments on days after sticking (DAS) 21, 28, 35, 42, 46, 50, 54, 58, 62, and 65. All fertilizer treatments were adjusted to pH 4.0 using 1M sulfuric acid for the duration of the experiment. Each treatment was administered using a re-pipet at 25 mL per cell per treatment instance.

### *Cutting type*

AP cuttings were selected as 7 to 10 cm stem sections which had a visible apical meristem and two lateral buds. ST cuttings were any 7 to 10 cm stem section which contained three lateral buds between the proximal and distal ends of the cutting. Cuttings for Expt. 2 were all ST cuttings due to availability of propagation material.

### *Cultural practices*

Cuttings were placed under overhead intermittent mist in a glass greenhouse for the duration of each experiment. The mist duration was adjusted weekly to maintain a desirable substrate moisture content at each stage of rooting. Expt. 1: week 1 - 8 s every 16 min, week 2 - 6 s every 16 min, week 3 - 8 s every 32 min, week 4 to end - 6 s every 32 min. Expt. 2: 6 s every 32 min for the duration. Overhead mist came from Dramm Misty Mist (Dramm Corp., Manitowoc, WI, USA) nozzles at a rate of 0.40 gal (1.51 L) per minute. Cuttings were watered overhead once weekly for the duration of the experiment (weeks 4 to 8) to mitigate issues associated with non-uniform mist patterns. In Expt.1, cuttings were fertilized one time per week for the final three weeks of the experiment on DAS 34, 41, and 48 with Peters Peat Lite Special Fertilizer 20-10-20 (20N-4.3P-16.6K) (Everris Int., Geldermalsen, NL) at 0.125 g fertilizer per L, or 25 mg N per L.

### *Data collected*

The rooted cuttings were evaluated for root rating (Figure 1.3), rooting percent (a cutting was considered rooted if it had a root rating $\geq 2$), root system length (cm; measured from the bottom of the callus tissue to the most terminal point of the root mass; Expt. 1 only), and dry mass of the root system (g; the root mass was removed from the stem at the top of the callus tissue, placed in a labeled container, then placed in a drying oven at 65°C for seven days; Expt. 1 only). Substrate chemical properties, pH and electrical conductivity (EC), were collected using a pour through method (Expt. 2 only) (Figure 1.4). Each cutting was irrigated to container capacity using an overhead mist system, allowed 30 to 60 min to solubilize salts, then held over a funnel where 10 mL of DI water was used to displace salts into sample vials. Samples were stored in a refrigeration unit until analysis. Data were subject to ANOVA and HSD means separation procedures in RStudio version 1.1.463 (Rstudio: Integrated Development for R. Rstudio, Inc., Boston, MA, USA).

## Results and Discussion

### *Cultivar*

Across substrates, lowbush 'Brunswick' rooted poorly (17.9%) compared to half-high 'Northland' (63.5%) (Table 1.1). Expt. 2 was provided more time than Expt. 1 to allow for improved root development of BW; however, the rate of death, especially in rockwool treatments, was high enough that despite allowing 12 additional days, rooting success was still low. The additional time given to NL in Expt. 2 compared to Expt. 1 did not substantially increase rooting percentage (63.42% vs 67.25%, respectively).

The 63 to 67% rooting success of NL exceeded the 45% rooting previously reported by Miller et al. (2004), but is less than the 85% rooting of Badescu et al. (1985). The low rooting success for 'Brunswick' was unexpected as original cultivar release data suggested this cultivar should have 100% rooting success (Hall et al. 1972). Additionally, Debnath (2007) compared stem cuttings and micropropagation and suggested that "lowbush blueberries rooted readily…" in both methods.

We observed that BW may be more photosensitive than NL based on symptoms of foliar necrosis consistent with photoinhibition (Figure 1.5). While this was not quantified in this research, it may have contributed to cutting death and therefore the rooting results observed. Lowbush cultivars are not exposed to the same light levels in their native range (Michigan to Maine, and North into Canada) as they were in Kansas during this experiment with ~13,600

$KJ \cdot m^{-2}$ and ~16,600 $KJ \cdot m^{-2}$ average daily sunlight between the native range and Kansas, respectively (NLDAS, 2013).

### *Substrate*

Substrate had a significant effect on rooting. In Expt. 1, NL rooted more successfully in traditional PP (95%) than shredded rockwool (45%) or rockwool cube (61%) (Table 1.2). In Expt. 2, BW rooted poorly in rockwool substrates (2%) (Table 1.1). Rooting was improved in traditional PP (27%) and highest in CO (41%) (Figure 1.6). The increased rooting for BW in CO seems contradictory since it retains more water than the other substrates. The low-bush blueberry's native habitat is described as "…dry sandy areas, peaty barrens, exposed rocky outcroppings…" (Vander Kloet, 1988) which does not align well with the properties of cococoir. Additionally, Vander Kloet (1988) mentions the native soils of *V. angustifolium* have an average pH of 4.4 which is a stark contrast to CO which had an average pH of 6.2 (Table 1.3). Little research has been reported on asexual propagation by stem cuttings of woody species in rockwool substrates. No literature was found that describes propagation of blueberries in rockwool substrates; however, when propagules of other woody species were started in tissue culture which included rockwool pucks, propagation success was high (Chu and Mudge, 1996).

In Expt. 2, there was a three-way interaction among the main effects of cultivar, substrate, and fertilizer for root rating, but not percent rooting in the ANOVA (Table 1.1). However, the HSD did not demonstrate a similar 3-way interaction.

### *Hormone*

Hormone application did not improve rooting percent, rating, or root weight between treatments, but did improve root length by over 7 mm when treated with 1E compared to WE (Table 1.2). Given the relative insignificance of this result within the scope of this experiment, the cost of applying auxin cannot be justified. Rooting hormone is not necessary to improve cutting quality or success in NL but may improve rooting success or quality in other cultivars (Tripti, 2016). Alcohol toxicity was not an issue in this experiment as it neither increased nor decreased cutting quality by any metric when comparing its presence and absence. Despite published recommendations advocating the use of a rooting hormone (e.g. Davies et al., 2018), our results do not support the need for hormone application. Further research on higher rate of application may support Davies' suggestion.

### *Fertilizer*

After Expt. 1, we speculated that low pH water and/or low-rate fertilizer additions after roots had emerged may promote root development. However, fertilizer application did not improve rooting percent or root rating in Expt. 2 (Table 1.1). Rooting percent was similar whether pH 4.0 water (44% rooting), acid-forming Oasis® (41% rooting), or base-forming ChemGro (38% rooting) fertilizer was applied. Future research could investigate "priming" of woody cuttings for transplant as hypothesized by Peterson et al, (2018b).

The pH of the rockwool substrates was high at 7.1 and lower in the CO and PP treatments (6.2, 5.5 respectively; Table 1.3). The EC had a direct relationship with pH across the substrates, where it was highest in the rockwool substrates, lower in CO, and lowest in PP. Plants rooted better in the substrates with lower pH and EC. It is difficult to discern whether rooting improved because the cuttings were using more of the available fertilizer salts or if the rockwool substrates simply leached less salts than CO or PP. Interestingly, BW in PP had the lowest pH and EC of all treatments, yet still rooted with less success than BW in CO which is contradictory to its standard growing habitat.

pH may have contributed to rooting success. Given the observation that fertilizer did not improve rooting, the pH of the water applied may have had an effect. Additional research could be conducted to evaluate different pH of water applications through the mist system. The most successful substrate also maintained the lowest pH across treatments. Therefore, to eliminate the potential substrate effect on rooting quality, a sub-mist system as used by Peterson et al. (2018a) might be evaluated for blueberry propagation.

### *Cutting type*

Cuttings with shoot apical meristems rooted 25% higher across hormone treatments and substrates (Table 1.2). These results for blueberry differ from citron (Al-Zebari and Al-Brifkany 2014) and poplar (Schroeder and Walker, 1990) in which basal stem section cuttings had higher rooting percentage.

Root weight and length had an inverse relationship between the two cutting types (Table 1.2). While AP cuttings had higher root percentage than ST, the latter had higher average root weight. Conversely, AP generated longer root systems on average, suggesting they may have rooted earlier.

## Conclusions

The low-bush blueberry cultivar BW rooted poorly compared to the half-high cultivar NL, and therefore would likely be difficult to adapt to a soilless substrate. Propagation of half-high blueberries in rockwool substrates was viable, but not as effective as in 3:1 perlite: peat. CO and PP substrates resulted in best overall rooting. Rooting percent was not improved with the use of the rooting hormone IBA, and NL and BW blueberry cuttings are not affected by ethyl alcohol. Rockwool substrates had a higher pH and EC which may have interfered with rooting for these acid-preferring species. After root initials developed, weekly fertilization did not improve rooting percentage. Blueberry stem section cuttings that include an apical meristem root better than basal stem section cuttings. Adding shade over the rooting location should be investigated for potential benefit since light induced necrosis was widespread.

With further research, soilless production of blueberries could prove to be a lucrative crop option for diversified growers. The application of a drip- or sub-irrigation system using any of these soilless substrates may offer growers a new means of producing small fruits with the potential to increase water- and space-use efficiency in controlled environment production. Growing in this setting could potentially offer near year-round production, as it may be possible to achieve two crops of berries from the same plants within one year. However, this method would be energy intensive.

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## Figures and Tables

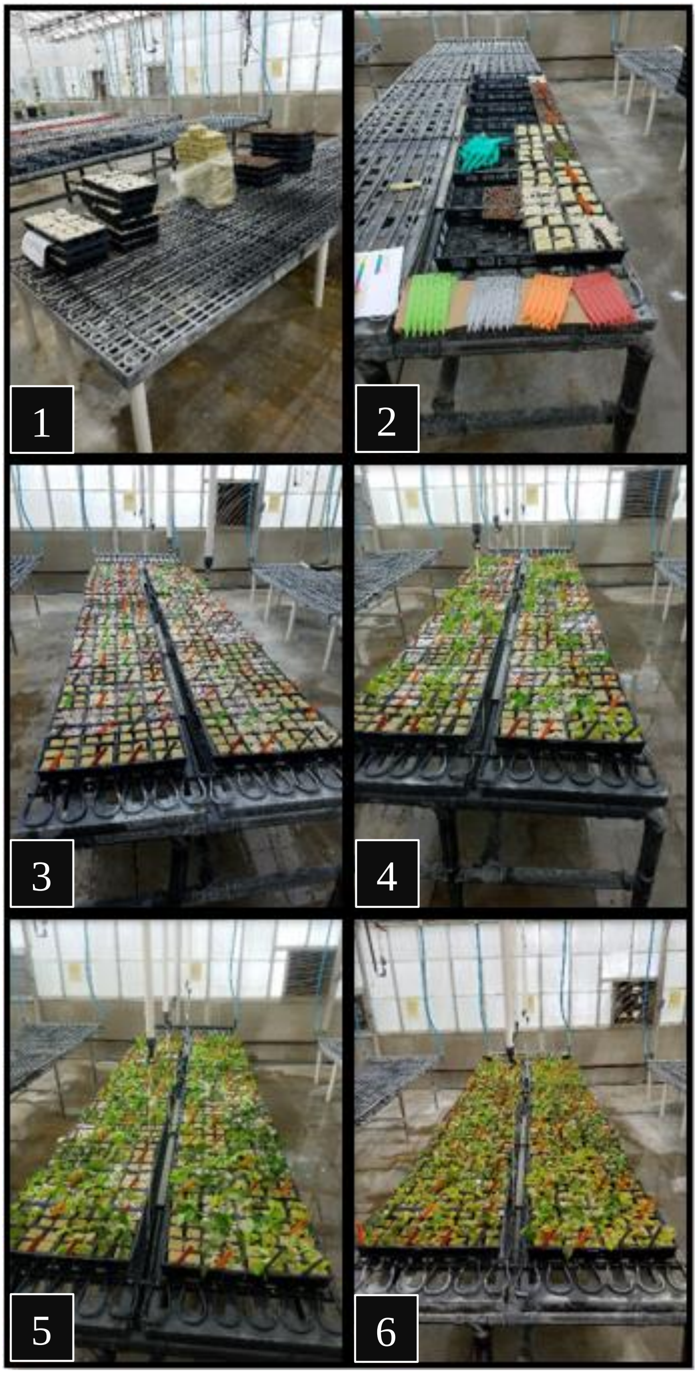


**Figure 1.1. Expt. 1 set-up. 1: Rooting containers have been filled with soilless substrates and are ready to be set in CRD; 2: CRD layout is beginning and treatment tags are being laid out; 3: All replications have been set out and tags are in place; 4: Cuttings being placed into respective treatments; 5: All cuttings placed into substrates; 6: Cuttings after 30 days in the system.**

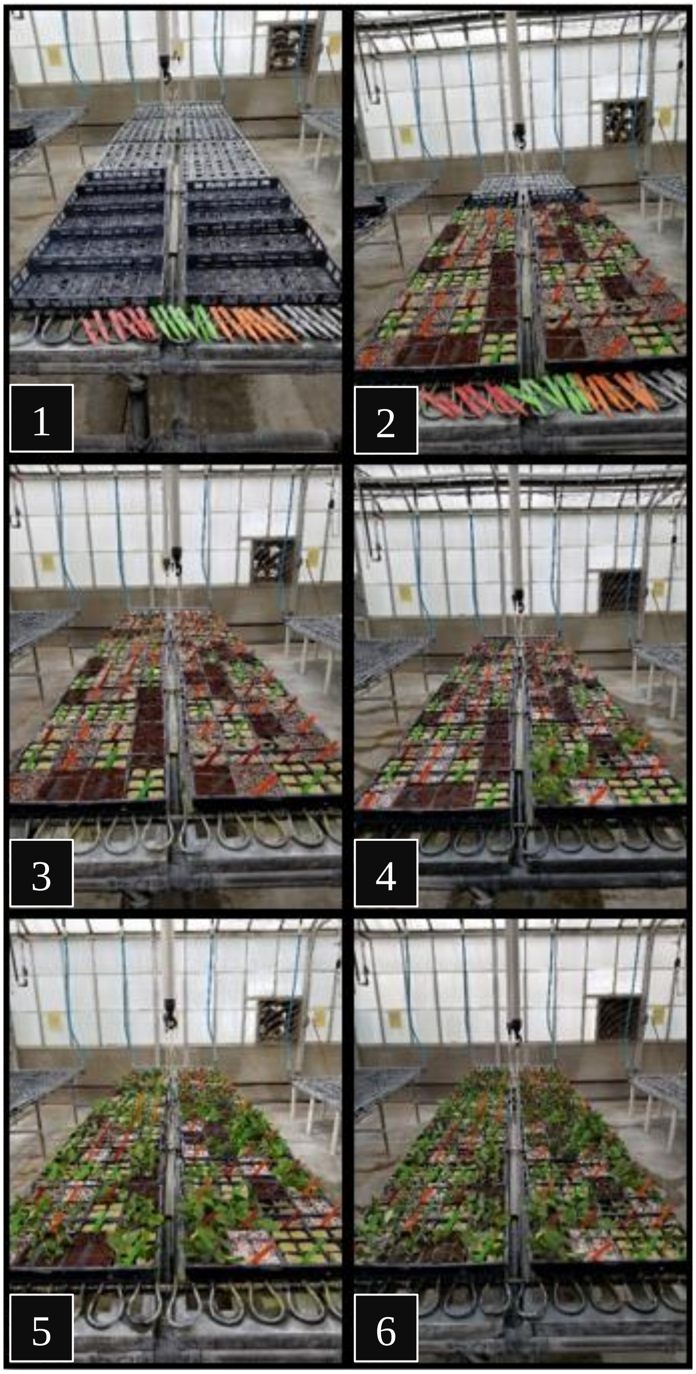


**Figure 1.2. Expt. 2 set-up process. 1: Net flats being set out to receive rooting containers; 2: Soilless substrates in rooting containers being set into CRD; 3: Soilless substrates completely set out; 4: Some cuttings stuck into respective treatments; 5: Cuttings mostly placed in treatments; 6: All cuttings in treatments, about to be watered in.**


**Figure 1.3. Root rating scale developed for use in this research. 0: unrooted; 1: callus, but no roots; 2: few, small roots; 5: well-rooted.**

**Figure 1.4. Collecting pour through leachate from one e.u. in the shredded rockwool substrate treatment (Expt. 2).**

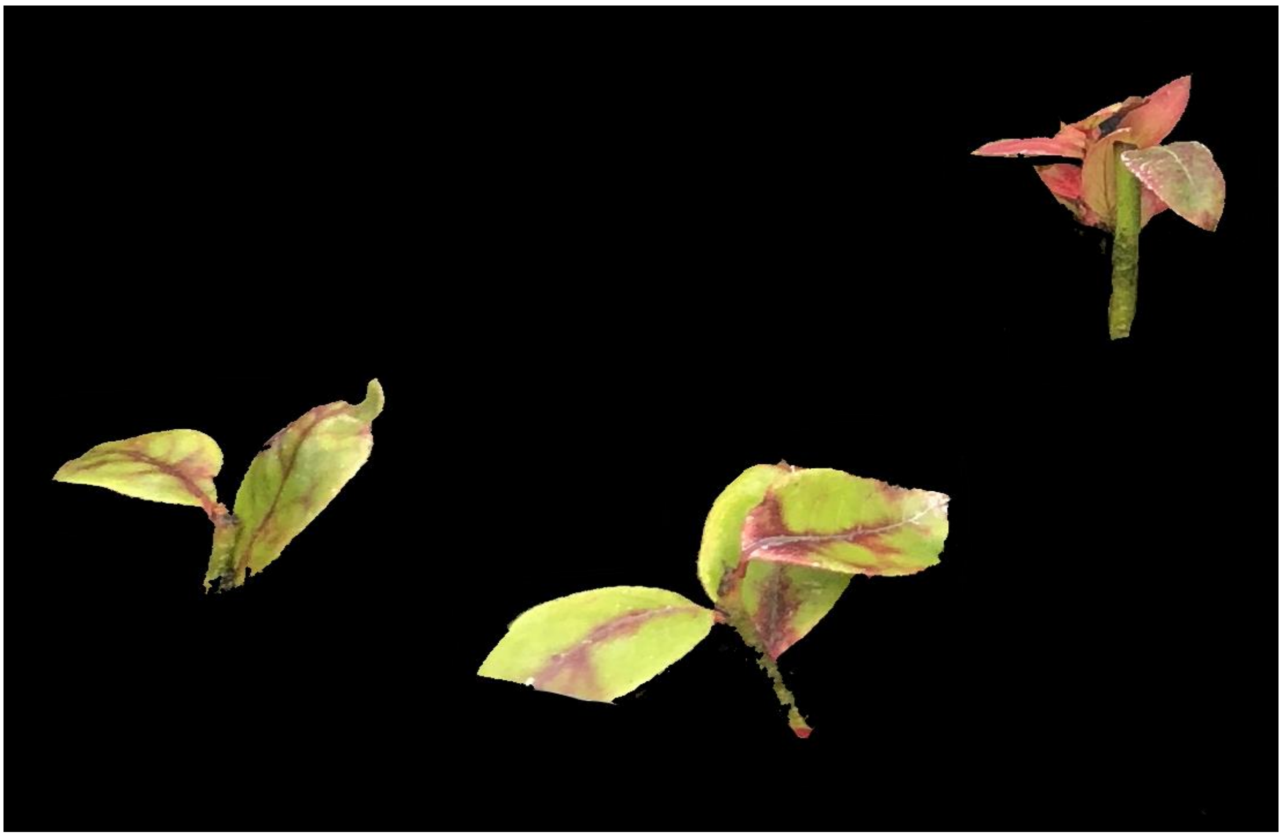

**Figure 1.5. Example of sunburn on foliage of cutting. This sunburn suggests the need for a shade structure in high light environments such as a Midwest greenhouse.**

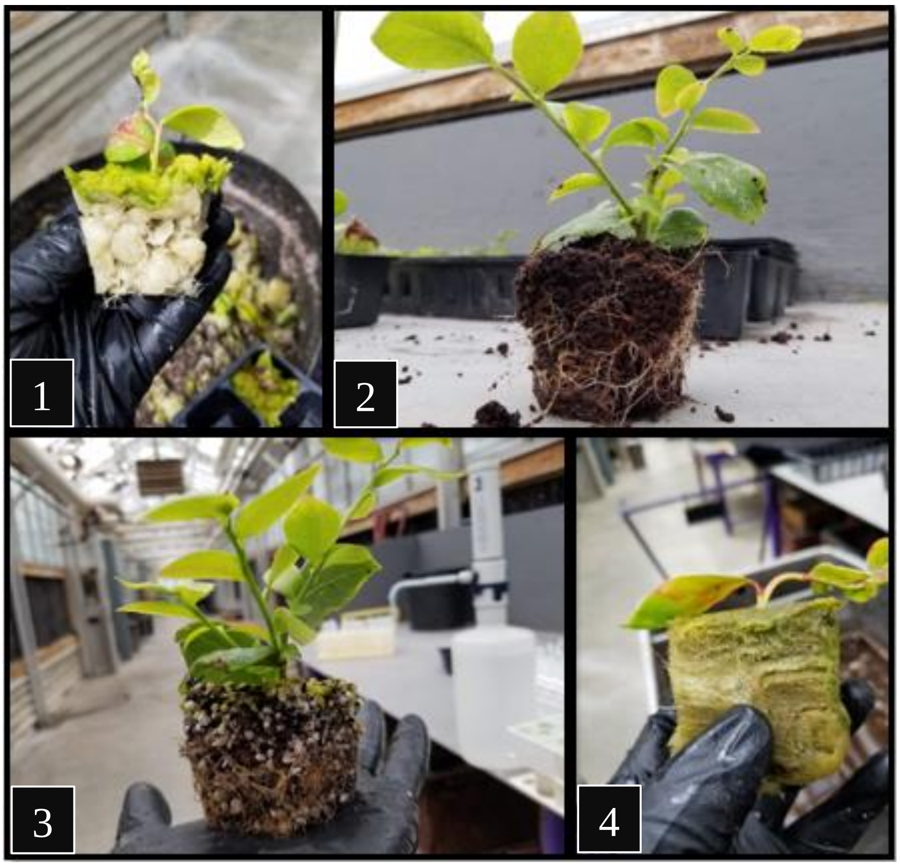

**Figure 1.6. Examples of rooted cuttings of *Vaccinium corymbosum* x *angustifolium* 'Northland' from Expt. 2. 1: shredded rockwool, rating 3; 2: cococoir, rating 5; 3: peat:perlite, rating 5; 4: rockwool cube, rating 2.**

**Table 1.1. Percent rooting and root rating by main effects of cultivar, substrate, and fertilizer for *V. angustifolium* X *corymbosum* 'Northland' and *V. angustifolium* 'Brunswick'. (Expt. 2).**

| Treatments | Rooting (%) | Rating |
|---|---|---|
| Cultivar | | |
| 'Brunswick' | 18[b] | 1.3[b] |
| 'Northland' | 63[a] | 2.5[a] |
| $HSD_{0.05}$[z] | 5.8 | 0.16 |
| Substrate | | |
| Rockwool Cube | 15[b] | 0.4[b] |
| Shredded Rockwool | 22[b] | 0.7[b] |
| Cococoir | 64[a] | 1.4[a] |
| Peat:perlite | 62[a] | 1.6[a] |
| $HSD_{0.05}$ | 10.8 | 0.28 |
| Fertilizer | | |
| Control (Water) | 44 | 2.0 |
| Oasis® | 41 | 1.9 |
| ChemGro | 38 | 1.8 |
| $HSD_{0.05}$ | NS | NS |
| Cultivar * Substrate | | |
| Brunswick * Rockwool Cube | 2[c] | 1.0[d] |
| Brunswick * Shredded Rockwool | 2[c] | 1.0[d] |
| Brunswick * Cococoir | 41[b] | 1.6[c] |
| Brunswick * Peat:perlite | 27[b] | 1.4[c] |
| Northland * Rockwool Cube | 28[b] | 1.3[cd] |
| Northland * Shredded Rockwool | 42[b] | 1.6[c] |
| Northland * Cococoir | 88[a] | 3.2[b] |
| Northland * Peat:perlite | 96[a] | 4.0[a] |
| $HSD_{0.05}$ | 15.1 | 0.35 |
| Significance | | |
| Cultivar | *** | *** |

| | | |
|---|---|---|
| Substrate | *** | *** |
| Fertilizer | NS | * |
| Cultivar * Substrate | *** | *** |
| Cultivar * Fertilizer | NS | NS |
| Substrate * Fertilizer | NS | NS |
| Cultivar * Substrate * Fertilizer | NS | ** |

[z]HSD used to compare differences in means, minimum significant difference reported provided significant treatment interactions; significant at p<0.05.
NS, *, **,*** not significant, significant at P≤0.05, significant at P≤0.01, or significant at P≤0.001 respectively; letter groups significant at P≤0.05
Means in the same column followed by the same superscript letter are not significantly different.

**Table 1.2. Percent rooting, root rating, root dry weight, and root length of *V. angustifolium* X *corymbosum* 'Northland'. By substrate, root promoting hormone, and cutting type (Expt. 1).**

| Treatments | Rooting (%) | Rating | Weight(g)$^z$ | Length(mm) |
|---|---|---|---|---|
| Substrate | | | | |
| Rockwool Cube | $61^b$ | $1.7^b$ | $0.11^c$ | $11.48^b$ |
| Shredded Rockwool | $46^c$ | $1.6^b$ | $0.16^b$ | $9.86^b$ |
| Peat:perlite | $95^a$ | $3.7^a$ | $0.30^a$ | $58.08^a$ |
| $HSD_{0.05}^y$ | 8.29 | 0.18 | 0.046 | 4.049 |
| Hormone | | | | |
| Water | 63 | 2.3 | 0.19 | $25.20^{ab}$ |
| Water + Ethanol | 69 | 2.3 | 0.18 | $23.93^b$ |
| 1,000ppm KIBA | 67 | 2.4 | 0.19 | $25.28^{ab}$ |
| 1,000ppm IBA + Ethanol | 72 | 2.2 | 0.19 | $31.49^a$ |
| $HSD_{0.05}$ | NS | NS | NS | 7.522 |
| Cutting Type | | | | |
| Apical | $80^a$ | $2.7^a$ | $0.16^b$ | $33.18^a$ |
| Stem | $54^b$ | $1.9^b$ | $0.22^a$ | $19.77^b$ |
| $HSD_{0.05}$ | 6.04 | 0.17 | 0.041 | 3.970 |
| Substrate * Hormone | | | | |
| Rockwool Cube * Water | 56 | $1.6^c$ | $0.09^d$ | $8.67^c$ |
| Rockwool Cube * Water + Ethanol | 54 | $1.6^c$ | $0.10^d$ | $8.29^c$ |
| Rockwool Cube * 1,000ppm KIBA | 61 | $1.8^c$ | $0.12^{cd}$ | $13.88^c$ |
| Rockwool Cube * 1,000ppm IBA + Ethanol | 72 | $1.8^c$ | $0.12^{cd}$ | $15.08^c$ |
| Shredded Rockwool * Water | 39 | $1.5^c$ | $0.13^{cd}$ | $8.22^c$ |
| Shredded Rockwool * Water + Ethanol | 56 | $1.6^c$ | $0.14^{cd}$ | $9.04^c$ |
| Shredded Rockwool * 1,000ppm KIBA | 44 | $1.5^c$ | $0.20^{bcd}$ | $11.33^c$ |
| Shredded Rockwool * 1,000ppm IBA + Ethanol | 46 | $1.6^c$ | $0.14^{cd}$ | $10.86^c$ |
| Peat:perlite * Water | 93 | $3.8^{ab}$ | $0.35^a$ | $58.71^{ab}$ |
| Peat:perlite * Water + Ethanol | 96 | $3.6^{ab}$ | $0.31^{ab}$ | $54.44^b$ |
| Peat:perlite * 1,000ppm KIBA | 94 | $3.9^a$ | $0.24^{abc}$ | $50.64^b$ |
| Peat:perlite * 1,000ppm IBA + Ethanol | 96 | $3.4^b$ | $0.31^{ab}$ | $68.51^a$ |

| | | | | |
|---|---|---|---|---|
| $HSD_{0.05}$ | NS | 0.50 | 0.128 | 11.114 |
| | | | | |
| Substrate * Cutting Type | | | | |
| Rockwool Cube * Apical | $76^{b}$ | $1.9^{c}$ | $0.08^{c}$ | $15.51^{c}$ |
| Rockwool Cube * Stem | $46^{c}$ | $1.4^{d}$ | $0.14^{c}$ | $7.45^{d}$ |
| Shredded Rockwool * Apical | $65^{b}$ | $1.8^{c}$ | $0.09^{c}$ | $14.44^{c}$ |
| Shredded Rockwool * Stem | $27^{d}$ | $1.3^{d}$ | $0.22^{b}$ | $5.28^{d}$ |
| Peat:perlite * Apical | $99^{a}$ | $4.2^{a}$ | $0.31^{a}$ | $69.58^{a}$ |
| Peat:perlite * Stem | $90^{a}$ | $3.1^{b}$ | $0.29^{ab}$ | $46.57^{b}$ |
| $HSD_{0.05}$ | 13.45 | 0.28 | 0.072 | 6.499 |
| | | | | |
| Significance | | | | |
| Substrate | *** | *** | *** | *** |
| Hormone | NS | NS | NS | *** |
| Cutting Type | *** | *** | *** | *** |
| Substrate * Hormone | NS | ** | *** | *** |
| Substrate * Cutting Type | *** | *** | * | *** |
| Hormone * Cutting Type | NS | NS | * | NS |
| Substrate * Hormone * Cutting Type | NS | NS | NS | NS |

[y]HSD used to compare differences in means, minimum significant difference reported provided significant treatment interactions; significant at $p<0.05$.
[z]Root weight is determined as the sum weights from of 4 out of 6 cuttings per e.u.
NS, *, **,*** not significant, significant at $P \leq 0.05$, significant at $P \leq 0.01$, or significant at $P \leq 0.001$ respectively; letter groups significant at $P \leq 0.05$
Means in the same column followed by the same superscript letter are not significantly different.

**Table 1.3. Final substrate pH and EC ($dS \cdot m^{-1}$) by cultivar, substrate, and fertilizer. (Expt. 2).**

| Treatments | pH | EC |
|---|---|---|
| Cultivar | | |
| ‘Brunswick’ | $6.4^{b}$ | $0.52^{b}$ |
| ‘Northland’ | $6.6^{a}$ | $0.58^{a}$ |
| $HSD_{0.05}^{z}$ | 0.26 | 0.048 |
| | | |
| Substrate | | |
| Rockwool Cube | $7.1^{a}$ | $0.65^{a}$ |
| Shredded Rockwool | $7.2^{a}$ | $0.61^{ab}$ |
| Cococoir | $6.2^{b}$ | $0.55^{b}$ |
| Peat:perlite | $5.5^{c}$ | $0.40^{c}$ |
| $HSD_{0.05}$ | 0.26 | 0.070 |
| | | |
| Fertilizer | | |
| Control (Water) | $6.5^{ab}$ | $0.50^{b}$ |
| Oasis® | $6.3^{a}$ | $0.53^{b}$ |
| ChemGro | $6.7^{b}$ | $0.62^{a}$ |
| $HSD_{0.05}$ | 0.38 | 0.068 |
| | | |
| Cultivar * Substrate | | |
| ‘Brunswick’ * Rockwool Cube | $7.0^{b}$ | $0.62^{ab}$ |
| ‘Brunswick’ * Shredded Rockwool | $6.9^{b}$ | $0.57^{b}$ |
| ‘Brunswick’ * Cococoir | $6.2^{c}$ | $0.54^{bc}$ |
| ‘Brunswick’ * Peat:perlite | $5.3^{e}$ | $0.37^{d}$ |
| ‘Northland’ * Rockwool Cube | $7.2^{ab}$ | $0.69^{a}$ |
| ‘Northland’ * Shredded Rockwool | $7.4^{a}$ | $0.65^{ab}$ |
| ‘Northland’ * Cococoir | $6.1^{cd}$ | $0.56^{b}$ |
| ‘Northland’ * Peat:perlite | $5.8^{d}$ | $0.43^{cd}$ |
| $HSD_{0.05}$ | 0.40 | $NS^{y}$ |
| | | |
| Cultivar * Fertilizer | | |
| ‘Brunswick’ * Control (Water) | $6.4^{ab}$ | $0.43^{c}$ |
| ‘Brunswick’ * Oasis® | $6.1^{b}$ | $0.50^{bc}$ |
| ‘Brunswick’ * ChemGro | $6.6^{ab}$ | $0.64^{a}$ |

| | | |
|---|---|---|
| 'Northland' * Control (Water) | 6.7[ab] | 0.57[ab] |
| 'Northland' * Oasis® | 6.5[ab] | 0.57[ab] |
| 'Northland' * ChemGro | 6.7[a] | 0.61[ab] |
| $HSD_{0.05}$ | NS | 0.112 |
| | | |
| Significance | | |
| Cultivar | *** | *** |
| Substrate | *** | *** |
| Fertilizer | *** | *** |
| Cultivar * Substrate | *** | NS |
| Cultivar * Fertilizer | NS | *** |
| Substrate * Fertilizer | NS | NS |
| Cultivar * Substrate * Fertilizer | *** | NS |

[z]HSD used to compare differences in means, minimum significant difference reported provided significant treatment interactions; significant at $p<0.05$.
[y]HSD significant at $p<0.10$.
NS, *, **,*** not significant, significant at $P\leq0.05$, significant at $P\leq0.01$, or significant at $P\leq0.001$ respectively; letter groups significant at $P\leq0.05$
Means in the same column followed by the same superscript letter are not significantly different.

# Chapter 2 - Volumetric water content impact on 'Northland' half-high blueberries across soilless production systems

## Abstract

Interest in soilless production and controlled environment food production is increasing. Therefore, it is important to look into the viability of different non-traditional soilless food crops. Blueberries are a high-value crop especially during early- and late-season production. Research was conducted into the viability of four soilless systems across three volumetric water content (VWC) treatments using *Vaccinium corymbosum* X *angustifolium* 'Northland'. System types included sub-irrigated cococoir, drip-irrigated rockwool slabs, leca clay in sub-irrigated Dutch buckets, and drip-irrigated peat:perlite in bag-culture. VWC treatments included a relatively dry 15%, medium 25%, and wet 35%. VWC was measured daily for accurate water management. Plants were initialized in 2019 and were grown from February to November to acclimate to the systems. The 2020 growing season was split into a Spring and Summer season to try and achieve two fruiting events in one calendar year. During 2019, the peat:perlite plants out-grew the other systems, doubling their size across all metrics. The leca clay system was removed due to poor performance. Rockwool plants outperformed coir plants by the end of 2019. After overcoming high salt-load from early 2019, the coir plants caught-up to the rockwool plants in Spring 2020 while peat:perlite continued to outgrow plants in both other treatments. This trend continued through Summer 2020. Plants grown in coir did not bear fruit. For Spring 2020, peat:perlite plants produced more fruit than rockwool, and in Summer 2020 rockwool plants out-produced peat:perlite. For both seasons rockwool plants produced more fruit than peat:perlite, but they were had similar total weight of fruit per plant. Fruit yield was low relative to the cultivar's potential which is attributed to a lack of pollinators.

# Introduction

Demand for locally produced food has been increasing in recent years (Brown, 2009; Grebitus, et al., 2013; Jekanowski, et al., 2000), therefore it is important to evaluate alternative methods to produce crops outside of their typical regions of production. Blueberry is a high-value crop commonly produced from Maine to Florida, inland to Michigan, and along the west coast. During the North American winter, blueberries are produced in Chile and shipped to the U.S. Transportation of blueberries requires massive fuel consumption and decreases relative freshness of the fruit. When combining the increased willingness to pay for local food and the high value of blueberries, this crop may be a candidate for year-round greenhouse production using soilless growing methods. Soilless growing is executed by growing using an inert substrate where all plant nutrient needs are supplied using a nutrient solution.

Currently, soilless growing methods are used primarily to produce lettuce and leafy greens, tomatoes, cucumbers, cut herbs, and melons. Some research has been conducted into viability of blueberry production in soilless substrates (Higashide, et al., 2006; Reyes-Diaz, et al., 2009; Schuch, et al., 2012) which supports the viability of using soilless systems for blueberry production. Stemming from these findings, further research into optimal water status and type of systems used for blueberry production is needed.

Blueberry thrives in low pH conditions of 4.3 to 5.0 (Webb, 1981) and lower salt loads of less than 3.0 $dS \cdot m^{-1}$ (Bryla, 2011). Using hydroponic nutrient delivery, pH and electrical conductivity (EC) should be easier to maintain at optimal levels. Hydroponic methods can also be used anywhere in the world in situations ranging from uncontrolled open field to controlled environment greenhouses.

In China, blueberries are primarily produced in-field, but instances of protected and controlled environment blueberry production are increasing (Li et al. 2017). From 2006 to 2015, blueberry production in greenhouses and high tunnels increased from 17 and 9 ha to 560 and 1165 ha, respectively (Li et al. 2017). These increases demonstrate that despite the higher costs associated with protected and controlled environment production, the fruit is valuable enough to make these production methods an economically viable option in China.

Research has been conducted in high tunnels and greenhouses regarding the viability of off-season production of blueberries. Fernandez and Ballington (2002) discuss high interest in their off-season research but were unable to achieve economically viable fruit yield in greenhouses and mention concerns over cultivar choice. The importance of cultivar choice is demonstrated by Bal (1997) who showed potential yield spread across 5-months as opposed to the typical 8 to 10 weeks. Ciordia et al. (2006) found that they were able to produce a large, marketable yield ~one month earlier than typical production in Spain using southern highbush blueberry cultivars. Similar research has demonstrated an ability to achieve marketable yield with northern highbush cultivars produced in containerized soilless substrates within high tunnels ending as early as mid-April in Spain (Ciordia et al. 2002).

The objectives of this research were to 1) evaluate different soilless system types in greenhouse production; 2) determine optimal water status for blueberry production in three different soilless substrates; and 3) evaluate viability of multiple berry crops per year in controlled environment production.

## Materials and Methods

A greenhouse experiment was conducted from February 2019 to September 2020 with *Vaccinium corymbosum* X *angustifolium* ‘Northland’ grown at three different volumetric water contents (VWC) in four soilless systems: coir-filled pots on sub-irrigation, rockwool slab culture, peat-perlite in containers, and Dutch buckets filled with leca clay pebbles. Systems were arranged in a completely random design (CRD). For 2019, the factorial treatment structure consisted of four soilless systems by three water-status treatments with twelve replications for a total of 144 plants, and in 2020 the factorial treatment structure was three soilless systems by three water status treatments with six replications for a total of 54 plants.

At the end of the first season, half of the plants were destructively harvested and because of poor performance, Dutch buckets were removed from the experiment. Therefore, for 2020, the factorial treatment structure consisted of three soilless systems by three water status treatments with six replications for a total of 54 plants.

### *Production systems*

Four production systems were used in this project. Cococoir substrate (Planet Coco, Allen, TX, USA) in 11.4 L (3 gal) pots (Poly-Tainer-Can No. 3, Nursery Supplies Inc., Fairless Hills, PA, USA) was placed on a Grow Bag Garden Tray (Garland Products Ltd., Kingswinford, West Midlands, ENG) with a single fill & drain fitting in the center (Hydro Flow, purchased from ZenHydro.com, Irwindale, CA, USA) to establish an ebb and flood style subirrigation system (Figure 2.1). During the first growing season, four months after transplanting, this treatment required thorough leaching in response to substrate EC of ~ 8 $dS\cdot m^{-1}$ to reduce salt levels down to ~0.2 $dS\cdot m^{-1}$.

A rockwool drip-irrigation system was constructed by using Grodan UniSlabs (Grodan ROXUL Inc., Milton, ON, CAN). A 12 cm diameter hole was cut in the plastic covering of the rockwool UniSlab and a 16.5 cm (6.5 in) diameter black plastic azalea pot (1,930 $cm^3$; Pöppelmann Plastics, Claremont, NC, USA), which had the bottom 2.5 cm removed (Figure 2.2), was inserted into the rockwool slab. This pot was then filled with Grodan ¼ in growcubes into which the cuttings were transplanted. The original irrigation system (Figure 2.2) was a Dramm dribble tube system that was replaced after issues such as irrigation inconsistency arose ~2 weeks after system construction. Two drip emitters (Netafim Woodpecker Pressure Compensating Junior, Netafim, Fresno, CA, USA) were attached to the irrigation supply line and a 45 cm drip line was attached to each emitter and routed to the surface of the pot. Visible in Figure 2.4.

The leca clay Dutch bucket system consisted of two 7.6 L (2 gal) (2D, Letica Co., Rochester, MI, USA) buckets (Figure 2.3) where an inner bucket was nested in the same size and style of outer bucket. The inner bucket had ~35 to 40 10 mm holes drilled in the bottom for drainage into the outer bucket which had one single 13 mm fill-and-drain port drilled into the sidewall of the bucket ~1 to 2 cm from the bottom. This port was fitted with a rubber grommet into which a 13mm fitting from the irrigation line was inserted.

The 1 peat: 1 perlite system used drip irrigation identical to the rockwool system (initially Dramm dribble tubes, later switched to Netafim drip emitters; Figure 2.4). The substrate consisted of sphagnum peat (Pro-Moss Sphagnum Peat Moss, Premier Tech Horticulture, Quakertown, PA, USA) and perlite (Therm-O-Rock West Inc., Chandler, AZ, USA) with no amendments. This filled the 11.6 L (3 gal) squat RootTrapper II 3S bags (RootMaker®, Huntsville, AL, USA). This treatment was similar to current containerized blueberry production systems that have been used in high tunnels, though plants are typically grown in plastic pots.

### ***Nutrient solution***

Plants in all systems were fertilized with the same nutrient solution. Once transplanted, these young plants were maintained at 24°C day and 18°C night. They were irrigated with 50ppm N from Oasis® 16-4-20 (16N-1.7P-14.1K) Hydroponic fertilizer dissolved in DI water, maintained at pH 4.5 to 5.0 using 1M sulfuric acid, and an EC of between 0.45 and 0.60 $dS \cdot m^{-1}$. The nutrient solution tank was filled, and fertilizer was added manually as needed. pH and EC were continuously monitored and recorded using a Hanna GroLine Monitor for Hydroponic Nutrients (Hanna instruments, Smithfield, RI, USA). The functional status of this monitor was checked weekly and calibrated as needed using pH 4.0, pH 7.0, and EC 1.412 $dS \cdot m^{-1}$ calibration fluids. All the systems were plumbed from one nutrient solution tank with shut-off valves at each individual repetition to allow for a completely random design (Figure 2.5).

### *Water status treatments*

Volumetric water content (VWC) curves were established for the coir, rockwool, and peat:perlite using METER Group's "Method A" (Figure 2.6; METER Group, 2020). These curves were calibrated to the sensor's readings. The leca clay pebbles were not measured using the sensor as that would have caused significant damage to the probes. The leca clay system was removed before VWC treatments were implemented during 2020 due to poor plant performance during the first growing season in this system.

The three water status treatments were selected to compare plant growth within a very dry, optimal, and very wet substrate. Within the first two weeks of the Spring 2020 season the treatment VWCs were optimized. Initially, the selected treatments were 15, 30, and 45%, but it was not possible to maintain the peat:perlite substrate at 45% as it would have required irrigation multiple times per day. The wettest treatment (45%) was reduced by 10%, which was more manageable, but still required irrigation near-daily. The middle rate was also reduced by 5% to create even irrigation intervals. Therefore, we settled on VWC treatments of 15, 25, and 35% (± 2%) as the irrigation treatments for the duration of both Spring and Summer 2020. VWC treatments were kept even across all three substrates to allow for direct comparison.

VWC was measured daily using a METER Group TEROS12 moisture sensor (METER Group, Inc., Pullman, WA, USA) attached to a METER Group ProCheck handheld device (Figure 2.7). The raw output was recorded in a spreadsheet where an average across six readings per treatment (one reading per experimental unit) was compared to the pre-determined water status levels for 15, 25, and 35% VWC. Plants were irrigated to pot capacity when the average across six plants per treatment fell into or below the predetermined intervals. For the two drip irrigation systems (rockwool and peat:perlite), this meant a steady drip of solution coming from the pot, so leaching occurred. The coir subirrigation system was irrigated by filling the tray until the base of the pots were 2 to 3cm under water and left for 24 hours to thoroughly imbibe nutrient solution (Figure 2.1). The leca clay system was irrigated until solution was just beginning to drip out of the union between the two buckets.

### ***Plant growth and production cycle***

Blueberry 'Northland' is a northern half-highbush variety that reaches a maximum height of 1 to 1.5 m, has a spreading growth habit, is early flowering, and maintains relatively high yields; it is also described as adapting to a variety of soil types (Gauthier and Kaiser, 2013; Johnston and Moulton, 1968; Moore, 1993; Nelson, 1985; and Siefker and Hancock, 1986). It was selected for use in this greenhouse study because the stature is well suited to a greenhouse space where massive canopies of other cultivars would limit the number of plants. Additionally, having a plant that spreads by rhizomes (a trait inherited from its lowbush (*V. angustifolium*) parentage) potentially increases the canopy density; this enables a high yield despite lower canopy volume when compared to full-highbush genetic lines.

Rooted cuttings of blueberry 'Northland' that had been established in soilless substrates including 1 peat: 3 perlite, cococoir, and shredded rockwool from previous research (see Chapter

1 - ) were transplanted into soilless systems on February 15, 2019 after receiving over their required 1,000 h (~2,100 h) in a cooler at ~4 to 7°C. Rooted cuttings were sorted into three quality tiers (ranked best to worst) and evenly distributed between irrigation treatments within their respective substrates (Figure 2.8). The cuttings rooted in 1 peat: 3 perlite were transplanted into the peat:perlite system, cococoir into cococoir, and rockwool into rockwool and leca clay. The plants were fertigated as necessary to acclimate and establish in the production systems for the first growing period which ended on November 1, 2019. At this time the first destructive harvest occurred. Of the 36 original plants in each of four system types, half (18 plants per system type) were destructively harvested (described later). The remaining 18 plants were taken to the cooler to receive ~1,100 h of cooling at ~5 to 7°C.

Plants were removed from the cooler and reestablished in their systems on December 17, 2019, and volumetric water content (VWC) treatments began. The first berry harvest concluded on April 14, 2020 (Spring 2020 growing season) and the plants were moved back to the cooler for another vernalization period on May 18, 2020, to encourage reproductive bud development for a second berry harvest within one year. The Spring 2020 season totaled 154 days. The blueberries were again removed from the cooler and reestablished in the systems for a final season on June 27, 2020 (Summer 2020 growing season) (~1,000 h in cooler). The Summer 2020 berry harvest concluded on September 18, 2020, and the remaining plants were destructively harvested for the final harvest data. The Summer 2020 growing season totaled 104 days. The Spring 2020 growing season was longer than the Summer 2020 growing season as the experiment was terminated after the second fruit harvest concluded. That is, in the Summer 2020 season, plants were not afforded the same additional ~30-day vegetative growth period after fruiting that the plants received in Spring 2020. During flowering events in both 2020 seasons, flowers were hand pollinated using a vibrating wand pollinator.

### *Data collected*

Growth data included foliage canopy height, and average spread. This was collected after the end of 2019, Spring- and Summer 2020. Canopy measurements were taken from the top of the root medium to the highest apparent growth point of the plant. Spread measurements were the average of two horizontal measurements that were perpendicular to each other and intersected at the base of the plant.

The destructive harvest data included fresh and dry weights, and root dry weight. This processes included cutting the foliage canopy at the surface of the root medium (Figure 2.9), placing it into a labeled paper bag, measuring the fresh weight, then placing the canopy in a drying oven at 60 to 65°C for 5 days before recording the dry weight. The root systems were thoroughly washed to remove as much root medium as possible (Figure 2.10). The roots were then hung to allow water to drip off (Figure 2.11), then placed in labeled bags and put in drying ovens to determine the root dry weight. Immediately preceding the Summer 2020 destructive harvest, leaf greenness was measured using a SPAD meter (Chlorophyll meter SPAD 502Plus, Konica Minolta Inc, N.J., USA). SPAD readings can be an indicator of plant health as it measures chlorophyll content which can be a good indicator of foliar nitrogen levels (Dunn, 2017).

Substrate nutritional data was collected as pour-through leachate during the two destructive harvest instances. Pots were irrigated to pot-capacity using the nutrient solution then let to sit for 30 to 60 min. At this time the pots were placed on solid 1020 flats, 800 mL of DI water was poured over the top to displace the leachate. The leachate was collected using labeled vials and the samples were read using an Accumet® XL20 meter (ThermoFisher Scientific, Waltham, MA, USA).

Fruit yield data was collected two times per week, with 3 or 4 days in between. Only ripe berries (Figure 2.12) were removed from the plant and placed in a labeled paper bag. Each bag of fruit was then immediately counted and weighed. Data was processed using ANOVA and LSD procedures for means separation using RStudio version 1.1.463 (RStudio: Integrated Development for R. RStudio, Inc., Boston, MA, USA).

## Results and Discussion

## Year 1

### *Growth data*

Plants in the peat:perlite system generated the largest canopy during 2019 (Table 2.1). While the coir, leca clay, and rockwool systems produced no difference in canopy height, rockwool resulted in significantly wider average spread than coir and leca clay. Plants grown in peat:perlite also generated the greatest biomass of all groups (Table 2.2). Plants grown in rockwool generated more biomass in both root and canopy mass compared to those grown in coir and leca clay.

The 2019 growing season (Year 1) was used to establish plants in the system, and VWC treatments were not maintained. Analysis of growth at the end of this period shows that neither canopy measurements nor biomass accumulation were different between established plants within each system for any of the system types (Table 2.1, Table 2.2). Therefore, the plants within each system were of similar size as the VWC treatments were implemented during the 2020 seasons.

### *Nutritional data*

Analysis of leachate at the end of 2019 showed that peat:perlite had the lowest pH and coir had the highest with rockwool in the middle for a total difference of ~1.1 units (Table 2.3). There was no difference between EC measurements. Coir posed a significant issue which was a high salt load on receipt of the product. This was not caught until symptoms of foliar chlorosis arose ~2 months into production. By sampling the leachate from the coir system, we found that it had an EC of ~8.0 $dS \cdot m^{-1}$. This was remedied by conducting a 10-pass leaching event using DI water. The EC was dropped to ~0.2 $dS \cdot m^{-1}$

## Year 2

### *Growth data*

By the end of Spring 2020, the peat:perlite plants again had the largest canopies (Table 2.1). Plants in coir had surpassed those in rockwool to be the second largest. Plants in the rockwool system did not increase their canopy height between the end of 2019 and the end of the Spring 2020 season. However, the rockwool plants did increase their average spread at the same rate that coir plants increased their height. A volumetric canopy measurement would likely show near identical volume between the coir and rockwool plants.

In Summer 2020, peat:perlite plants finished at over double the height of the coir and rockwool plants, and the average spread was ~65% wider for plants in peat:perlite. At this time, the rockwool plants reached the same height as the coir plants, while the coir plants reached approximately the same average spread (Table 2.1). Growing the plants for more seasons may have shown which system will achieve the greatest canopy area increase. Blueberry growth previously had not been documented in rockwool; therefore, predicting plant success is not possible. However, blueberry growth has been documented in coir. Kingston et al. (2017) found that 9:1 coir: perlite had very similar biomass accumulation to the same ratio (9:1) sphagnum peat and perlite at 128 DAT.

By the end of Summer 2020, plants in peat:perlite had far exceeded growth in both other substrates in all metrics of biomass accumulation by over 400% (Table 2.2). Plants in both coir and rockwool had similar biomass accumulation for canopy fresh and dry weight, as well as root dry weight. Coir plants were lagging behind those in rockwool at the end of 2019 but caught up to them by the end of 2020. Growth for plants in coir was likely stunted in 2019 by the very high initial EC and required time to recover. For this reason, it is likely that plants in coir would exceed growth of those in rockwool and perhaps with a perlite amendment, may have been similar to the peat:perlite treatment. Further research into different soilless substrate amendment strategies should be conducted.

Spring 2020 yielded no difference in height of plants across all VWC treatments, but average spread increased as VWC increased. 35% over doubled the average spread when compared to 25% (Table 2.1). While the ANOVA for height and spread numbers for VWC treatments in Summer 2020 are significant, the LSD indicated no separation. Fresh weight of the 35% treatment was greater than 15%. 25% was not different in fresh weight compared to the other VWCs. The ANOVA indicated a difference between VWC for both dry weight measures, but the LSD did not indicate separation.

Canopy measurements for interactions between system type and VWC showed no significant difference for all of 2020 except for spread measurements for Spring 2020.

### *Nutritional data*

Analysis of leachate from pour-throughs at the end of Summer 2020 showed the rockwool system to have the lowest pH and highest EC (Table 2.3). While statistically significant, these results are not practically significant with a pH and EC difference of ~0.5, and 0.15 dS·m$^{-1}$ respectively. Plants in both rockwool and peat:perlite systems had similarly high SPAD readings, but coir was lower by ~9 units suggesting that they were not as healthy as the other plants.

The VWCs all had no difference in pH and EC readings. SPAD data showed that 35% VWC had greener plants than 15%. The apparent increase in health could be due to the increased irrigation rate leading to more nutrients being available to each plant. There was no significant interaction between system type and VWC for pH, EC, or SPAD readings. The average SPAD reading for plants in this research were similar, but slightly higher than similar research conducted in Chapter 3 where an average SPAD reading of ~35 was measured compared to ~47 in this experiment. This could be due to the high tunnel having a 50% shade covering while the plants in this study were under glass. During August 2020, the high tunnel had between ~700 to 900 μmol·m$^{-2}$·s$^{-1}$ while the glass greenhouse had ~900 to 1,200 μmol·m$^{2}$·s$^{-1}$. This may account for the relative reduction in chlorophyll content in the high tunnel.

### *Irrigation data*

Both coir and rockwool systems were irrigated at very similar frequencies between both Spring and Summer 2020 (Table 2.4). Peat:perlite plants at all VWCs were irrigated far more frequently than the other systems with the 35% being irrigated near-daily. At the 15% level, peat:perlite plants were irrigated more frequently than all VWCs for the other two systems. The volume of water applied to each plant within both rockwool and peat:perlite systems was very similar with the peat:perlite 35% receiving less water per irrigation instance than the others likely due to many irrigations being “maintenance irrigation” or effectively topping-off the pots with ~800 mL.

During Spring 2020 the irrigation frequency (days between irrigation instances) for coir ranged between 13 days for the wet treatment and 31 days for the dry treatment, rockwool was between 14 and 26 days between irrigation events, and peat:perlite was between 2 and 6 days between irrigation events. In Summer 2020 the days between irrigation instances were nearly halved for almost every treatment. Coir was between 9 and 17 days, rockwool was between 9 and 13 days, and peat:perlite stayed the same at 2 to 6 days. With more time the irrigation frequencies for plants in the coir and rockwool systems may have been more comparable to the peat:perlite plants.

### ***Fruit yield data***

No statistical analysis was run on this data due to missing data related to poor pollination. Coir plants did not yield any fruit during either 2020 season. This may also be due to the need for recovery from the initial high salt levels. For Spring 2020, the peat:perlite plants yielded over double the fruit per plant compared to plants in rockwool (Table 2.5). However, the rockwool plants in Summer 2020 doubled the yield from plants in the peat:perlite treatment. For the whole 2020 year, rockwool plants yielded more fruit per plant than those in peat:perlite, but both had similar average weight per plant. This suggests that while plants in rockwool yielded more fruit, the quality of the fruit from the peat:perlite plants was likely better.

During Spring 2020, plants in the 15% treatment yielded ~double the fruit and weight compared to those in 25% and 35% VWC treatments. During Summer 2020, yield seemed to correlate with the VWC treatments with wetter plants having higher yield. For the entire 2020 year, plants in both 15% and 25% had almost identical yield, and those in the wetter 35% VWC treatment were slightly higher.

Fruit yield, shown in Table 2.6, demonstrates several instances of 'Northland' yielding near ~2 kg per bush. The low yields in this project was likely due to a lack of access to pollinators. Blueberry flower morphology suggests that the plants do not readily self-pollinate (Coville, 1910). It has also been found that both unpollinated and emasculated 'Northland' plants had significantly reduced yield compared to plants that were open pollinated (MacKenzie, 1997). That research also found that self-pollination had similar results to open pollination. In MacKenzie's research, pollen was manually transferred whereas in our experiment pollination was carried out using a vibrating-wand pollinator. It is likely that the pollen was insufficiently transferred or received as "*Vaccinium* flowers are generally protandrous; the pollen is ready for dispersal a day or two before the stigma becomes receptive" (Vander Kloet, 1988).

Observations of additional off-study plants, produced in the same soilless systems and that had access to bees, occurred during the Spring 2020 season. These off-study plants were growing in identical conditions to the plants in this project, including the same rockwool and peat:perlite substrate and the same nutrient solution. The off-study plants produced significantly higher yield across fewer plants than was achieved in this experiment (Table 2.7). The total yield of plants in rockwool and peat:perlite in this off-study set of plants dwarfed the total yield from this experiment on ~10 fewer plants per substrate type. For this reason, if a grower were to proceed with controlled environment blueberries, the benefit of pollinators cannot be overstated.

## Conclusions

Plants in the peat:perlite system out-performed the other systems in all metrics except water-use. Given a "fair-shake" the coir may have been a viable system with a perlite amendment and having been leached to reduce initial salt load before transplant. While plants in the rockwool system did maintain equal levels of harvestable yield compared to the peat:perlite plants, the growth characteristics lagged far behind. For this reason, it is difficult to suggest the use of rockwool slabs for blueberry production. However, further research could be conducted into different rockwool forms including different slabs, shredded rockwool, or even propagating into 1 in cubes, then into a traditional slab system. It would also be of interest to evaluate whether mycorrhizal associations can be established in soilless substrates to benefit iron uptake by Ericaceous plants such as blueberry (Shaw et al., 1990). The leca clay Dutch bucket system was difficult to manage in this scale and would likely prove to be more difficult if the system were to be scaled-up. If a grower was able to manage the irrigation issues which arose, this type of system may become viable.

Blueberry production in soilless substrates using fertilizer solution for nutrient delivery is a viable production method and could offer a method for two harvests in one year in a greenhouse setting. For this type of system, pollinators would be essential to generate substantial harvestable yield.

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# Figures and Tables

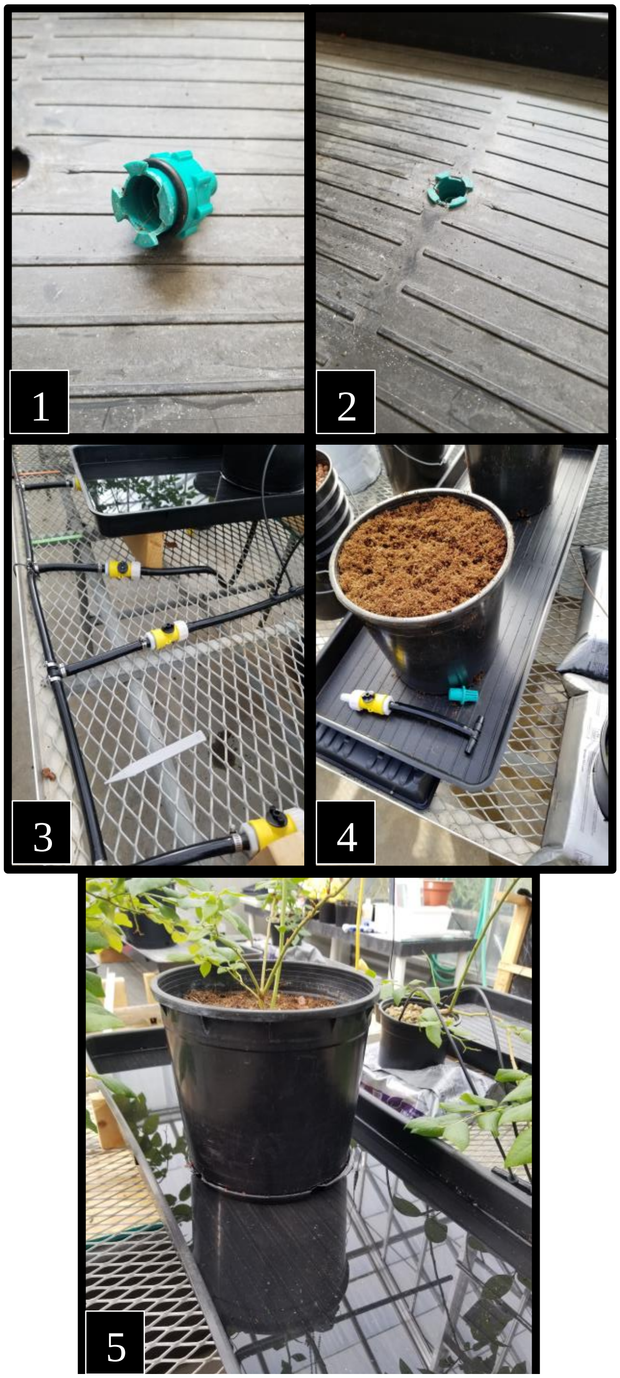


**Figure 2.1. Cococoir sub-irrigation system. 1: Hole drilled in center of tray and Hydro Flow fill/drain port, modified to allow tray to completely drain. 2: Fill/drain inserted in hole. 3: Shut-off valve and irrigation line flowing beneath bench and to the fill/drain port. 4: A pot on a tray before plants have been added. 5: A plant being irrigated with about 2 cm of standing fertilizer solution.**


**Figure 2.2 Rockwool Slab system construction. 1: With the bottom of the 16.5 cm pot removed, a circle is traced on the rockwool slab where the plastic will be cut to insert the pot. 2: With the plastic cut the pot is inserted. 3: The pot is inserted into the plastic and slightly pressed into the slab for stability. 4: Filling the pot with the ¼ in cubes; the Dramm dribble tube is present for this photo but was changed to Netafim drip emitters.**


**Figure 2.3 Leca clay Dutch bucket system assembly. 1: The inner pot, showing the holes for drainage into the outer pot. 2: The leca clay filling the pot. 3: The fitting joining the two pots with each other and with the shut-off valve. 4: Both pots together with the shut-off valve visible on the left.**


**Figure 2.4 Peat:perlite system assembly and with a plant. 1: Filling the RootTrapper bag with 1 sphagnum peat : 1 perlite. 2: A filled bag sits with the Dramm dribble tube before transplant. 3: A plant in 2020 growing with the updated Netafim irrigation system.**

**Figure 2.5. Greenhouse soilless systems on the day of transplant. Shows the CRD with all systems plumbed into the same main irrigation line. All plants were watered-in with hydroponic fertilizer. Shut-off valves are visible leading to each set of pots.**

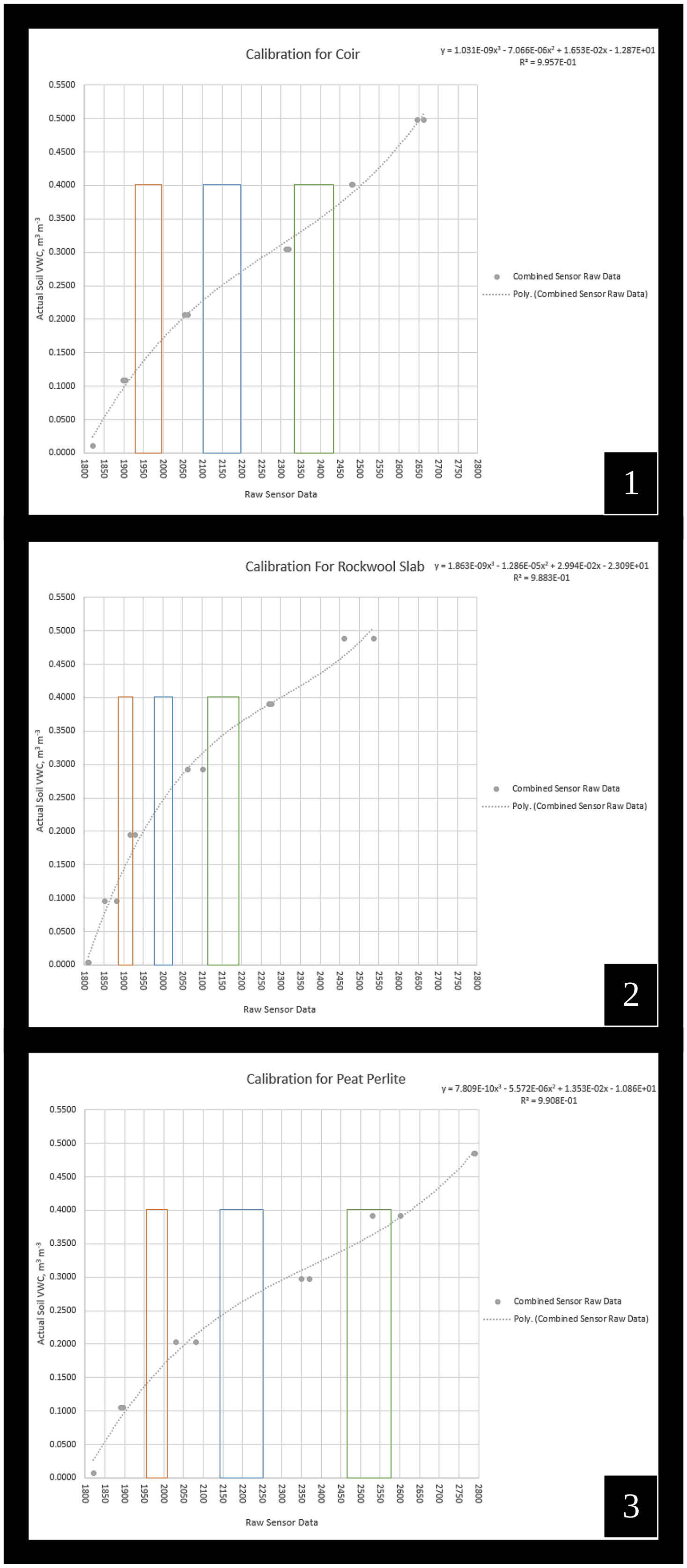


**Figure 2.6 Calibration curves for different soilless substrates: 1 – Coir, 2 – rockwool, 3 – peat:perlite. The different boxes indicate VWC intervals ± 2%. Orange: 13-17%; Blue: 23-27%; Green: 33-37%.**


**Figure 2.7 1: METER Group TEROS12 sensor and ProCheck used for daily water status measurements. 2: Sensor inserted in a peat:perlite container demonstrating no air gap between sensor and substrate. 3: The raw output from the sensor reading a sample from a well-irrigated plant.**

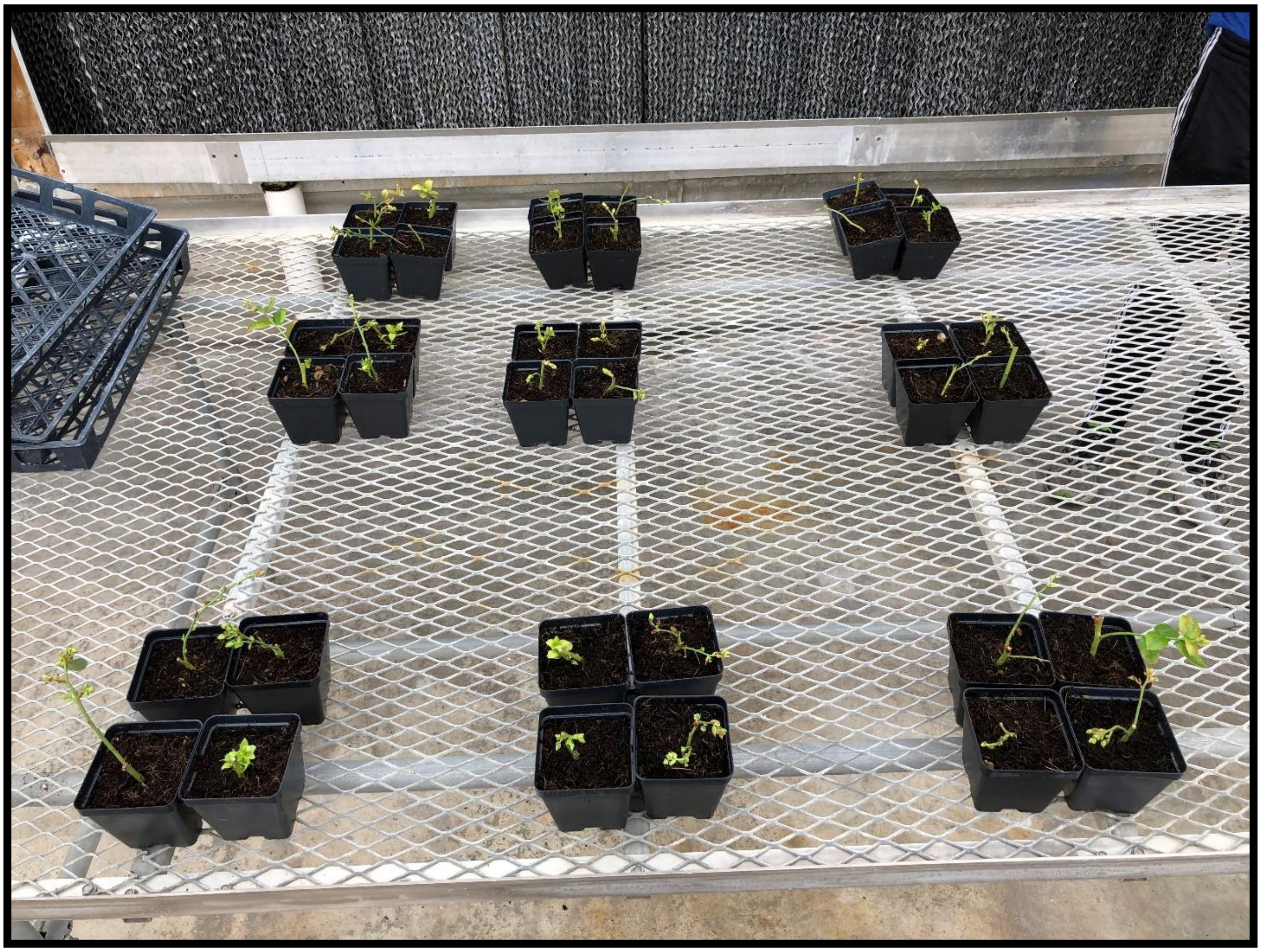

**Figure 2.8 Rooted cuttings of variable quality randomized across coir treatments. Demonstrates that plants of various quality levels were evenly distributed. The same procedure was followed for all substrate types.**

**Figure 2.9 Example of destructive harvest canopy removal at the end of 2020. Top: peat:perlite plant cut back to the substrate surface. Bottom: Rockwool plant with pot and plastic covering removed.**


**Figure 2.10 Examples of root systems at the end of the 2019. 1 - Rockwool before cleaning. 2 - Rockwool after cleaning. 3 - Peat:perlite before cleaning. 4 - Leca clay before cleaning. 5 - Leca clay after cleaning (rockwool was removed before roots were weighed). 6 - Cococoir before cleaning.**

**Figure 2.11 Root systems air-drying after washing and before being placed in bags for oven-drying at 65°C for 7 days. Plants were tagged for identification. Drip-drying occurred over-night to aid drying time and reduce paper bag degradation.**

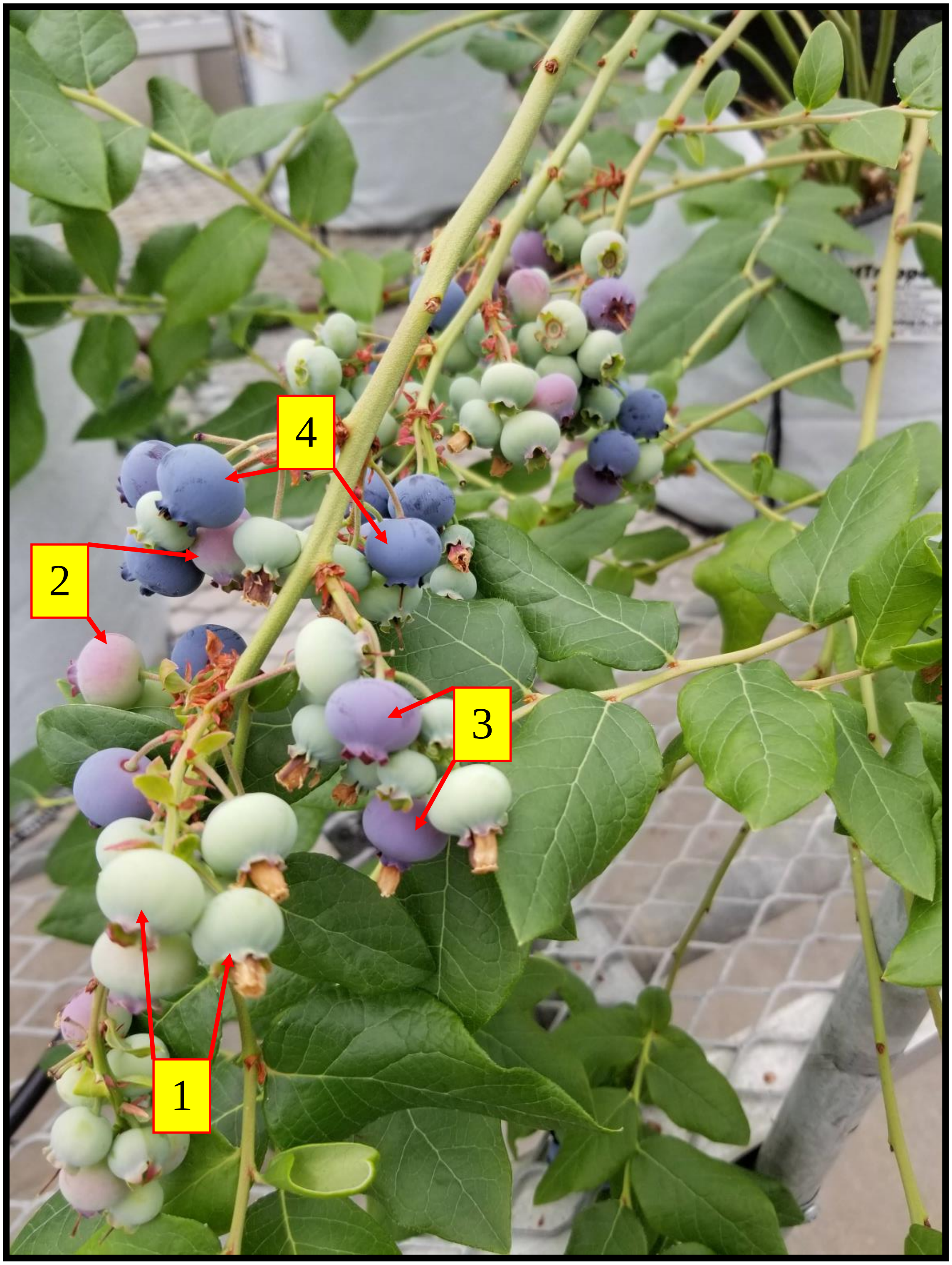


**Figure 2.12. Shows fruit at various stages of ripeness. 1: Unripe green berry; 2: Starting to flush pink; 3: changing from pink to purple; 4: ripe, harvestable, blued fruit.**

**Table 2.1. Canopy height and spread measurements at the end of each of the three growing seasons. Height was recorded from the top of the rooting substrate surface to the highest visible growing point. Spread was measured as the widest two horizontal measurements with a perpendicular intersection at the center of the canopy, then averaged.**

| Treatment | 2019 | | Spring 2020 | | Summer 2020 | |
|---|---|---|---|---|---|---|
| | Height | Spread | Height | Spread | Height | Spread |
| Substrate | | | | | | |
| Coir | 18 | 14[c] | 43[b] | 26[c] | 42 | 57 |
| Rockwool | 25 | 26[b] | 25[c] | 40[b] | 43 | 63 |
| Leca clay | 14 | 16[c] | - | - | - | - |
| Peat:perlite | 51[a] | 51[a] | 69[a] | 85[a] | 106[a] | 99[a] |
| $LSD_{0.05}$[z] | 10.7 | 6.1 | 9.0 | 7.6 | 12.3 | 10.2 |
| VWC | | | | | | |
| 15% | 28 | 25 | 41 | 26[c] | 52 | 66 |
| 25% | 25 | 29 | 46 | 40[b] | 65 | 73 |
| 35% | 29 | 27 | 50 | 85[a] | 74 | 80 |
| $LSD_{0.05}$ | NS | NS | NS | 7.6[y] | 23.4 | 15.7 |
| Substrate * VWC | | | | | | |
| Coir | | | | | | |
| 15% | 16 | 14 | 35 | 23[d] | 29 | 54 |
| 25% | 18 | 14 | 45 | 23[d] | 44 | 54 |
| 35% | 22 | 14 | 49 | 34[cd] | 54 | 64 |
| Rockwool | | | | | | |
| 15% | 22 | 20 | 22 | 44[c] | 38 | 60 |
| 25% | 22 | 33 | 22 | 34[cd] | 45 | 60 |
| 35% | 30 | 26 | 32 | 42[c] | 46 | 68 |
| Leca clay | | | | | | |
| 15% | 22 | 19 | - | - | - | - |
| 25% | 11 | 16 | - | - | - | - |
| 35% | 11 | 15 | - | - | - | - |
| Peat:perlite | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 15% | 52 | 49 | 65 | 75[b] | 90 | 84 |
| 25% | 47 | 52 | 71 | 92[a] | 108 | 104 |
| 35% | 53 | 52 | 70 | 89[a] | 122 | 108 |
| $LSD_{0.05}$ | NS | NS | NS | 11.9 | NS | NS |
| Significance | | | | | | |
| Substrate | *** | *** | *** | *** | *** | *** |
| VWC | NS | NS | NS | NS | ** | * |
| Substrate * VWC | NS | NS | NS | * | NS | NS |

[z]LSD used to compare differences in means, minimum significant difference reported provided significant treatment interaction; significant at p<0.05.
[y]LSD significant at p<0.10.
NS, *, **, *** not significant, significant at P≤0.05, significant at P≤0.01, or significant at P≤0.001 respectively; letter groups significant at P≤0.05
Means in the same column followed by the same superscript letter are not significantly different.

**Table 2.2. Canopy fresh and dry weights and root dry weights for both 2019 and 2020 years. All samples were collected and dried at 65°C for 7 days. Fresh weights were collected immediately after harvest then placed in the drying oven.**

| Treatment | 2019 | | | 2020 | | |
|---|---|---|---|---|---|---|
| | Canopy Fr. Wt. [g] | Canopy Dr. Wt. [g] | Root Dr. Wt. [g] | Canopy Fr. Wt. [g] | Canopy Dr. Wt. [g] | Root Dr. Wt. [g] |
| Substrate | | | | | | |
| Coir | $5.1^{c}$ | $3.0^{c}$ | $6.2^{c}$ | 61.3 | 27.0 | 27.8 |
| Rockwool | $19.6^{b}$ | $9.2^{b}$ | $10.4^{b}$ | 98.3 | 42.7 | 27.2 |
| Leca clay | $6.9^{c}$ | $3.5^{c}$ | $5.0^{c}$ | - | - | - |
| Peat:perlite | $82.7^{a}$ | $36.5^{a}$ | $42.3^{a}$ | $446.5^{a}$ | $193.9^{a}$ | $167.8^{a}$ |
| $LSD_{0.05}{}^{z}$ | 10.65 | 4.83 | 4.17 | 54.05 | 21.99 | 21.23 |
| VWC | | | | | | |
| 15% | 26.1 | 12.1 | 15.9 | $139.0^{b}$ | 62.5 | 52.8 |
| 25% | 30.6 | 13.4 | 15.6 | $195.7^{ab}$ | 86.1 | 80.8 |
| 35% | 29 | 13.7 | 16.4 | $271.3^{a}$ | 115.1 | 89.3 |
| $LSD_{0.05}$ | NS | NS | NS | 125.72 | 54.31 | 49.09 |
| Substrate * VWC | | | | | | |
| Coir | | | | | | |
| 15% | 4.0 | 2.5 | 5.9 | $39.9^{f}$ | $16.4^{f}$ | $22.4^{c}$ |
| 25% | 6.0 | 3.2 | 6.1 | $63.3^{ef}$ | $30.2^{ef}$ | $28.6^{c}$ |
| 35% | 5.3 | 3.3 | 6.6 | $80.8^{e}$ | $34.5^{e}$ | $32.6^{c}$ |
| Rockwool | | | | | | |
| 15% | 15.0 | 7.7 | 9.4 | $82.2^{e}$ | $36.3^{e}$ | $26.7^{c}$ |
| 25% | 8.0 | 9.8 | 12.2 | $82.9^{e}$ | $35.4^{e}$ | $24.5^{c}$ |
| 35% | 20.3 | 10.0 | 9.7 | $129.8^{d}$ | $56.4^{d}$ | $30.4^{c}$ |
| Leca clay | | | | | | |
| 15% | 9.3 | 4.7 | 6.0 | - | - | - |
| 25% | 8.0 | 3.9 | 5.6 | - | - | - |
| 35% | 3.3 | 2.1 | 3.4 | - | - | - |
| Peat:perlite | | | | | | |
| 15% | 76.0 | 33.4 | 42.3 | $295.0^{c}$ | $134.7^{c}$ | $109.2^{b}$ |
| 25% | 85.0 | 36.9 | 38.6 | $441.1^{b}$ | $192.6^{b}$ | $189.4^{a}$ |

| | | | | | | |
|---|---|---|---|---|---|---|
| 35% | 87.0 | 39.3 | 45.9 | 603.4[a] | 254.4[a] | 204.8[a] |
| $LSD_{0.05}$ | NS | NS | NS | 31.61 | 16.72 | 32.74 |
| Significance | | | | | | |
| Substrate | *** | *** | *** | *** | *** | *** |
| VWC | NS | NS | NS | *** | *** | *** |
| Substrate * VWC | NS | NS | NS | *** | *** | *** |

[z]LSD used to compare differences in means, minimum significant difference reported provided significant treatment interaction; significant at p<0.05.
NS, *, **, *** not significant, significant at P≤0.05, significant at P≤0.01, or significant at P≤0.001 respectively; letter groups significant at P≤0.05
Means in the same column followed by the same superscript letter are not significantly different.

**Table 2.3. Nutritional data of plants at end of first and second years. Leachate pH and EC measurements were collected before moving the plants to the cooler in 2019 and immediately prior to destructive harvest in 2020. SPAD data was only collected at end of 2020.**

| Treatment | 2019 | | 2020 | | |
|---|---|---|---|---|---|
| | pH | EC | pH | EC | SPAD |
| Substrate | | | | | |
| Coir | 6.2[a] | 0.53 | 5.74 | 0.75[b] | 41.8[b] |
| Rockwool | 5.6[b] | 0.50 | 5.10[b] | 0.90[a] | 50.8 |
| Peat:perlite | 5.1[c] | 0.56 | 5.66 | 0.83[ab] | 49.1 |
| $LSD_{0.05}$[z] | 0.24 | NS | 0.277 | 0.093 | 2.47 |
| VWC | | | | | |
| 15% | 5.9[a] | 0.56 | 5.52 | 0.81 | 45.6[b] |
| 25% | 5.6[b] | 0.54 | 5.47 | 0.85 | 46.7[ab] |
| 35% | 5.5[b] | 0.50 | 5.51 | 0.82 | 49.4[a] |
| $LSD_{0.05}$ | 0.30 | NS | NS | NS | 3.48 |
| Substrate * VWC | | | | | |
| Coir | | | | | |
| 15% | 6.2[a] | 0.49 | 5.83 | 0.69 | 41.2 |
| 25% | 6.3[a] | 0.60 | 5.60 | 0.75 | 39.5 |
| 35% | 6.1[a] | 0.51 | 5.82 | 0.80 | 44.8 |
| Rockwool | | | | | |
| 15% | 6.1[a] | 0.50 | 5.05 | 0.93 | 49.3 |
| 25% | 5.5[b] | 0.50 | 5.08 | 0.83 | 51.3 |
| 35% | 5.3[bcd] | 0.50 | 5.19 | 0.90 | 51.9 |
| Peat:perlite | | | | | |
| 15% | 5.4[bc] | 0.68 | 5.70 | 0.80 | 46.4 |
| 25% | 4.9[d] | 0.53 | 5.64 | 0.91 | 49.3 |
| 35% | 5.1[cd] | 0.49 | 5.64 | 0.76 | 51.7 |
| $LSD_{0.05}$ | 0.38 | NS | NS | NS | NS |
| Significance | | | | | |
| Substrate | *** | NS | *** | ** | *** |

| | | | | | |
|---|---|---|---|---|---|
| VWC | *** | NS | NS | NS | ** |
| Substrate * VWC | * | NS | NS | NS | NS |

[z]LSD used to compare differences in means, minimum significant difference reported provided significant treatment interaction; significant at $p<0.05$.
NS, *, **, *** not significant, significant at $P \leq 0.05$, significant at $P \leq 0.01$, or significant at $P \leq 0.001$ respectively; letter groups significant at $P \leq 0.05$
Means in the same column followed by the same superscript letter are not significantly different.

**Table 2.4. Irrigation frequency for each treatment. The spring 2020 season was substantially longer than summer 2020 as the experiment was concluded after fruit harvest concluded. Water status was recorded each day and plants were irrigated when they fell within a range of ±2%. “Irrigation instance” is a count of the number of times each treatment was watered. “Average irrigation volume” was measured by having a one set of emitters running into graduated beakers. For coir sub-irrigation each pot was weighed before irrigation then again after sitting in water for 24 hours; the deviation was the assumed water uptake. An average over several samples to determine ~1.6L of water uptake in each irrigation instance.**

| Treatments | Spring 2020 (154 days) | | | Summer 2020 (104 days) | | |
|---|---|---|---|---|---|---|
| | Irrigation instances | Average irrigation volume [L] | Total irrigation volume [L] | Irrigation instances | Average irrigation volume [L] | Total irrigation volume [L] |
| Substrates | | | | | | |
| Coir | | | | | | |
| 15% | 5 | 1.6 | 8.0 | 6 | 1.6 | 9.6 |
| 25% | 6 | 1.6 | 9.6 | 9 | 1.6 | 14.4 |
| 35% | 12 | 1.6 | 19.2 | 11 | 1.6 | 17.6 |
| Rockwool | | | | | | |
| 15% | 6 | 1.57 | 9.4 | 8 | 1.86 | 14.9 |
| 25% | 7 | 1.56 | 10.9 | 9 | 1.88 | 16.9 |
| 35% | 11 | 1.50 | 16.5 | 11 | 1.77 | 19.5 |
| Peat:perlite | | | | | | |
| 15% | 24 | 1.31 | 31.6 | 17 | 1.84 | 31.2 |
| 25% | 40 | 1.22 | 48.8 | 32 | 1.64 | 52.4 |
| 35% | 76 | 1.06 | 80.3 | 59 | 1.34 | 79.3 |

**Table 2.5. Fruit yield across treatments. Population size is indicated in parenthesis in the treatment column. Parenthesis in the "Fruit / plant" columns are the sample size. Fruit were harvested in labeled containers then immediately counted and weighed.**

| Treatment | Spring 2020 | | Summer 2020 | | Total Yield | |
|---|---|---|---|---|---|---|
| | Fruit / plant | Weight [g / plant] | Fruit / plant | Weight [g / plant] | Fruit / plant | Weight [g / plant] |
| Substrate | | | | | | |
| Rockwool (18) | 5(12) | 3.0 | 28(14) | 16.2 | 27(17) | 15.5 |
| Peat:perlite (18) | 12(15) | 10.6 | 13(9) | 7.8 | 17(17) | 13.5 |
| VWC | | | | | | |
| 15% (12) | 13(9) | 10.5 | 13(9) | 7.6 | 20(12) | 13.6 |
| 25% (12) | 6(8) | 4.7 | 24(7) | 15.2 | 20(11) | 13.1 |
| 35% (12) | 7(10) | 6.3 | 33(7) | 17.5 | 27(11) | 16.9 |
| Substrate * VWC | | | | | | |
| Rockwool | | | | | | |
| 15% (6) | 8(3) | 4.9 | 17(6) | 10.2 | 21(6) | 12.7 |
| 25% (6) | 4(4) | 2.6 | 31(4) | 19.5 | 23(6) | 14.7 |
| 35% (6) | 3(5) | 2.3 | 43(4) | 22.0 | 38(5) | 19.9 |
| Peat:perlite | | | | | | |
| 15% (6) | 16(6) | 13.3 | 4(3) | 2.5 | 18(6) | 14.5 |
| 25% (6) | 8(4) | 6.8 | 16(3) | 9.5 | 16(5) | 11.2 |
| 35% (6) | 10(5) | 10.4 | 19(3) | 11.4 | 18(6) | 14.3 |

**Table 2.6. Result of fruit yield reported in literature from research that included 'Northland'. Yield [kg per bush] comes from the findings within each experiment; the numbers in parenthesis are the range of fruit yield within each experiment. Year range is the span of the experiment and Year plants started shows the age of the plants in the experiment.**

| Group: | Yield [kg / plant] | Year Range | Year plants started |
|---|---|---|---|
| Kühn, 1991 | 0.25 | 1987:1990 | 1986 |
| MacKenzie, 1997 | 0.07 | 1990:1991 | Unknown |
| Nelson, 1985 | 2.77 (1.1 – 4.56) | 1969:1983 | 1966 |
| Pavlovski, 2010 | 2.00 (0.2 – 5.0) | 1993:2009 | 1988 |
| Schwab et al., 2020 | 0.44 (0.3 – 0.7) | 2020 | 2019 |
| Siefker. 1986 | 2.83 | 1969:1981 | 1966 |
| Šterne et al., 2011 | 1.60 | 2008:2010 | 2001 |
| Wach, 2008 | 2.13 (0.83 – 2.68) | 1996:1999 | 1993 |
| Table A.1 | 0.12 | 2020 | 2019 |

**Table 2.7. Yield from blueberry plants grown soilless substrates (2020), off study, irrigated as needed with hydroponic solution, which had access to bee-pollinators. Demonstrates potential yield with access to pollinators in second-year plants.**

| Treatments | Yield [Fruit / plant] | Yield [g / plant] |
|---|---|---|
| Substrates | | |
| Rockwool (7) | 74 | 70.5 |
| Peat:perlite (8) | 185 | 197.8 |

# Chapter 3 - Organic and conventional management of containerized blueberries in high tunnel production


## Abstract

Blueberries are typically produced in managed agricultural fields in regions with low soil pH or with organic acidifying soil amendments. Growers with otherwise unsuitable soil may consider alternative methods such as container production. In June 2019, 60 greenhouse-grown *Vaccinium corymbosum* x *angustifolium* 'Northland' blueberry plants in 3-gallon RootTrapper II grow bags were installed in a high tunnel in Haysville, Kansas, United States. Conventional (Osmocote® 3-month) versus organic (Holly-tone®) slow-release fertilizer treatments of 0.6 g N (low rate) or 1.8 g N (high rate) per 3gal container were applied as a top dress twice (April 12 and July 19) during production. Plants were irrigated as needed with high alkalinity well-water. Substrate amendments of elemental sulfur (1X=17 $g \cdot pot^{-1}$) or iron sulfate drench (1X=0.3 $g \cdot pot^{-1}$) were applied twice during production [June 14 (1X rate) and July 19 (2X rate)] and were compared to no amendment. From June to October 2019, canopy height, diameter in two directions, and substrate pH and electrical conductivity (EC) were collected monthly. In October, plants that received a higher rate of either fertilizer were larger based on height and spread, but not different based on conventional versus organic fertilizer source. High rates of conventional and organic fertilizer resulted in EC of 1.65 and 2.0 $dS \cdot m^{-1}$, respectively; low rates resulted in 1.43 and 1.73 $dS \cdot m^{-1}$, respectively. Therefore, increased growth was not related solely to higher EC. Amendments did not affect substrate pH, with all treatments ranging from 7.2 to 7.9; as such, no difference in plant growth occurred across these pH treatments. 2020 showed similar results for canopy measurements, pH and EC data. Harvestable yield data demonstrated that type of fertilizer was not important, but rate was, with the higher rate of fertilizer increasing fruit

count and total weight. Based on this data, blueberry plant growth can be expected to be similar using conventional or organic fertilization methods and amendments intended to adjust pH may not be necessary in container production using soilless substrate.

## Introduction

First brought into cultivation just over 100 years ago, blueberry is an important horticultural food crop. The first cultivars were bred by Frederick Coville and Elizabeth White in the early 1900's. Together they released several new blueberry cultivars, many of which are still grown today (Mainland and Ehlenfeldt, 2017). Starting in New Jersey in the early 1920s, blueberry production quickly spread to Michigan, North Carolina, and Washington. By 1949 there was a combined 3,393 acres of cultivated blueberry production across these four states according to the U.S. Bureau of Census (Mainland and Ehlenfeldt, 2017).

Cultivated blueberries today are a high-value crop that generated $908.7 million in the US fresh and processed berry market 2019 (USDA, 2020). In the United States, blueberry shrubs are typically produced in-ground along the eastern seaboard from Maine to Florida, inland to Michigan, and in the Pacific Northwest and California. Despite high soil pH, a small number of diversified farms in the Midwest also produce blueberries, often by modifying the soil with peat and pH-lowering amendments. Blueberry is known to prefer acidic growing conditions (pH of 4.3 to 5.0; Webb, 1981) and low salt with an electrical conductivity (EC) of less than 3.0 $dS \cdot m^{-1}$-1 (Bryla and Machado, 2011). Growing this crop in-ground in the Midwest would require growers to reduce the pH of the alkaline native soil by significantly amending the soil, often with elemental sulfur or iron sulfate. To optimize the root zone conditions, blueberries could be grown in containers in protected, or even controlled, environment culture.

High tunnels are protected environment structures, unheated and generally covered with clear, plastic film, which offer crop protection which is intermediate between open field and greenhouse production (hightunels.org, 2010). These structures can be beneficial for season extension, wind reduction, light intensity reduction, and reduced crop damage from extreme environmental events (Lamont, 2005; Millner et al., 2009). High tunnels can also be preferable compared to controlled-environment structures due to their lower financial barrier to entry as they cost only $0.50 per square foot to install compared to as much as $20 per square foot for a Quonset or greenhouse (hightunels.org, 2010). Most high tunnels are commonly used in Asia accounting for approximately 75% of the total worldwide high tunnel production (Papadopoulos and Demers, 2003). Just under 3% of the total high tunnel acreage is found in the Americas.

China has demonstrated a high potential for blueberry yield using high tunnels. In 2015, growers in China produced 43,244 tons of blueberries on 31,210 ha in field production. In the same year, Chinese growers produced 6,030 tons of blueberries over 1,165 ha of high tunnels. This was an increase over field production from 1.39 to 5.18 tons per ha (Li et al., 2017). In contrast, in 2009, ~ 40 ha of blueberries were reported to be produced in high tunnels in Oregon (Demchak, 2009) which suggests that there is a significant potential for an increase in production area. High tunnel blueberry production has been gaining momentum in the US in locations such as Florida and Arkansas (FGN, 2017; Giles, 2019; Moran, 2015). While high tunnels may be able to improve yield, more important is the increase in “reliability of production" (Demchak, 2009).

Growing in high tunnels using containerized production with soilless substrates can reduce the need for soil amendments. This production method can also increase water-use efficiency, reduce soil compaction and erosion, and reduce weed competition (Lamont, 1993).

Additionally, high tunnels can protect crops from excessive rain which can lead to poor fruit quality and mold development (Ishikawa and Sugawara, 1993). With recent increases of interest regarding soilless culture (Voogt et al, 2014), some growers may prefer an organic option as organic blueberries can demand a 20 to 100% price premium (Strik, 2014). Consumers have also indicated that having an organic option is important to them (Griffin & Frongillo, 2003; Hunt, 2007; Kremen et al., 2004). Currently, there are many high tunnels internationally which use compost, manure, etc. to accomplish organic production (Lamont 2009). A comparison of rates of organic and conventional fertilizer and pH amendment strategies is necessary to better inform growers of their options.

The overall objectives of this research were to evaluate containerized blueberry production in the protected environment of a high tunnel in the Midwest. Using growth and yield metrics, we specifically 1) assessed the effects of the two types of fertilizer on growth and substrate chemical properties, 2) narrowed the optimal rate at which to apply these fertilizers, and 3) determined the need for pH amendments with alkaline water source.

## Materials and Methods

The experiment had a 3-way factorial treatment structure with two slow-release fertilizers (the conventional Osmocote® and the organic Holly-tone®), two application rates (low and high), and three amendments to adjust pH (none, elemental sulfur, and iron sulfate).

### *Plant growth and production cycle*

On March 26, 2018, we received 103 one-year, rooted liners of *Vaccinium corymbosum* X *angustifolium* 'Northland' (Stokes Blueberry Farm and Nursery, Grand Junction, MI, USA) measuring 17 to 30cm (7 to 12 in) tall. We chose 'Northland' for this study due to its potential for rhizomatous growth, stature of 1 to 1.5 m, early flowering, relatively high fruit yield, and cold hardiness (Gauthier and Kaiser, 2013; Johnston and Moulton, 1968; Moore, 1993; Nelson, 1985; Siefker and Hancock, 1986). These rooted liners were transplanted into 16.5cm black plastic azalea pots (1,930cm$^3$) (Pöppelmann Plastics USA LLC, Claremont, NC, USA) filled with a Pro-Moss Sphagnum Peat Moss (Premier Tech Horticulture, Quakertown, PA, USA) substrate. On May 24, 2018, the plants were pruned to ~10 cm for consistency of size. Plants were maintained in the Throckmorton greenhouse facility at Kansas State University, Manhattan, KS, USA until their transport to the John C. Pair Horticulture Center Haysville, KS, USA on September 7, 2018 where they were maintained and overwintered in a cold frame.

On March 15, 2019, we transplanted 60 plants of similar quality into 3-gallon squat fabric pots (25.4cm tall X 25.4 cm wide; 11,356cm$^3$) (RootTrapper II 3S, RootMaker®, Huntsville, AL, USA) then placed them back into the cold frame structure. The substrate was 50% Pro-Moss Canadian sphagnum peat moss (Premier Tech Horticulture, Quakertown, PA, USA) : 50% perlite (Therm-O-Rock West Inc., Chandler, AZ, USA) amended pre-plant with: 3 $kg \cdot m^{-3}$ gypsum (Coarse USG Calcium Sulfate, USG Industrial & Specialty Solutions, Detroit, MI, USA), 0.3 $kg \cdot m^{-3}$ Epsom salts (Magriculture Magnesium Sulfate, Giles Chemical, Waynesville, NC, USA), and 0.45 $kg \cdot m^{-3}$ (Micromax Micronutrient, ICL Specialty Fertilizers, Summerville, SC, USA) (Merhaut, et al. 2018; Nelson, 2012).

On June 3, 2019, plants were moved into a 20 ft X 100 ft (6.1 m X 30.5 m) high tunnel where the experiment was carried out. Initial spacing was 1.5 m on center (Figure 3.1). Due to some plant loss, spacing was increased uniformly. At the end of the second year of the study, space was ~2m on center. The plants remained in the high tunnel under 50% shade cloth for the duration of the growing season. Plants were moved back to the cold frame structure to overwinter. At first budbreak, the plants were again placed in the high tunnel for the 2020 growing season on March 27, 2020.

During 2019 plants were irrigated using pressure compensated drip emitters (Netafim Woodpecker Pressure Compensating Junior, Netafim, Fresno, CA, USA), but due to systemic issues of clogged emitters, plants were hand-watered during the first half of 2020. After cleaning the irrigation system, the plants were again irrigated with the drip system. Plants received water as needed using local well-water (Table 3.1)

### *Fertilizer amendments*

Two rates of two slow release fertilizer formulations were used in this study. Fertilizers were applied at 0.6 g N·pot$^{-1}$ (low) or 1.8 g N·pot$^{-1}$ (high) as a top-dress. These rates were determined by literature and manufacturer's suggested label rates (Merhaut, et al. 2018; Nelson, 2012). The commercially available slow-release fertilizers employed were an organic [Espoma Organic® Holly-tone® 4-3-4 (4.0N-1.3P-3.3K), The Espoma Company, MillVille, NJ, USA] and a conventional [Osmocote® Plus 15-9-12 (15.0N-3.9P-10.0K) 3-4-month, ICL Specialty Fertilizers, Summerville, SC, USA]  product. We applied the fertilizer treatments twice during each growing season. In 2019, the first application was April 12 [29 days after transplanting (DAT)] as root growth was occurring, and June 3 (81 DAT) during the peak vegetative growth period. In 2020 applications were made on March 27 and June 26 (379 DAT and 470 DAT, respectively).

### *pH amendments*

An organic and a conventional product were employed to reduce rootzone pH. Efficacy of both were compared to a non-treated control which received no pH amendment. The organic pH amendment strategy was a top-dress application of elemental sulfur (Montana Sulphur, Billings, MT, USA) at a 1X rate of 17 g·pot$^{-1}$. The conventional strategy was a liquid-formula drench of iron sulfate (Ferrous Sulfate Heptahydrate 20%, Diamond Brand®, Verdesian NUE™, Cary, NC, USA) at a 1X rate of 0.3 g·L$^{-1}$ applied per container. Initial rates (1X) were determined to achieve a 2.0 pH reduction for the volume of substrate (Nelson, 2012). The second application in 2019 was doubled (2X) to improve the effect. Two pH amendment applications were made in 2019. The first occurred on June 14 (91 DAT) after first observations of foliar chlorosis, and the second occurred on July 19 (126 DAT) after pour-through data indicated insufficient substrate pH decrease. In 2020 applications were made at a 2X rate on March 27 (379 DAT), April 27 (410 DAT), May 27 (440 DAT), June 26 (470 DAT), and July 27 (500 DAT).

### *Data collected*

We compared environmental data within the high tunnel to the ambient data (Kansas Mesonet, 2017) using a HOBO Temperature/RH Data Logger (HOBO MX2301; Onset Computer Corporation, Bourne, MA, USA) and a HOBO Pendant® MX Temperature/Light Data Logger (HOBO MX2202).

Data collected during 2019 included canopy height, 2-axis spread, and rootzone pH and EC. In 2020 we added fruit fresh weight as total yield (g of fruit per bush), quantity of fruit per bush, and sugar content % total soluble solids (TSS) measured as $^{o}$Brix. At the end of 2020 a destructive harvest occurred to acquire canopy fresh and dry weights. Leaf greenness readings were also collected at this time.

Canopy measurements were collected from the top of the rooting medium to the highest visible growing point. Canopy width measurements were the average of two horizontal measurements perpendicular to each other that intersected at the base of the plant (Figure 3.2).

The pots were oriented the same direction for every measurement instance to improve consistency. These measurements can be converted to a growth index. Pour-through data was collected by first irrigating each pot to container capacity and letting all free water drain from the substrate (approx. 30 to 60 min). Pots were  then placed a standard solid-bottom 1020 flat and 800mL of reverse osmosis water was applied to the top of the growing medium. Displaced water was then collected in pre-labeled vials and held in a refrigeration unit prior to determining pH and EC (Accumet® XL20, ThermoFisher Scientific, Waltham, MA, USA) (Figure 3.3).

In 2019, canopy measurements, and rootzone pH and EC were collected on June 3, July 5, August 6, September 12, and October 12. In 2020 rootzone pH and EC were collected on March 27, April 27, May 27, June 26, July 27, and August 28 and canopy measurements occurred on June 26, and August 28.

Berry harvest began on June 1, and berries were collected weekly until July 6. Only ripe berries were harvested. Marketable berries were retained for data collection while unmarketable berries were discarded (Figure 3.4). Fruit was placed in a labeled paper bag until it was counted and weighed later the same day. TSS was determined using a hand-held refractometer (Digital Refractometer for Brix Measurements, Hanna instruments, Smithfield, RI, USA).

For destructive harvest, plant canopies were removed at the substrate surface, placed in pre-labeled bags, then immediately weighed for fresh weight. These bags were then placed in a drying oven for seven days at 65°C when they were then removed and weighed for canopy dry weight. During the 2020 final data collection, relative foliar chlorophyll content was measured using a SPAD meter (SPAD 502Plus Chlorophyll meter, Konica Minolta Inc, N.J., USA).

Data was subjected to ANOVA and means were separated by LSD using RStudio 1.1.463 (RStudio: Integrated Development for R. RStudio, Inc., Boston, MA, USA).

# Results and Discussion

## *Environmental data*

The high tunnel offered significant protection to the blueberries during both years. Despite the typically higher winds common in central Kansas, plant blow-overs were minimal. During 2019, atypically high rain incidence caused flooding throughout much of the central US; the plants in the high tunnel were unaffected by the increased rain incidence which could cause over-watering damage to in-ground plants (Figure 3.5). Bees were seen regularly visiting flowers; this suggested that the structure did not appear to reduce their interest in or access to the flowers. Netting was also placed over each end of the high tunnel to reduce potential herbivory from birds and deer. However, this may have led to an increase in insect feeding damage due to the lack of natural bird control, but fruit loss from insect pests was not substantial. The average maximum temperature within the high tunnel structure was ~4°C warmer than the external temperature (23.9 and 19.3°C respectively). The average minimum temperature was the same internal and external at ~6.6°C. The average internal relative humidity was ~23% more humid than external (93.0 and 70.7% respectively) (Figure 3.6).

## *Growth data*

The main effects of fertilizer source and rate influenced some aspects of plant growth, however, there was no interaction detected. Osmocote® resulted in greater fresh and dry weights compared to Holly-tone® (Table 3.2). However, height and average spread were not different based on fertilizer source (Table 3.3). The higher rate of 1.8g N per 3gal pot resulted in approximately double fresh and dry weight compared to the lower rate of 0.6 g N per 3gal pot, regardless of source (Table 3.2). Height and average spread data show that by October 2019, the higher rate of fertilizer resulted in growth that surpassed the low rate (Table 3.3). Visible growth differences can be seen in Figure 3.7.

An interaction between the main effects was observed for SPAD readings. Plants fertilized with Osmocote® had higher SPAD values than those fertilized with Holly-tone®, suggesting plants fertilized with conventional Osmocote® had more chlorophyll. Interestingly, the low application rate of Osmocote® produced greener foliage (highest SPAD values) than other treatments, while a low rate of Holly-tone® produced the least green foliage (lowest SPAD values). High rates of both fertilizers fell in between.

Elemental sulfur applications had no impact on plant growth during 2019, but the increased application rate and frequency during 2020 caused near complete crop loss. This treatment resulted in high EC (over 10 $dS \cdot m^{-1}$) and low pH (~ 2.0) which ultimately contributed to plant death; for this reason, this treatment was removed from statistical analysis for 2020. "Previous application of $S^o$ may increase oxidation rates in many soils, presumably by stimulating $S^o$ oxidizing populations." (Germida and Janzen, 1993). This supports the hypothesis that due to the increased frequency and increased rate of elemental sulfur application the plants were damaged by the significant pH decrease due to the increased oxidation rates of the elemental sulfur.

The iron sulfate pH amendment marginally increased fresh and dry weight biomass compared to no pH amendment (Table 3.2, significant in ANOVA, but not in LSD) but did not increase height or spread measurements (Table 3.3) or SPAD readings. The iron sulfate treatment may have caused more shoot proliferation, larger foliage, or larger stem diameters which may have increased weight. While rate of fertilizer and pH amendment individually did not have an effect on SPAD readings, an interaction was detected. Iron sulfate with fertilizer (high or low rate) produced similar relative chlorophyll content. Lowest chlorophyll content was detected with a low rate of fertilizer and no pH adjustment (Table 3.2). During 2020, the iron sulfate pH amendment with a high rate of fertilizer produced significantly taller plants, but not wider plants (Table 3.3).

### *Fruit yield data*

Harvest began on June 1, 2020 and concluded on July 2, 2020. Moving the plants into the high tunnel sooner, or over-wintering in the high tunnel may speed-up the production cycle. Aside from berry sugar content, type of fertilizer did not affect fruit yield. Osmocote® at a high rate produced berries with the highest TSS content with no difference between the three other fertilizer * rate combinations (Table 3.4). However, the main effect of fertilizer rate did effect yield. Higher fertilizer rates increased yield by over 200g per plant and increased the average weight per berry (Table 3.4). The higher rate also contributed to higher TSS in berries. Rate of fertilizer had a significant effect on growth (Table 3.3) which likely contributed to the improved yield.

Plants with no pH amendment had the same fruit yield when compared to iron sulfate (Table 3.4). Additionally, the average weight per berry was the same between the two treatments. Yield was increased when using iron sulfate at a high rate of fertilizer. This may be due to the increase in available iron. Similar results were found when iron sulfate and zinc sulfate were applied to *Citrus limmetta* (Aboutalebi1 and Hassanzadeh, 2013). Additionally, no pH amendment with a low rate of fertilizer yielded the least sweet berries. While the iron sulfate treatments increased overall yield, the no pH amendment group with a high rate of Osmocote® produced the berries with highest soluble solids overall.

A brief analysis of other research involving the yield of 'Northland' showed that the yield in this experiment was relatively low (Table 3.5). Compared to these other experiments collecting harvest data for 3 y or more, the duration of this experiment was very short. Additionally, the plants used in this experiment were in their third year of growth when yield was recorded and only their second year in these containers. In the other experiments, plants had been growing in the ground for at least three years before fruiting was studied. Fruit yield results from other high tunnel research involving in-ground plants of a similar age showed slightly lower yield than was found in this experiment. This suggests that the low yield was not necessarily due to containerized production, but in fact the age of the plants (Ogden and van Iersel, 2009, Table A.1). Further research into yield over longer time in containerized production could determine if yield can be increased in containerized production to match levels found in field production.

Research within a greenhouse in Volcano, Hawai'i involving container size also suggested that 3-gal containers would produce less fruit than larger containers with their research showing 10-gal containers to improve yield from 115 to 161 g of fruit per plant respectively (Motomura et al. 2016). With an increased duration, transplanting from the 3-gal bags used in this research into larger 10-gal bags may further increase yield.

### *Substrate pH/EC*

For both 2019 and 2020, fertilizer source had no meaningful effect on the pH of the substrate (Table 3.6, Table 3.7). Rate of fertilizer affected pH during the first part of the 2019 season, but due to the increasing pH from the highly alkaline irrigation water, effect of rate and type of fertilizer on pH was diminished over time.

Through the 2019 growing season, pH was consistent between no pH amendment and iron sulfate treatments, but towards the end of 2019, pH in the elemental sulfur treatment started to drop lower than for other treatments (Table 3.6, Table 3.7). In 2020, the pH for no amendment and iron sulfate was comparable, though the pH in iron sulfate stayed slightly higher (Table 3.7; Figure 3.8). Many of the plants in the elemental sulfur treatment were dead after the second measurement resulting in removal of that treatment from further analysis. The pH in no amendment and iron sulfate remained between 7.6 and 8.1, whereas elemental sulfur dropped from 7.3 at the end of 2019 down to below 3.0 by April 2020. Perhaps due to the less regular application of pH amendments during 2019 the leachate results were inconsistent between samples. In 2020 the trends in EC became more distinct where iron sulfate and no amendment were equal, and elemental sulfur spiked from 1.8 $dS \cdot m^{-1}$ at the end of 2019 to 4.1 $dS \cdot m^{-1}$ after the first application of 2020. The EC for elemental sulfur eventually exceeded 10.0 $dS \cdot m^{-1}$ by the end of 2020. The high EC and low pH are likely the reason for the great decline in these plants.

Local irrigation water had high alkalinity (Table 3.1). This is potentially an issue as the high alkalinity will reduce the rooting medium's ability to resist pH change. Therefore, it is likely that the pH amendments were unable to mitigate the effects of high alkalinity over time. Additionally, some EC readings in 2020 were as low as 1.3 $dS \cdot m^{-1}$. The EC of the local water was 1.06 $dS \cdot m^{-1}$. This suggests that the plants could have been fertilized more frequently or the rates of fertilizer could have been increased.

In a substrate that has very little buffering capacity, such as sphagnum peat, maintaining a pH of 4.5 may not be necessary. Plants in Ericaceae are well known to thrive in lower pH substrates. Research also suggests that blueberries can thrive with pH as low as 4.0 (Smagula and Litten, 2003). However, it has been suggested that blueberries may not actually need pH 4.3 to

5.0 to grow and yield well (Webb, 1981). Webb carried out trials with containerized blueberries in field soil grown between pH 3.8 and 6.0 in greenhouse conditions and noted that there was no difference in growth, though Webb mentioned the need for further trials. During 2020 the no amendment treatment steadily increased its pH from 7.6 to 8.1 and the iron sulfate increased from 7.9 to 8.2 over the growing season. Despite iron not being readily available, there was little difference in SPAD readings suggesting equivalent chlorophyll content between the two treatments. While we cannot compare yield and plant performance between low to high pH, as our results were in the high range, we can report that adequate growth and yield occurred for these plants.

## Conclusions

Fertilizer applied at a rate of 1.8 g N per 3-gal container produced larger plants and higher fruit yield than 0.6g N from either Holly-tone® or Osmocote® slow release fertilizers. The rate of fertilizer had a greater effect than type of fertilizer which had nearly no measurable effect on canopy size. However, Osmocote® generated more biomass within approximately the same canopy area. The conventional Osmocote® produced sweeter berries over the organic Holly-tone®, though the relatively minor difference may not be noticeable to consumers.

Blueberries can be grown in peat-based substrates without any pH amendments, but more research into rates of pH amendments is needed as a low, “optimal” pH of ~4.5 was not achieved in our research. This experiment resulted in acceptable plant growth and yield when substrate pH was in the 7.0 to 8.0 range, but optimal substrate pH could improve growth and yield. The pH treatments did not affect yield. Elemental sulfur may be a viable organic option to reduce substrate pH, but further experimentation with rates and timing of application should be conducted. In the current study, plants treated with elemental sulfur all had an EC of above 4.0 $dS \cdot m^{-1}$ and died.

The plants in this experiment were destructively harvested after their second growing year in the high tunnel. To have a more complete dataset, a longer experiment should be conducted. Achieving a maximum yield of 0.63 kg per plant after only two years suggests that containerized blueberry production has potential for use in high tunnels as a crop for diversified farms. Adding this as a "You-Pick" feature into a farm could help increase exposure and community interaction with relatively low input. Other observations about the benefits of high tunnels include minimal bird damage; adequate pollination from naturally occurring pollinators; protection from heavy rains and blow-overs in Kansas winds.

These benefits demonstrated by this research for containerized blueberry production in the Midwest support the potential for including blueberry in product mixes of diversified farms in our region.

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# Figures and Tables

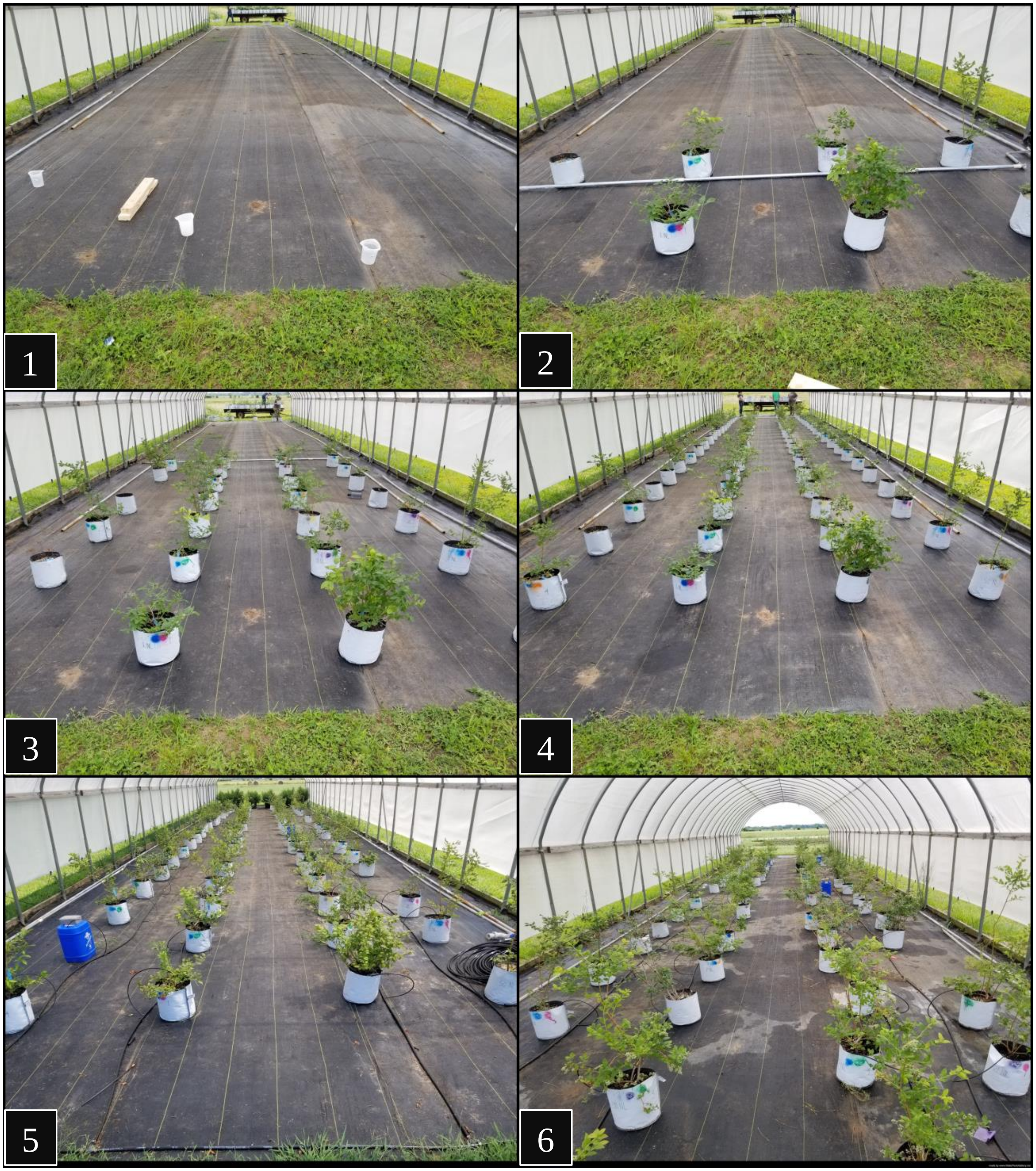


**Figure 3.1. Progression of high tunnel layout and subsequent plant growth. Images 1 to 4 are from initial installation on June 3, 2019; image 5 is from Aug. 6, 2019 near the end of the first season; and image 6 is from May 27, 2020 during peak growing in the second season.**

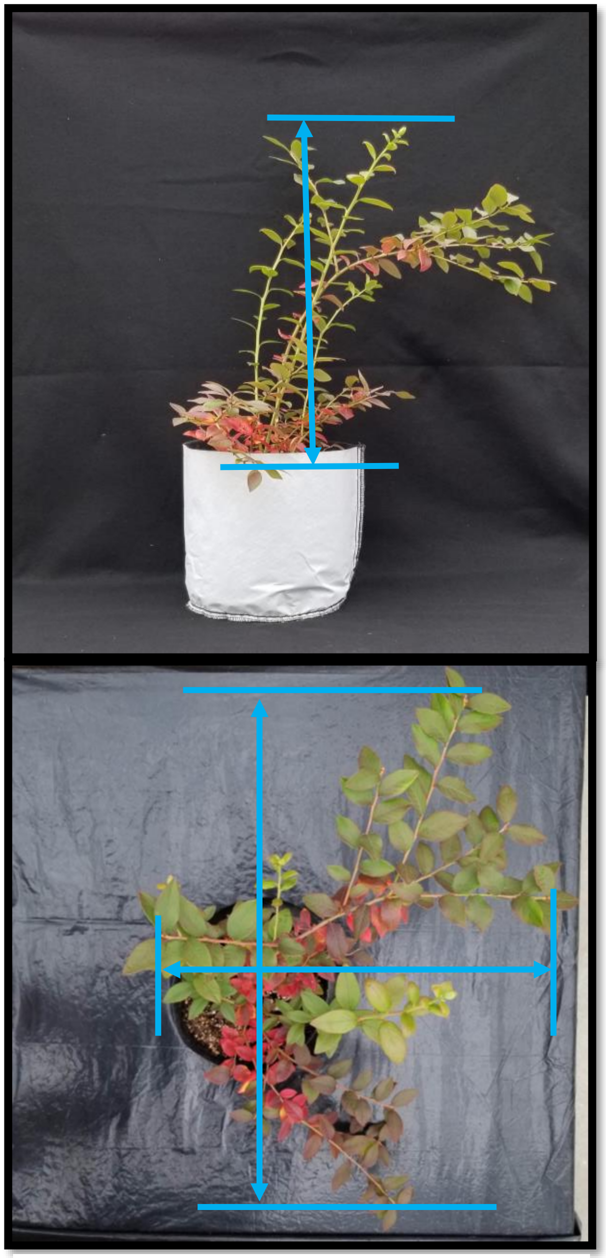

**Figure 3.2. Measurement points for height (top) and 2-axis spread (bottom) canopy measurements.**

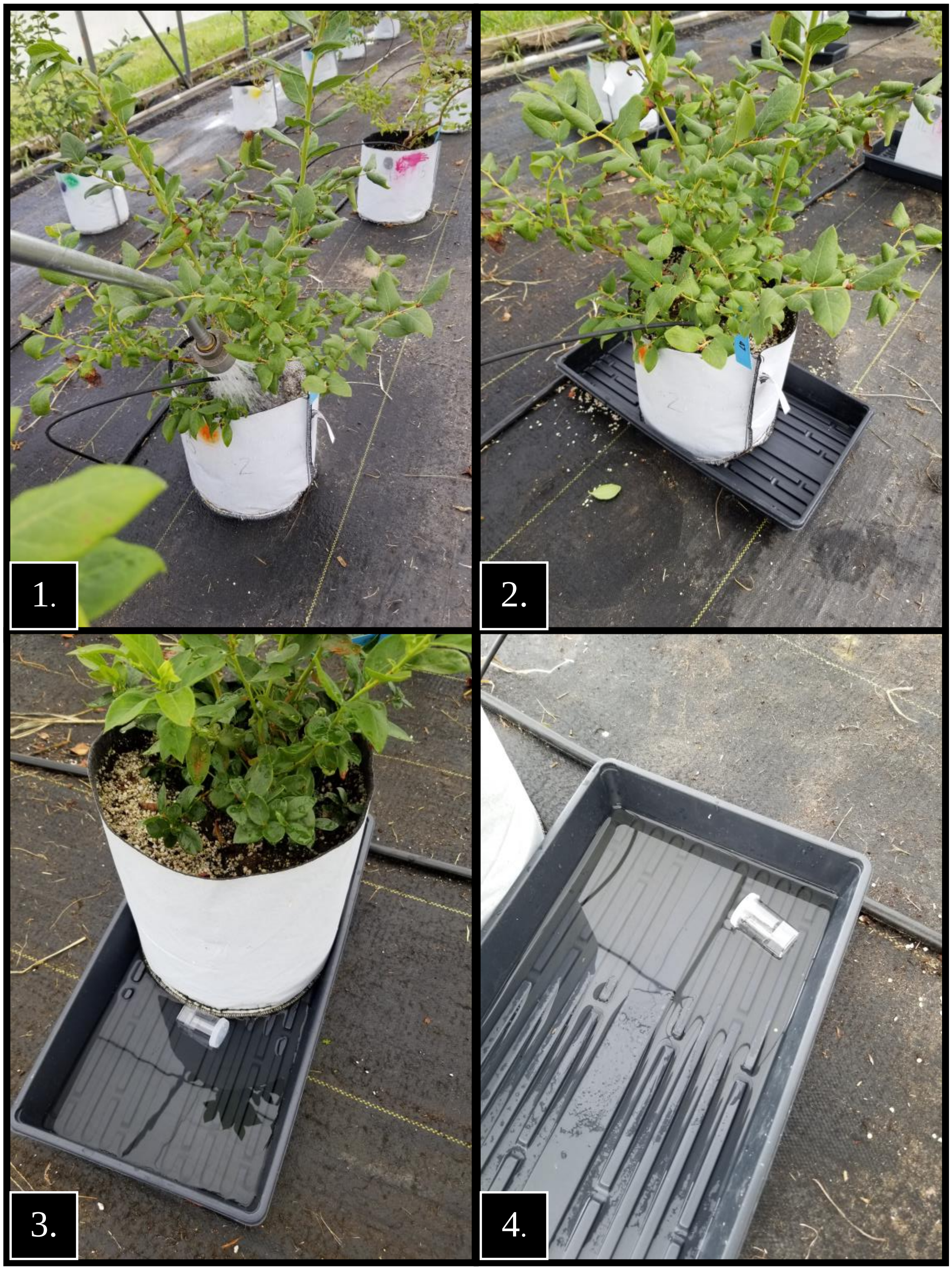


**Figure 3.3. Process of collecting pour through leachate. 1. Pots are irrigated to container capacity. 2. After 30 to 60 min pots are moved onto solid flats. 3. 800 mL of RO water is applied to the surface to displace solubilized salts. 4. Displaced leachate is collected in a labeled vial.**

**Figure 3.4: Example of harvested, but rejected, non-marketable blueberries grown in a high tunnel. Berries are rejected due to (from left to right) ripeness, insect damage, harvest damage, insect damage, insect damage, and over-ripeness.**

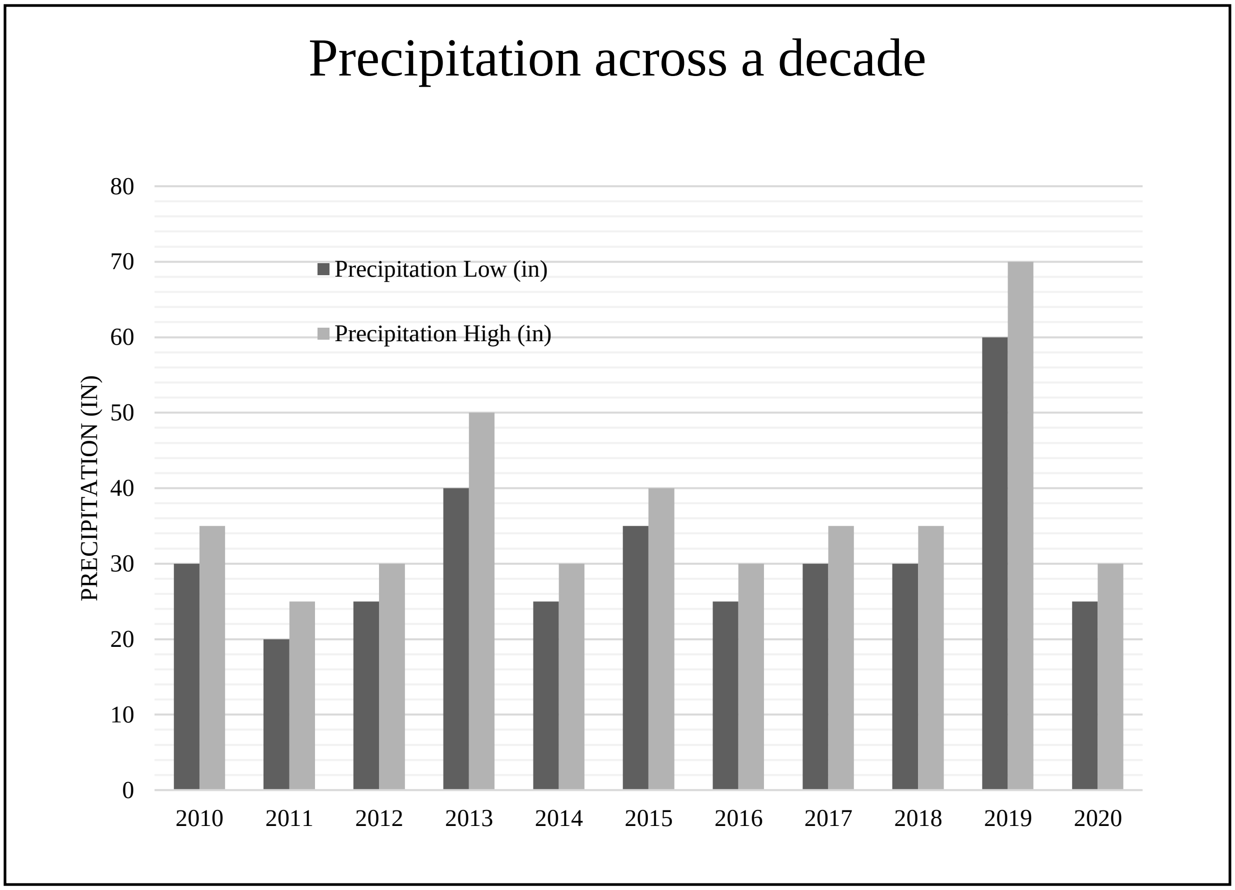


**Figure 3.5. Graph depicts precipitation trends in Haysville, KS from 2010 to 2020. The first year of this experiment occurred in 2019 which was also a year which experienced extreme rain events causing mass flooding across the Mid-west US (NOAA, 2020).**

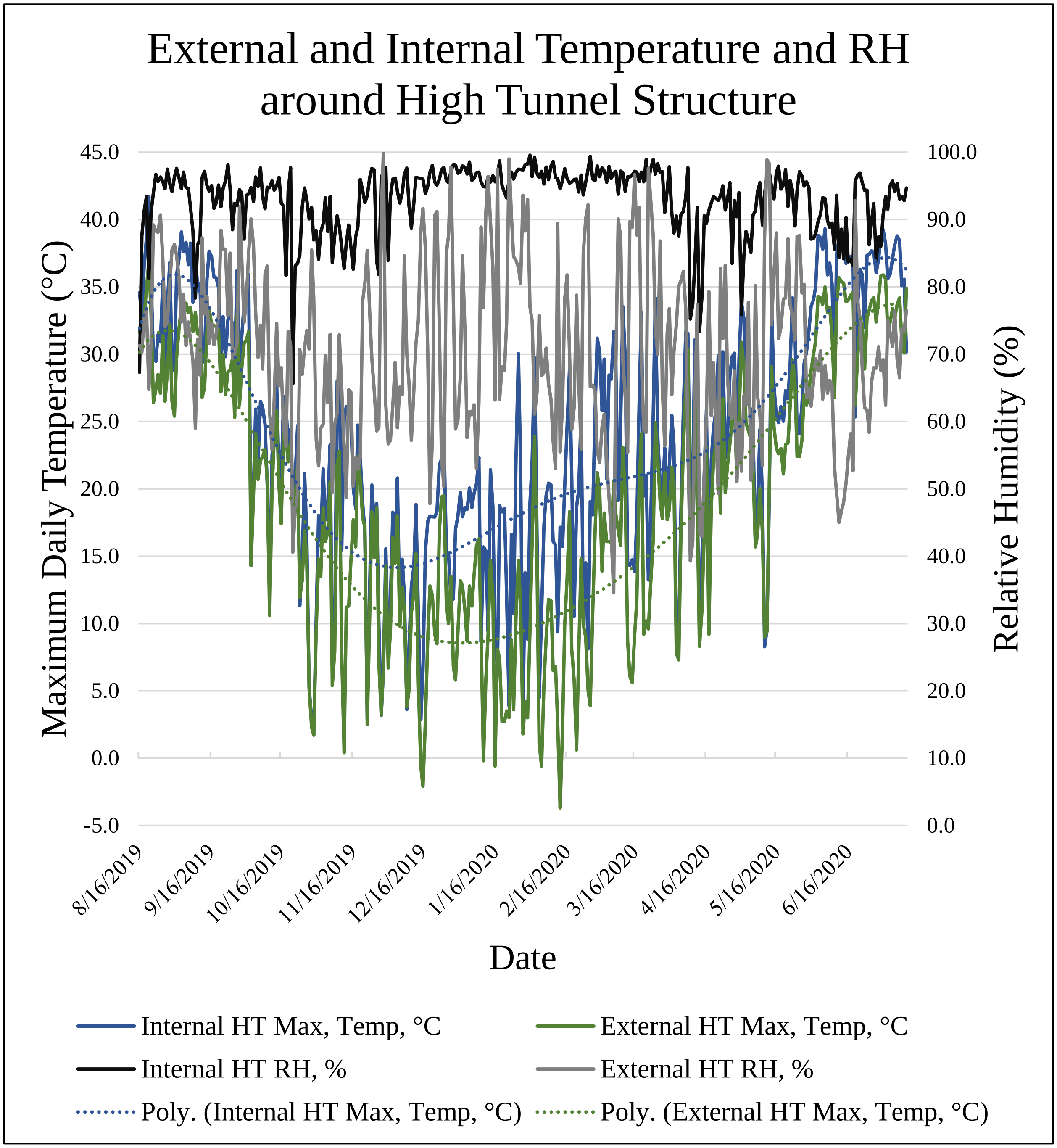


**Figure 3.6. Graph of average maximum temperature and relative humidity measured inside and outside the high tunnel. External temperature data collected from on-sight weather station data (Kansas Mesonet, 2017). 6-order polynomial line generated in Microsoft Excel as trendline.**

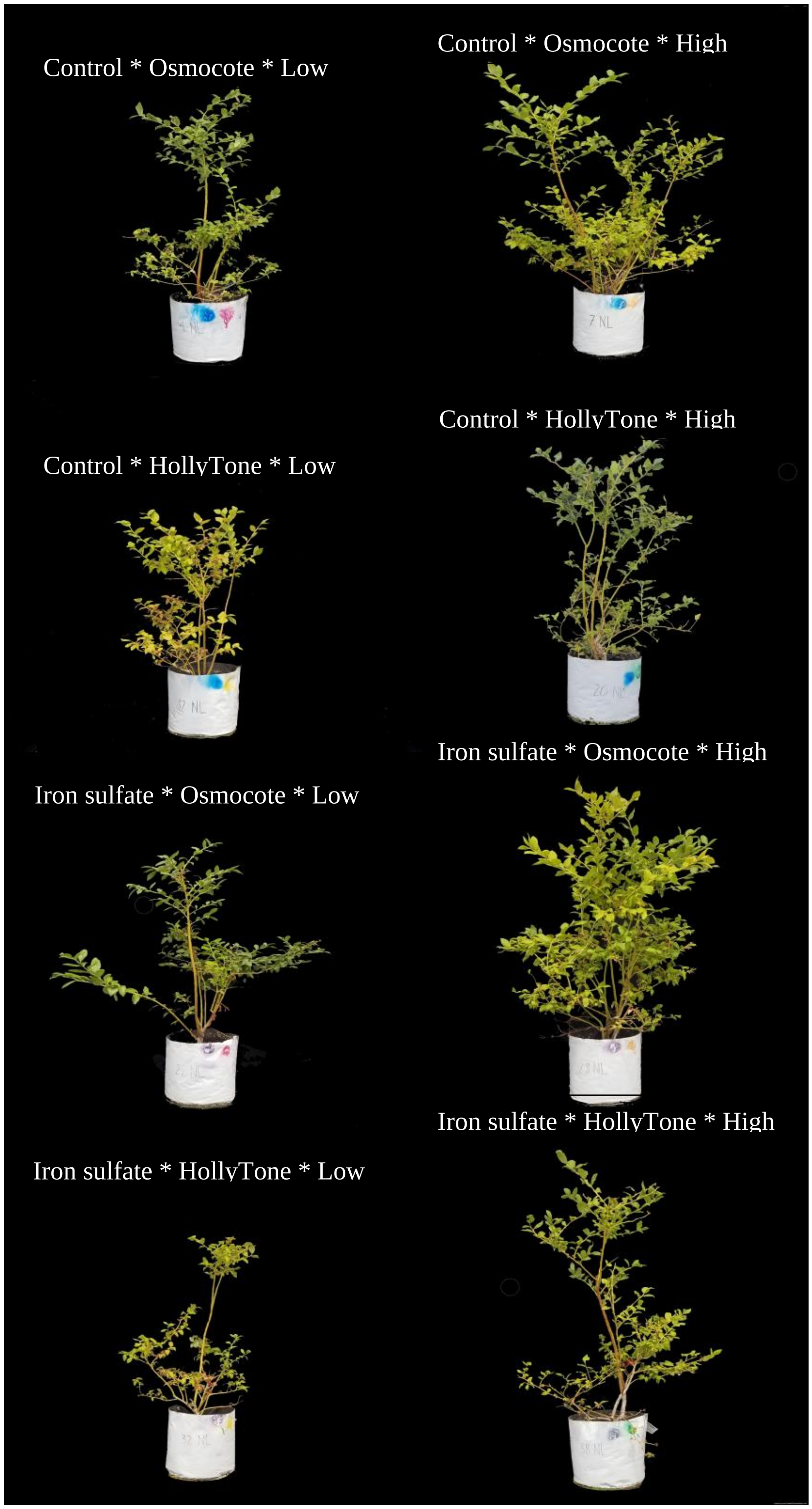


**Figure 3.7. Representative plants from each treatment. Images were taken from a set distance and height and were processed for consistent size, positioning, and to achieve a black background. Elemental sulfur is not pictured.**

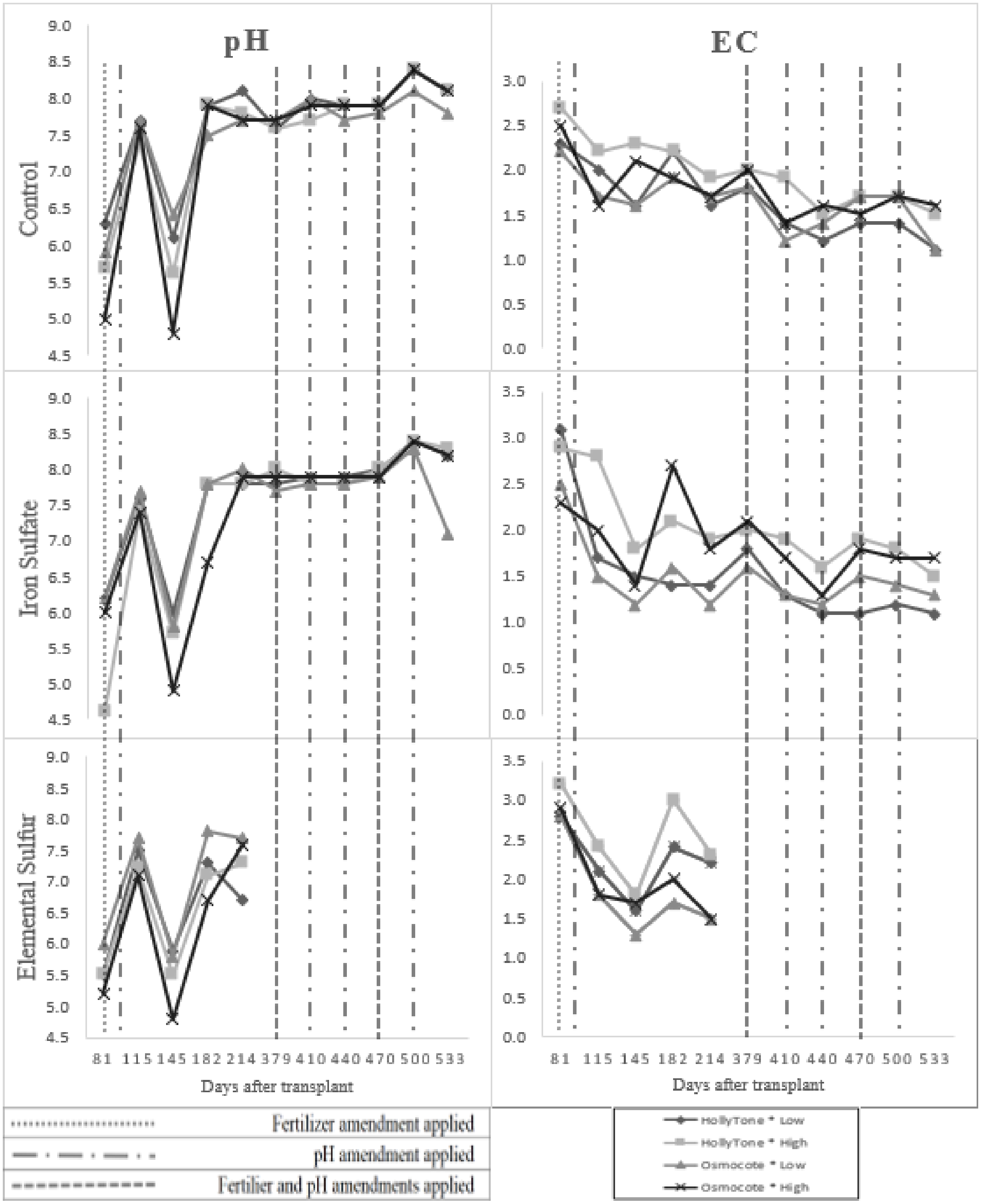


**Figure 3.8. Graphs of pour-through leachate pH and EC (dS·m$^{-1}$) over the duration of this experiment. Leachate data was taken every ~30 days during the both growing seasons. Elemental sulfur data ends at 214 DAT as the plants were removed from the study. The vertical lines are to indicate amendment application time.**

**Table 3.1. Irrigation water analysis of John C. Pair Horticulture Center, Haysville, KS. Test results from Hoch (2018); desired ranges from Merhaut et al. (2018).**

| Characteristic | Actual Level | Desired Level | Upper Limit |
|---|---|---|---|
| pH | 7.45 | 5.4 to 6.8 | 7.0 |
| Hardness ($CaCO_3$ equivalent) | 396.63 | < 100 ppm | 150 ppm |
| Conductivity | 1.06 $dS \cdot m^{-1}$ | 0.2 to 0.5 $dS \cdot m^{-1}$ | 1.5 $dS \cdot m^{-1}$ |
| Total dissolved solids | 677.76 ppm | 128 to 320 ppm | 960 ppm |
| Calcium | 130.2 ppm | < 60 ppm | 120 ppm |
| Iron | 1.16 ppm | < 1 ppm | 5 ppm |
| Total alkalinity ($CaCO_3$ equivalent) | 270.13 ppm | 46 to 65 ppm | 150 ppm |
| Bicarbonate | 329.61 | 40 to 65 ppm | 122 ppm |

**Table 3.2. Data from the destructive harvest (August 27, 2020) which includes SPAD, and canopy fresh and dry weights. SPAD data was collected using a Minolta 502Plus Chlorophyll meter. Fresh and dry weights were collected by removing the canopy at the top of the substrate, placing it in labeled bags and immediately weighing the canopy. They were then placed in a drying oven at 65°C for 7 days. The bags were then removed and weighed.**

| Treatment | SPAD | Fresh Weight | Dry Weight |
|---|---|---|---|
| pH | | | |
| Control | 36.2 | 209 | 112 |
| Iron Sulfate | 35.1 | 244 | 130 |
| $LSD_{0.05}$[z] | NS | 60.8 | 32.8 |
| Fertilizer | | | |
| Holly-tone® | 33.1[b] | 189[b] | 101[b] |
| Osmocote® | 38.1[a] | 264[a] | 141[a] |
| $LSD_{0.05}$ | 3.38 | 56.9 | 30.7 |
| Rate of Fertilizer (oF) | | | |
| Low | 34.9 | 158[b] | 84[b] |
| High | 36.4 | 295[a] | 158[a] |
| $LSD_{0.05}$ | NS | 42.6 | 22.6 |
| pH * Fertilizer | | | |
| Control * Holly-tone® | 34.2 | 180 | 96 |
| Control * Osmocote® | 38.1 | 238 | 128 |
| Iron Sulfate * Holly-tone® | 32.1 | 199 | 106 |
| Iron Sulfate * Osmocote® | 38.2 | 290 | 153 |
| $LSD_{0.05}$ | NS | NS | NS |
| pH * Rate oF | | | |
| Control * Low | 33.6[b] | 162[c] | 88[c] |
| Control * High | 38.8[a] | 255[b] | 135[b] |
| Iron Sulfate * Low | 36.2[ab] | 154[c] | 79[c] |
| Iron Sulfate * High | 34.0[ab] | 334[a] | 181[a] |
| $LSD_{0.05}$ | 5.09 | 55.9 | 29.0 |

| Fertilizer * Rate oF | | | |
|---|---|---|---|
| Holly-tone® * Low | 28.7[c] | 131 | 71 |
| Holly-tone® * High | 37.6[b] | 247 | 131 |
| Osmocote® * Low | 41.1[a] | 185 | 96 |
| Osmocote® * High | 35.2[b] | 342 | 185 |
| $LSD_{0.05}$ | 3.32 | NS | NS |

| Significance | | | |
|---|---|---|---|
| pH | NS | * | * |
| Fertilizer | *** | *** | *** |
| Rate oF | NS | *** | *** |
| pH * Fertilizer | NS | NS | NS |
| pH * Rate oF | *** | ** | ** |
| Fertilizer * Rate oF | *** | NS | NS |
| pH * Fertilizer * Rate oF | NS | NS | NS |

[z]LSD used to compare differences in means, minimum significant difference reported provided significant treatment interaction; significant at $p<0.05$.
NS, *, **, *** not significant, significant at $P\leq0.05$, significant at $P\leq0.01$, or significant at $P\leq0.001$ respectively; letter groups significant at $P\leq0.05$
Means in the same column followed by the same superscript letter are not significantly different.

**Table 3.3. Canopy measurements over time taken during the 2019 and 2020 growing seasons and the beginning, middle, and end of each year. The measurement for Oct. 12, 2019 is treated as both the end of 2019 and beginning of 2020 as negligible growth occurred.**

| Treatment | Height (cm) | | | | | Average Spread (cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2019 | | | 2020 | | 2019 | | | 2020 | |
| | June 3 | Aug. 8 | Oct. 12 | June 26 | Aug. 27 | June 3 | Aug. 8 | Oct. 12 | June 26 | Aug. 27 |
| pH | | | | | | | | | | |
| Control | 48 | 63 | 70 | 76 | 80 | 57 | 59 | 59 | 67 | 70 |
| Iron Sulfate | 47 | 64 | 70 | 79 | 83 | 56 | 62 | 62 | 69 | 74 |
| Elemental Sulfur | 44 | 58 | 75 | - | - | 55 | 62 | 61 | - | - |
| $LSD_{0.05}$[z] | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Fertilizer | | | | | | | | | | |
| Holly-tone® | 47 | 61 | 72 | 75 | 80 | 57 | 61 | 61 | 66 | 69 |
| Osmocote® | 45 | 63 | 72 | 79 | 83 | 55 | 61 | 60 | 70 | 75 |
| $LSD_{0.05}$ | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS[y] |
| Rate of Fertilizer (oF) | | | | | | | | | | |
| Low | 48 | 59 | 64[b] | 69[b] | 74[b] | 55 | 55[b] | 53[b] | 59[b] | 65[b] |
| High | 44 | 65 | 79[a] | 86[a] | 89[a] | 57 | 66[a] | 68[a] | 77[a] | 79[a] |
| $LSD_{0.05}$ | NS | NS[y] | 7.1 | 8.6 | 7.8 | NS | 5.7 | 5.6 | 6.9 | 7.3 |
| pH * Fertilizer | | | | | | | | | | |
| Control * Holly-tone® | 52 | 61 | 69 | 76 | 77 | 55 | 58 | 57 | 65 | 67 |
| Control * Osmocote® | 44 | 65 | 71 | 77 | 83 | 59 | 60 | 61 | 70 | 72 |
| Iron Sulfate * Holly-tone® | 46 | 65 | 74 | 77 | 83 | 57 | 62 | 63 | 68 | 70 |
| Iron Sulfate * Osmocote® | 48 | 63 | 75 | 81 | 83 | 55 | 61 | 60 | 71 | 78 |
| Elemental Sulfur * Holly-tone® | 44 | 57 | 72 | - | - | 58 | 62 | 63 | - | - |
| Elemental Sulfur * Osmocote® | 44 | 60 | 68 | - | - | 52 | 61 | 59 | - | - |
| $LSD_{0.05}$ | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| pH * Rate oF | | | | | | | | | | |
| Control * Low | 49 | 63 | 67 | 72[bc] | 79[bc] | 58 | 55 | 53 | 60 | 62 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Control * High | 48 | 62 | 74 | 79[b] | 81[b] | 57 | 62 | 65 | 75 | 77 |
| Iron Sulfate * Low | 52 | 57 | 62 | 65[c] | 70[c] | 52 | 54 | 51 | 58 | 67 |
| Iron Sulfate * High | 43 | 71 | 88 | 73[a] | 97[a] | 59 | 70 | 72 | 80 | 81 |
| Elemental Sulfur * Low | 44 | 56 | 65 | - | - | 56 | 57 | 56 | - | - |
| Elemental Sulfur * High | 43 | 50 | 75 | - | - | 54 | 66 | 66 | - | - |
| $LSD_{0.05}$ | NS | NS | NS[y] | 11.3 | 9.6 | NS | NS | NS | NS | NS |
| **Fertilizer * Rate oF** | | | | | | | | | | |
| Holly-tone® * Low | 52 | 58 | 62 | 68 | 71 | 57 | 58 | 56 | 58 | 63 |
| Holly-tone® * High | 43 | 64 | 72 | 83 | 89 | 57 | 64 | 66 | 74 | 74 |
| Osmocote® * Low | 45 | 60 | 67 | 70 | 77 | 54 | 53 | 50 | 59 | 66 |
| Osmocote® * High | 46 | 65 | 76 | 88 | 89 | 56 | 68 | 69 | 81 | 84 |
| $LSD_{0.05}$ | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| **Significance** | | | | | | | | | | |
| pH | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Fertilizer | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Rate oF | NS | NS | *** | *** | *** | NS | *** | *** | *** | *** |
| pH * Fertilizer | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| pH * Rate oF | NS | NS | NS | * | ** | NS | NS | NS | NS | NS |
| Fertilizer * Rate oF | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| pH * Fertilizer * Rate oF | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

[z]LSD used to compare differences in means, minimum significant difference reported provided significant treatment interaction; significant at $p<0.05$.
[y]LSD significant at $p<0.10$
NS, *, **, *** not significant, significant at $P\leq0.05$, significant at $P\leq0.01$, or significant at $P\leq0.001$ respectively; letter groups significant at $P\leq0.05$
Means in the same column followed by the same superscript letter are not significantly different.

**Table 3.4. Harvestable yield of high tunnel plants during 2020 growing season. Ripe berries were harvested one time per week. All salable fruit was counted and weighed, then a random sample of 5 fruit were selected for Brix analysis.**

| Treatment | Berries per plant | Weight (g) per plant | Weight (g) per berry | Average Brix |
|---|---|---|---|---|
| pH | | | | |
| Control | 485 | 411.5 | 0.85 | 11.9 |
| Iron Sulfate | 555 | 468.0 | 0.85 | 12.1 |
| $LSD_{0.05}$[z] | NS | NS | NS | NS |
| Fertilizer | | | | |
| Holly-tone® | 504 | 431.4 | 0.85 | 11.7[b] |
| Osmocote® | 536 | 448.1 | 0.86 | 12.3[a] |
| $LSD_{0.05}$ | NS | NS | NS | 0.45 |
| Rate of Fertilizer (oF) | | | | |
| Low | 402[b] | 324.7[b] | 0.83[b] | 11.8[b] |
| High | 638[a] | 554.8[a] | 0.88[a] | 12.2[a] |
| $LSD_{0.05}$ | 102.2 | 78.90 | 0.049 | 0.46 |
| pH * Rate oF | | | | |
| Control * Low | 432[bc] | 341.1[c] | 0.81 | 11.3[b] |
| Control * High | 539[b] | 482.0[b] | 0.90 | 12.5[a] |
| Iron Sulfate * Low | 373[c] | 307.4[c] | 0.85 | 12.1[a] |
| Iron Sulfate * High | 737[a] | 627.6[a] | 0.86 | 12.1[a] |
| $LSD_{0.05}$ | 131.4 | 103.16 | NS | 0.63 |
| Fertilizer * Rate oF | | | | |
| Holly-tone® * Low | 362 | 298.8 | 0.84 | 11.8[b] |
| Holly-tone® * High | 646 | 564.0 | 0.88 | 11.5[b] |
| Osmocote® * Low | 443 | 350.6 | 0.81 | 11.8[b] |
| Osmocote® * High | 630 | 545.6 | 0.88 | 12.9[a] |
| $LSD_{0.05}$ | NS | NS | NS | 0.61 |
| pH * Fertilizer * Rate oF | | | | |

| | | | | |
|---|---|---|---|---|
| Control * Holly-tone® * Low | 369 | 304.9 | 0.85 | 11.6[bcd] |
| Control * Holly-tone® * High | 595 | 519.4 | 0.88 | 10.9[d] |
| Control * Osmocote® * Low | 494 | 377.2 | 0.77 | 11.3[cd] |
| Control * Osmocote® * High | 482 | 444.5 | 0.92 | 13.7[a] |
| Iron Sulfate * Holly-tone® * Low | 355 | 393.7 | 0.84 | 12.0[bc] |
| Iron Sulfate * Holly-tone® * High | 696 | 608.6 | 0.87 | 12.1[b] |
| Iron Sulfate * Osmocote® * Low | 392 | 324.1 | 0.86 | 12.1[b] |
| Iron Sulfate * Osmocote® * High | 777 | 646.7 | 0.84 | 12.2[b] |
| $LSD_{0.05}$ | NS | NS | NS[y] | 0.77 |
| **Significance** | | | | |
| pH | NS | NS | NS | NS |
| Fertilizer | NS | NS | NS | ** |
| Rate oF | *** | *** | * | * |
| pH * Fertilizer | NS | NS | NS | ** |
| pH * Rate oF | ** | * | NS | * |
| Fertilizer * Rate oF | NS | NS | NS | *** |
| pH * Fertilizer * Rate oF | NS | NS | NS | *** |

[z]LSD used to compare differences in means, minimum significant difference reported provided significant treatment interaction; significant at p<0.05.
NS, *, **, *** not significant, significant at P≤0.05, significant at P≤0.01, or significant at P≤0.001 respectively; letter groups significant at P≤0.05
Means in the same column followed by the same superscript letter are not significantly different.

**Table 3.5. Result of fruit yield reported in literature from research that included 'Northland'. Yield [kg per bush] comes from the findings within each experiment; the numbers in parenthesis are the range of fruit yield within each experiment. Year range is the span of the experiment and Year plants started shows the age of the plants in the experiment.**

| Group: | Yield [kg per bush] | Years of study | Year plants started |
|---|---|---|---|
| Kühn, 1991 | 0.25 | 1987:1990 | 1986 |
| MacKenzie, 1997 | 0.07 | 1990:1991 | Unknown |
| Nelson, 1985 | 2.77 (1.1 – 4.56) | 1969:1983 | 1966 |
| Pavlovski, 2010 | 2.00 (0.2 – 5.0) | 1993:2009 | 1988 |
| Siefker. 1986 | 2.83 | 1969:1981 | 1966 |
| Šterne et al., 2011 | 1.60 | 2008:2010 | 2001 |
| Wach, 2008 | 2.13 (0.83 – 2.68) | 1996:1999 | 1993 |
| Table A.1 | 0.12 | 2020 | 2019 |

**Table 3.6. Pour through leachate measurements of pH and EC during 2019 growing season. Measurements were collected approximately every 30 days.**

| Treatment | pH | | | | | EC | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3June | 7July | 6Aug | 12Sept | 14Oct | 3June | 7July | 6Aug | 12Sept | 14Oct |
| pH | | | | | | | | | | |
| Control | 5.7 | $7.6^{a}$ | 5.7 | $7.8^{a}$ | $7.8^{a}$ | $2.4^{b}$ | 1.8 | $1.9^{a}$ | 2.1 | 1.7 |
| Iron Sulfate | 5.7 | $7.6^{a}$ | 5.6 | $7.5^{ab}$ | $7.9^{a}$ | $2.7^{ab}$ | 2.0 | $1.5^{b}$ | 1.2 | 1.6 |
| Elemental Sulfur | 5.5 | $7.4^{b}$ | 5.5 | $7.2^{b}$ | $7.3^{b}$ | $2.9^{a}$ | 2.0 | $1.6^{ab}$ | 2.3 | 1.8 |
| $LSD_{0.05}^{z}$ | NS | 0.15 | NS | 0.48 | 0.40 | 0.33 | NS | 0.35 | NS | NS |
| Fertilizer | | | | | | | | | | |
| Holly-tone® | 5.6 | 7.5 | $5.8^{a}$ | 7.6 | 7.6 | $2.8^{a}$ | $2.2^{a}$ | 1.8 | 2.2 | 1.9 |
| Osmocote® | 5.7 | 7.5 | $5.4^{b}$ | 7.4 | 7.8 | $2.5^{b}$ | $1.7^{b}$ | 1.5 | 2.0 | 1.6 |
| $LSD_{0.05}$ | NS | NS | 0.33 | NS | NS | 0.28 | 0.24 | NS | NS$^{y}$ | 0.22 |
| Rate of Fertilizer (oF) | | | | | | | | | | |
| Low | $6.0^{a}$ | $7.6^{a}$ | $6.0^{a}$ | 7.7 | 7.7 | 2.6 | $1.8^{b}$ | $1.5^{b}$ | $1.9^{b}$ | $1.6^{b}$ |
| High | $5.3^{b}$ | $7.4^{b}$ | $5.2^{b}$ | 7.4 | 7.7 | 2.8 | $2.1^{a}$ | $1.8^{a}$ | $2.3^{a}$ | $1.8^{a}$ |
| $LSD_{0.05}$ | 0.39 | 0.11 | 0.27 | NS$^{y}$ | NS | NS | 0.26 | 0.28 | 0.31 | 0.22 |
| pH * Fertilizer | | | | | | | | | | |
| Control * Holly-tone® | 6.0 | 7.6 | 5.8 | 7.9 | $7.9^{a}$ | 2.5 | 2.1 | 1.9 | $2.2^{ab}$ | $1.7^{b}$ |
| Control * Osmocote® | 5.4 | 7.7 | 5.6 | 7.7 | $7.7^{a}$ | 2.4 | 1.4 | 1.8 | $1.9^{b}$ | $1.7^{b}$ |
| Iron Sulfate * Holly-tone® | 5.4 | 7.5 | 5.9 | 7.8 | $7.8^{a}$ | 3.0 | 2.2 | 1.6 | $1.8^{b}$ | 1.6b |
| Iron Sulfate * Osmocote® | 6.1 | 7.6 | 5.4 | 7.2 | $7.9^{a}$ | 2.4 | 1.7 | 1.3 | $2.1^{b}$ | $1.5^{b}$ |
| Elemental Sulfur * Holly-tone® | 5.5 | 7.3 | 5.7 | 7.2 | $7.0^{b}$ | 3.0 | 2.3 | 1.7 | $2.7^{a}$ | $2.2^{a}$ |
| Elemental Sulfur * Osmocote® | 5.6 | 7.4 | 5.3 | 7.3 | $7.7^{a}$ | 2.9 | 1.8 | 1.5 | $1.8^{b}$ | $1.5^{b}$ |
| $LSD_{0.05}$ | NS | NS | NS | NS | NS | NS | NS | NS | 0.51 | 0.35 |
| pH * Rate oF | | | | | | | | | | |
| Control * Low | 6.1 | 7.7 | 6.3 | 7.7 | 7.9 | 2.2 | $1.8^{bc}$ | 1.6 | $2.0^{a}$ | 1.6 |
| Control * High | 5.3 | 7.5 | 5.2 | 7.9 | 7.8 | 2.6 | $1.9^{bc}$ | 2.2 | $2.1^{a}$ | 1.8 |
| Iron Sulfate * Low | 6.1 | 7.7 | 5.9 | 7.8 | 7.9 | 2.8 | $1.6^{c}$ | 1.3 | $1.5^{b}$ | 1.3 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Iron Sulfate * High | 5.3 | 7.4 | 5.3 | 7.3 | 7.8 | 2.6 | 2.4[a] | 1.6 | 2.4[a] | 1.9 |
| Elemental Sulfur * Low | 5.7 | 7.6 | 5.9 | 7.6 | 7.2 | 2.8 | 2.0[b] | 1.4 | 2.0[a] | 1.8 |
| Elemental Sulfur * High | 5.3 | 7.2 | 5.1 | 6.9 | 7.4 | 3.1 | 2.1[ab] | 1.7 | 2.5[a] | 1.9 |
| $LSD_{0.05}$ | NS | NS | NS | NS | NS | NS | 0.42 | NS | 0.51 | NS |
| Fertilizer * Rate oF | | | | | | | | | | |
| Holly-tone® * Low | 6.0 | 7.6 | 6.0[a] | 7.7 | 7.5 | 2.8 | 1.9 | 1.5 | 2.0 | 1.7 |
| Holly-tone® * High | 5.2 | 7.3 | 5.6[b] | 7.6 | 7.6 | 2.9 | 2.5 | 2.0 | 2.4 | 2.0 |
| Osmocote® * Low | 6.0 | 7.7 | 6.0[a] | 7.7 | 7.8 | 2.5 | 1.6 | 1.4 | 1.7 | 1.5 |
| Osmocote® * High | 5.4 | 7.4 | 4.8[c] | 7.1 | 7.7 | 2.6 | 1.8 | 1.7 | 2.2 | 1.7 |
| $LSD_{0.05}$ | NS | NS | 0.33 | NS | NS | NS | NS | NS | NS | NS |
| pH * Fertilizer * Rate oF | | | | | | | | | | |
| Control * Holly-tone® * Low | 6.3 | 7.7 | 6.1 | 7.9 | 8.1 | 2.3 | 2.0 | 1.6 | 2.2 | 1.6 |
| Control * Holly-tone® * High | 5.7 | 7.4 | 5.6 | 7.9 | 7.8 | 2.7 | 2.2 | 2.3 | 2.2 | 1.9 |
| Control * Osmocote® * Low | 5.9 | 7.7 | 6.4 | 7.5 | 7.7 | 2.2 | 1.7 | 1.6 | 1.9 | 1.7 |
| Control * Osmocote® * High | 5.0 | 7.6 | 4.8 | 7.9 | 7.7 | 2.5 | 1.6 | 2.1 | 1.9 | 1.7 |
| Iron Sulfate * Holly-tone® * Low | 6.2 | 7.6 | 6.0 | 7.8 | 7.8 | 3.1 | 1.7 | 1.5 | 1.4 | 1.4 |
| Iron Sulfate * Holly-tone® * High | 4.6 | 7.4 | 5.7 | 7.8 | 7.8 | 2.9 | 2.8 | 1.8 | 2.1 | 1.9 |
| Iron Sulfate * Osmocote® * Low | 6.2 | 7.7 | 5.8 | 7.8 | 8.0 | 2.5 | 1.5 | 1.2 | 1.6 | 1.2 |
| Iron Sulfate * Osmocote® * High | 6.0 | 7.4 | 4.9 | 6.7 | 7.9 | 2.3 | 2.0 | 1.4 | 2.7 | 1.8 |
| Elemental Sulfur * Holly-tone® * Low | 5.5 | 7.5 | 5.9 | 7.3 | 6.7 | 2.8 | 2.1 | 1.6 | 2.4 | 2.2 |
| Elemental Sulfur * Holly-tone® * High | 5.5 | 7.2 | 5.5 | 7.1 | 7.3 | 3.2 | 2.4 | 1.8 | 3.0 | 2.3 |
| Elemental Sulfur * Osmocote® * Low | 6.0 | 7.7 | 5.8 | 7.8 | 7.7 | 2.8 | 1.8 | 1.3 | 1.7 | 1.5 |
| Elemental Sulfur * Osmocote® * High | 5.2 | 7.1 | 4.8 | 6.7 | 7.6 | 2.9 | 1.8 | 1.7 | 2.0 | 1.5 |
| $LSD_{0.05}$ | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Significance | | | | | | | | | | |
| pH | NS | *** | NS | * | * | * | NS | * | NS | NS |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fertilizer | NS | NS | ** | NS | NS | * | *** | NS | NS | ** |
| Rate oF | *** | *** | *** | NS | NS | NS | ** | ** | ** | ** |
| pH * Fertilizer | * | NS | NS | NS | NS | NS | NS | NS | ** | ** |
| pH * Rate oF | NS | NS | NS | NS | NS | NS | ** | NS | * | NS |
| Fertilizer * Rate oF | NS | NS | ** | NS | NS | NS | NS | NS | NS | NS |
| pH * Fertilizer * Rate oF | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

[z]LSD used to compare differences in means, minimum significant difference reported provided significant treatment interaction; significant at $p<0.05$.
[y]LSD significant at $p<0.10$
NS, *, **, *** not significant, significant at $P\leq0.05$, significant at $P\leq0.01$, or significant at $P\leq0.001$ respectively; letter groups significant at $P\leq0.05$
Means in the same column followed by the same superscript letter are not significantly different.

**Table 3.7. Pour through leachate measurements of pH and EC during 2020 growing season. Measurements were collected approximately every 30 days.**

| Treatment | pH | | | | | | EC | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 27 Mar | 27 Apr | 27 May | 26 June | 26 July | 28 Aug | 27 Mar | 27 Apr | 27 May | 26 June | 26 July | 28 Aug |
| pH | | | | | | | | | | | | |
| Control | 7.6[a] | 7.9 | 7.9 | 7.9[b] | 8.3 | 8.1 | 1.9 | 1.5 | 1.4 | 1.6 | 1.6 | 1.3 |
| Iron Sulfate | 7.9[a] | 7.9 | 7.9 | 8.0[a] | 8.4 | 8.2 | 1.9 | 1.5 | 1.3 | 1.6 | 1.5 | 1.4 |
| $LSD_{0.05}$[z] | 0.14 | NS | NS | 0.07 | NS | 0.09 | NS | NS | NS | NS | NS | NS |
| Fertilizer | | | | | | | | | | | | |
| Holly-tone® | 7.7 | 7.9 | 7.9 | 7.9 | 8.4 | 8.2 | 1.9 | 1.6 | 1.4 | 1.5 | 1.5 | 1.3 |
| Osmocote® | 7.8 | 7.9 | 7.8 | 7.9 | 8.3 | 8.1 | 1.9 | 1.4 | 1.4 | 1.6 | 1.6 | 1.4 |
| $LSD_{0.05}$ | NS | NS | NS | NS | 0.10 | 0.10 | NS | 0.21 | NS | NS | 0.16 | 0.20 |
| Rate of Fertilizer (oF) | | | | | | | | | | | | |
| Low | 7.7 | 7.9 | 7.8 | 7.9 | 8.3 | 8.1 | 1.7 | 1.3 | 1.2[b] | 1.4[b] | 1.4[b] | 1.2 |
| High | 7.8 | 7.8 | 7.9 | 7.9 | 8.4 | 8.2 | 2.0 | 1.7 | 1.5[a] | 1.7[a] | 1.7[a] | 1.6 |
| $LSD_{0.05}$ | NS | NS | NS | NS | 0.09 | 0.09 | 0.15 | 0.17 | 0.15 | 0.17 | 0.14 | 0.15 |
| pH * Fertilizer | | | | | | | | | | | | |
| Control * Holly-tone® | 7.6 | 7.9 | 7.9 | 7.9 | 8.4 | 8.1 | 1.9 | 1.7 | 1.3 | 1.6 | 1.5 | 1.3 |
| Control * Osmocote® | 7.7 | 7.9 | 7.8 | 7.8 | 8.3 | 8.0 | 1.9 | 1.3 | 1.5 | 1.6 | 1.7 | 1.4 |
| Iron Sulfate * Holly-tone® | 7.9 | 7.8 | 7.6 | 8.0 | 8.4 | 8.3 | 1.9 | 1.6 | 1.3 | 1.5 | 1.5 | 1.3 |
| Iron Sulfate * Osmocote® | 7.8 | 7.9 | 7.8 | 7.9 | 8.4 | 8.1 | 1.9 | 1.5 | 1.4 | 1.6 | 1.6 | 1.5 |
| $LSD_{0.05}$ | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| pH * Rate oF | | | | | | | | | | | | |
| Control * Low | 7.6 | 8.0 | 7.8 | 7.8 | 8.3 | 8.0 | 1.8 | 1.3 | 1.3 | 1.5[b] | 1.6[b] | 1.1 |
| Control * High | 7.6 | 7.8 | 7.9 | 7.9 | 8.4 | 8.1 | 2.0 | 1.7 | 1.5 | 1.6[b] | 1.7[ab] | 1.5 |
| Iron Sulfate * Low | 7.8 | 7.9 | 7.9 | 8.0 | 8.4 | 8.1 | 1.7 | 1.3 | 1.2 | 1.3[c] | 1.3[c] | 1.2 |
| Iron Sulfate * High | 8.0 | 7.9 | 7.9 | 8.0 | 8.4 | 8.2 | 2.0 | 1.8 | 1.5 | 1.8[a] | 1.8[a] | 1.6 |
| $LSD_{0.05}$ | NS | NS | NS | NS | NS | NS | NS | NS | NS | 0.22 | 0.18 | NS |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fertilizer * Rate oF** | | | | | | | | | | | | |
| Holly-tone® * Low | 7.7 | 8.0 | 7.9 | 7.9 | 8.4 | 8.2 | 1.8 | 1.3 | 1.2 | $1.3^{c}$ | $1.3^{c}$ | 1.1 |
| Holly-tone® * High | 7.8 | 7.7 | 7.9 | 7.9 | 8.4 | 8.2 | 2.0 | 1.9 | 1.5 | $1.8^{a}$ | $1.8^{a}$ | 1.5 |
| Osmocote® * Low | 7.7 | 7.9 | 7.8 | 7.9 | 8.2 | 8.0 | 1.7 | 1.3 | 1.3 | $1.6^{b}$ | $1.6^{b}$ | 1.2 |
| Osmocote® * High | 7.8 | 7.9 | 7.9 | 7.9 | 8.4 | 8.2 | 2.0 | 1.5 | 1.5 | $1.6^{ab}$ | $1.7^{ab}$ | 1.6 |
| $LSD_{0.05}$ | NS | NS | NS | NS | 0.12 | 0.12 | NS | NS | NS | 0.21 | 0.16 | NS |
| **pH * Fertilizer * Rate oF** | | | | | | | | | | | | |
| Control * Holly-tone® * Low | 7.6 | 8.0 | 7.9 | 7.9 | 8.4 | $8.1^{ab}$ | 1.8 | 1.4 | 1.2 | 1.4 | 1.4 | 1.1 |
| Control * Holly-tone® * High | 7.6 | 7.7 | 7.9 | 7.9 | 8.4 | $8.1^{b}$ | 2.0 | 1.9 | 1.5 | 1.7 | 1.7 | 1.5 |
| Control * Osmocote® * Low | 7.7 | 8.0 | 7.7 | 1.8 | $8.1^{b}$ | $7.8^{c}$ | 1.8 | 1.2 | 1.4 | 1.7 | 1.7 | 1.1 |
| Control * Osmocote® * High | 7.7 | 7.9 | 7.9 | 7.9 | 8.4 | $8.1^{ab}$ | 2.0 | 1.4 | 1.6 | 1.5 | 1.7 | 1.6 |
| Iron Sulfate * Holly-tone® * Low | 7.8 | 7.9 | 7.9 | 8.0 | 8.4 | $8.2^{ab}$ | 1.8 | 1.3 | 1.1 | 1.1 | 1.2 | 1.1 |
| Iron Sulfate * Holly-tone® * High | 8.0 | 7.8 | 7.8 | 8.0 | 8.4 | $8.3^{a}$ | 2.0 | 1.9 | 1.6 | 1.9 | 1.8 | 1.5 |
| Iron Sulfate * Osmocote® * Low | 7.7 | 7.8 | 7.8 | 7.9 | 8.3 | $8.1^{b}$ | 1.6 | 1.3 | 1.2 | 1.5 | 1.4 | 1.3 |
| Iron Sulfate * Osmocote® * High | 7.9 | 7.9 | 7.9 | 7.9 | 8.4 | $8.2^{ab}$ | 2.1 | 1.7 | 1.3 | 1.8 | 1.7 | 1.7 |
| $LSD_{0.05}$ | NS | NS | NS | NS | 0.16 | 0.14 | NS | NS | NS | NS | NS | NS |
| **Significance** | | | | | | | | | | | | |
| pH | ** | NS | NS | ** | NS | ** | NS | NS | NS | NS | NS | NS |
| Fertilizer | NS | NS | NS | NS | * | ** | NS | ** | NS | NS | * | * |
| Rate oF | NS | NS | NS | NS | * | ** | ** | *** | *** | *** | *** | *** |
| pH * Fertilizer | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| pH * Rate oF | NS | NS | NS | NS | NS | NS | NS | NS | NS | ** | * | NS |
| Fertilizer * Rate oF | NS | NS | NS | NS | * | * | NS | NS | NS | *** | *** | NS |
| pH * Fertilizer * Rate oF | NS | NS | NS | NS | * | ** | NS | NS | NS | NS | NS | NS |

[z]LSD used to compare differences in means, minimum significant difference reported provided significant treatment interaction; significant at $p<0.05$.
[y]LSD significant at $p<0.10$.
NS, *, **, *** not significant, significant at $P\leq0.05$, significant at $P\leq0.01$, or significant at $P\leq0.001$ respectively; letter groups significant at $P\leq0.05$
Means in the same column followed by the same superscript letter are not significantly different.

## Appendix A - Greenhouse cultivar and fertilizer yield trial

A greenhouse fertilizer trial that was parallel to the high tunnel experiment described in Chapter 3 occurred with four cultivars of Northern high- and half-highbush blueberries from March 22, 2019 through August 25, 2020. One-year rooted liners of four cultivars were transplanted into 15.1 L (4-gal) pots and grown in controlled environment conditions at 23 to 25°C for two growing seasons. The plants were held in a cooler at 5 to 7°C for ~1,050 h between 2019 and 2020. The treatments included a top-dress of a low- or high-rate (0.6, and 1.8 g N per pot respectively) of Osmocote® or Holly-tone® fertilizers (the same as Chapter 3) that were added to the pots one time at the beginning of the two growing seasons. An additional fertilizer treatment of hydroponic fertilizer (at the same rate given in Chapter 2) was applied at each irrigation instance. The treatment structure was: five fertilizer treatments * five replications * four cultivars for a total of total of 100 plants. Berry yield (Table A.1) was measured during the 2020 growing season. Canopy height and spread (Table 2) was measured on August 20, 2020 at the end of the second season.

**Table A.1. Fruit yield differences between cultivars, fertilizer types, and rates of application in containerized production in a greenhouse. Fruit were harvested, counted, and weight every three to four days.**

| Treatment | Berries per plant | Weight (g) fruit per plant | Average weight per berry (g) |
|---|---|---|---|
| Cultivar | | | |
| Blueberry Glaze | 181[a] | 84.2[b] | 0.47[c] |
| Jelly Bean | 70[c] | 83.1[b] | 1.16[a] |
| Northland | 141[b] | 118.6[a] | 0.86[b] |
| Pink Icing | 118[b] | 136.9[a] | 1.19[a] |
| $LSD_{0.05}$[z] | 40.1 | 31.80 | 0.133 |
| Fertilizer Type | | | |
| Holly-tone® | 139 | 114.3 | 0.93 |
| Hydroponic | 123 | 107.4 | 1.01[y] |

| | | | |
|---|---|---|---|
| Osmocote® | 118 | 96.3 | 0.87 |
| $LSD_{0.05}$ | NS | NS | 0.156 |
| | | | |
| Fertilizer Rate | | | |
| Low | $101^{b}$ | 100.8 | $1.03^{a}$ |
| High | $156^{a}$ | 109.9 | $0.77^{b}$ |
| Hydro | $123^{y}$ | 107.4 | $1.01^{y}$ |
| $LSD_{0.05}$ | 36.7 | NS | 0.144 |
| | | | |
| Cultivar * Fert. Type | | | |
| Blueberry Glaze | | | |
| Holly-tone® | 181 | 84.7 | $0.47^{f}$ |
| Hydroponic | 181 | 79.9 | $0.44^{y}$ |
| Osmocote® | 181 | 85.9 | $0.48^{f}$ |
| Jelly Bean | | | |
| Holly-tone® | 78 | 87.2 | $1.08^{bc}$ |
| Hydroponic | 59 | 84.3 | $1.46^{y}$ |
| Osmocote® | 68 | 78.4 | $1.09^{bc}$ |
| Northland | | | |
| Holly-tone® | 167 | 131.3 | $0.85^{e}$ |
| Hydroponic | 125 | 108.9 | $0.90^{y}$ |
| Osmocote® | 123 | 110.7 | $0.90^{de}$ |
| Pink Icing | | | |
| Holly-tone® | 129 | 154.2 | $1.30^{a}$ |
| Hydroponic | 128 | 156.4 | $1.23^{y}$ |
| Osmocote® | 101 | 110.0 | $1.06^{bcd}$ |
| $LSD_{0.05}$ | NS | NS | 0.195 |
| | | | |
| Cultivar * Fert. Rate | | | |
| Blueberry Glaze | | | |
| Low | $1.5^{cde}$ | $50.6^{cd}$ | $0.49^{e}$ |
| High | $258^{a}$ | $119.9^{ab}$ | $0.47^{e}$ |
| Hydro | $181^{y}$ | $79.9^{y}$ | $0.44^{y}$ |
| Jelly Bean | | | |
| Low | $92^{cde}$ | $116.9^{ab}$ | $1.24^{b}$ |

| | | | |
|---|---|---|---|
| High | 53[e] | 48.7[d] | 0.93[c] |
| Hydro | 59[y] | 84.3[y] | 1.46[y] |
| Northland | | | |
| Low | 115[bcd] | 104.8[abc] | 0.95[c] |
| High | 175[b] | 137.3[ab] | 0.76[d] |
| Hydro | 125[y] | 108.9[y] | 0.90[y] |
| Pink Icing | | | |
| Low | 93[cde] | 130.7[ab] | 1.45[a] |
| High | 137[bc] | 133.5[ab] | 0.91[cd] |
| Hydro | 128[y] | 145.4[y] | 1.23[y] |
| $LSD_{0.05}$ | 54.5 | 51.23 | 0.135 |
| **Fert. Type * Fert. Rate** | | | |
| Holly-tone® | | | |
| Low | 101 | 96.9[ab] | 1.04 |
| High | 176 | 131.8[a] | 0.81 |
| Hydro | | | |
| Hydro | 123 | 107.4[ab] | 1.01 |
| Osmocote® | | | |
| Low | 101 | 87.9[b] | 1.02 |
| High | 136 | 104.6[ab] | 0.72 |
| $LSD_{0.05}$ | NS | 37.52 | NS |
| **Significance** | | | |
| Cultivar | *** | *** | *** |
| Fertilizer Type | NS | NS | * |
| Fertilizer Rate | *** | NS | *** |
| Cult * Type | NS | NS | ** |
| Cult * Rate | *** | *** | *** |
| Type * Rate | NS | * | NS |
| Cultivar * Type * Rate | NS | NS | NS |

[z]LSD used to compare differences in means, minimum significant difference reported provided significant treatment interaction; significant at p<0.05.
NS, *, **,*** not significant, significant at P≤0.05, significant at P≤0.01, or significant at P≤0.001 respectively; letter groups significant at P≤0.05

Table A.2. Canopy height and spread measurements across fertilizer treatments at experiment end, August 20, 2020.

| Cultivar | Height (cm) | Spread (cm) |
|---|---|---|
| Jelly Bean | $32.5^{c}$ | $35.1^{c}$ |
| Blueberry Glaze | $51.3^{b}$ | $52.7^{bc}$ |
| Peach Sorbet | $60.7^{b}$ | $77.2^{ab}$ |
| Pink Icing | $79.2^{a}$ | $101.7^{a}$ |
| Northland | $86.4^{a}$ | $85.6^{ab}$ |
| $LSD_{0.05}$[z] | 15.92 | 35.47 |
| **Significance** | | |
| Cultivar | *** | ** |

[z]LSD used to compare differences in means, minimum significant difference reported provided significant treatment interaction; significant at $p<0.05$.
NS, *, **, *** not significant, significant at $P\leq0.05$, significant at $P\leq0.01$, or significant at $P\leq0.001$ respectively; letter groups significant at $P\leq0.05$
Means in the same column followed by the same superscript letter are not significantly different.

# Appendix B - Survey fielded at Great Pains Growers' Conference in 2020

Thank you for taking the time to participate in this research study by completing this short survey. Your participation is completely voluntary. There is no penalty for not participating. If you choose to participate, the survey will take approximately 5 to 10 minutes to complete. You can withdraw from the survey at any time without penalty, and you do not have to answer any question you do not wish to answer. All answers are confidential.

This project is sponsored by the USDA Specialty Crops Block Grant Program that is administered by the Kansas Department of Agriculture. This survey gathers information about needs of specialty crop growers in our region with special focus on small fruits production. There are no known risks associated with this study, and there is no compensation or other direct benefit to you for participation (except our huge thanks!). All responses will be anonymous and reported in aggregate. If you would like to learn more about this study, please contact Dr. Kim Williams by e-mail at kwilliam@ksu.edu. If you have questions about your rights as a research participant, please contact Kansas State University's Institutional Review Board, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, (785) 532-3224, IRB#10007.

By checking agree below, you agree that you have read this statement and are aware of your rights and are willing to continue taking the survey.

- o Yes
- o No

1. Did you grow small fruit crops for sale in 2019? Examples of small fruits include blackberry, blueberry, raspberry, strawberry, etc.

    - Yes
    - No

2. Are you interested in growing small fruit specialty crops such as blackberry, blueberry, raspberry or strawberry for sale?

    - Yes
    - No

3. Which of the following small fruit crops have you grown in the past (but not currently), currently grow, would consider growing or have no interest in growing?

| Crop | Have grown in the past, but not currently | Yes, currently growing | No, but would consider growing in the future | No interest in growing |
|---|---|---|---|---|
| Blackberry | □ | □ | □ | □ |
| Blueberry | □ | □ | □ | □ |
| Raspberry | □ | □ | □ | □ |
| Strawberry | □ | □ | □ | □ |
| Other (please specify) | □ | □ | □ | □ |
| Other (please specify) | □ | □ | □ | □ |
| Other (please specify) | □ | □ | □ | □ |

4. Describe your acreage for each small fruit crop grown in 2019 (list number of acres).

| Crop | Acres |
|---|---|
| Blackberry | __ |
| Blueberry | __ |
| Raspberry | __ |
| Strawberry | __ |
| Other specialty crops | __ |

5. What production system(s) do you use or have considered using to produce small fruit?

| **Production Systems** | **Have in the past, but not currently** | **Yes, currently use** | **No, but would consider using in the future** | **No interest in using** |
|---|---|---|---|---|
| Greenhouses (heated) | ☐ | ☐ | ☐ | ☐ |
| High tunnels (unheated and plants in ground) | ☐ | ☐ | ☐ | ☐ |
| Field/In ground (uncovered) | ☐ | ☐ | ☐ | ☐ |
| Shade structures | ☐ | ☐ | ☐ | ☐ |
| Other (please specify) | ☐ | ☐ | ☐ | ☐ |

6. If you currently grow small fruit planted in the ground or field, would you consider using alternative production methods? Check one for each type of system.

| **Production system** | **Yes, I would be interested** | **No, I would not be interested** |
|---|---|---|
| Hydroponic (soilless media with recirculating water/nutrient solution) | ☐ | ☐ |
| Potted in containers | ☐ | ☐ |
| Pot-in-pot nursery system (potted in a container which is then placed in a slightly larger container anchored in the ground) | ☐ | ☐ |
| Other (please specify) | ☐ | ☐ |

7. How much land/space do you have available and/or use for crop protection?

| **Question** | **Unprotected acres** | **Protected (greenhouse/high tunnel) acres/square feet/hectares** | **Total acres** |
|---|---|---|---|
| Available land for specialty crop production | ___ | ___ | ___ |
| Land currently in use for specialty crop production | ___ | ___ | ___ |
| Land currently used for non-specialty crop production (agronomic crops) | ___ | ___ | ___ |

8. How do you primarily grow crops on your land?

- o Organic, certified
- o Organic practices, not certified
- o Conventional
- o Combination of organic and conventional

9. Which markets to you currently access to sell your crops?

| **Market** | **Yes** | **No** |
|---|---|---|
| U-Pick | ☐ | ☐ |
| Retail on location | ☐ | ☐ |
| Retail off location (Farmers Market, roadside stand, etc.) | ☐ | ☐ |
| Wholesale to distributor | ☐ | ☐ |
| Wholesale to grocery store | ☐ | ☐ |
| Other (please specify) | ☐ | ☐ |

10. Do you currently market some or all of your crops through a state-sponsored specialty crop production program such as “Kansas Grown” or “From the Land of Kansas”?

- o Yes
- o No

11. What barriers to growing small fruit specialty crops do you perceive as significant for you?

| Barrier | Not a significant barrier | Somewhat significant barrier | Very significant barrier |
|---|---|---|---|
| Land/space | ☐ | ☐ | ☐ |
| Infrastructure | ☐ | ☐ | ☐ |
| Equipment | ☐ | ☐ | ☐ |
| Financing | ☐ | ☐ | ☐ |
| Labor | ☐ | ☐ | ☐ |
| Access to a market(s) | ☐ | ☐ | ☐ |
| Educational/informational support for growing culture | ☐ | ☐ | ☐ |
| Educational/informational support for marketing program development | ☐ | ☐ | ☐ |
| Business management skills | ☐ | ☐ | ☐ |
| Risk of crop loss | ☐ | ☐ | ☐ |
| Lack of access to processing facilities | ☐ | ☐ | ☐ |
| Other (please specify) | ☐ | ☐ | ☐ |

12. Please list any specialty crops that you grew for sale in 2019.

Examples of specialty crops include: **Fruits and Tree Nuts** such as chestnut, filbert (hazelnut) pecan, walnut, apple, cherry, peach, plum, blueberry, blackberry, raspberry, or strawberry; **Vegetables** such as tomatoes, asparagus, or carrots; **Culinary Herbs and Spices** such as basil, mint, or rosemary; **Medicinal Herbs** such as foxglove, ginkgo biloba, or St. John’s wort; **Horticultural Products** such as honey, hops, maple syrup or turfgrass; Nursery and Greenhouse Crops such as annual bedding plants, cut flowers, Christmas trees, shrubs, and shade trees.

13. What type of educational resources do you find most valuable for crop production?

| **Resources** | **Not at all valuable** | **Somewhat valuable** | **Very valuable** |
|---|---|---|---|
| Publications (print) | ○ | ○ | ○ |
| Publications (online) | ○ | ○ | ○ |
| Websites | ○ | ○ | ○ |
| Conferences, workshops, or seminars | ○ | ○ | ○ |
| Field days | ○ | ○ | ○ |
| Webinars | ○ | ○ | ○ |
| Videos (online) | ○ | ○ | ○ |
| Local County Extension Agents | ○ | ○ | ○ |
| State Extension Specialists | ○ | ○ | ○ |
| Radio programs | ○ | ○ | ○ |
| News articles | ○ | ○ | ○ |
| Trade magazine articles | ○ | ○ | ○ |
| Books | ○ | ○ | ○ |
| E-newsletters | ○ | ○ | ○ |
| Social media (Facebook, Twitter, Instagram, etc.) | ○ | ○ | ○ |
| Associate or technical degree | ○ | ○ | ○ |
| Undergraduate degree | | | |
| Graduate degree | ○ | ○ | ○ |
| Access to non-credit, college-level courses | ○ | ○ | ○ |
| Other (please specify) | ○ | ○ | ○ |

14. Do you like to view farming/crop production information on a smartphone?

- o Yes
- o Maybe
- o No
- o Does not apply because I do not use a smartphone

15. In what state do you primarily farm/grow specialty crops?

- o Iowa
- o Kansas
- o Missouri
- o Nebraska
- o Other (please Specify)

16. What is the primary zip code of the land that you farm?

This information will be used to determine urban versus rural farming locations.

17. How long have you been farming/growing specialty crops?

- o 1 to 2 years
- o 3 to 7 years
- o 8 to 15 years
- o 16+ years

18. How many employees worked for your business on payroll, including yourself, for wages in 2019? Enter "0" if none in the category.

- o Full-time (40 hours per week) ___________
- o Part-time (39 or less hours per week) ___________
- o Seasonal (employed only during certain times of the year) ___________

19. What was your age on December 31, 2019?

- o Under 18
- o 18 to 24
- o 25 to 34
- o 35 to 44
- o 45 to 54
- o 55 to 64
- o 65 to 74
- o 75 to 84
- o 85 or older

20. What is your gender?

- o Male
- o Female

21. Are you interested in learning more about growing blueberries or other small fruits in (or near) Kansas?

- o Yes
- o No

22. If you would like more information about producing and marketing blueberries or other small fruit crops, please submit your email address below (this will not be associated with your survey response).

**Thank you so much for your time and interest!**