Asexual Propagation by Stem Cuttings of Half-high and Low-bush Blueberries in Soilless Substrates[1]

Jacob D. Schwab[2], Kimberly A. Williams[3], and Jason J. Griffin[4]

Abstract

Two experiments evaluated rooting of blueberry in substrates for use in soilless production systems. Apical and basal semi-hardwood stem cuttings of *Vaccinium corymbosum x angustifolium* 'Northland' were rooted in rockwool cubes, shredded rockwool, or 3 perlite:1 sphagnum peat moss (v/v). Cuttings were treated with 0.1% indolebutyric acid (IBA) in 1:1 95% ethyl alcohol: water, 0.1% potassium salt of indolebutyric acid (K-IBA), 1:1 95% ethyl alcohol: water, or water. In Expt. 2, basal stem cuttings of 'Northland' and *V. angustifolium* 'Brunswick' were rooted in the same substrates with the addition of coco coir, treated with 1,000 ppm K-IBA, then fertilized weekly (after rooting began) with water, 75 ppm N from 16-4-17 fertilizer or 4-18-38 and $Ca(NO_3)_2$ plus $MgSO_4$ fertilizer, all adjusted to pH 4.0. Rooting percentages were calculated, and rooting quality was assessed using a 6-point visual scale. 'Northland' roots well (>80%) in peat:perlite and coco coir substrates and acceptably in two rockwool substrates (~50%). 'Brunswick' rooted acceptably in peat:perlite and coco coir (27% and 41%, respectively), and very poorly in two rockwool substrates (<2%). Rooting of 'Northland' was not improved with application of 0.1% auxin. Apical cuttings of 'Northland' had a higher rooting success than basal stem cuttings. Weekly fertilization did not improve root ratings, and had minimal effect on rooting success.

Index words: adventitious rooting, auxin, coco coir, hydroponics, indolebutyric acid, rockwool, *Vaccinium*.

Species used: 'Northland' half-highbush blueberry, *Vaccinium corymbosum* L. X *angustifolium* Aiton, 'Brunswick' low-bush blueberry, *V. angustifolium* Aiton.

Chemicals used: auxin, potassium salt indolebutyric acid, K-IBA; Sigma-Aldrich, St. Louis, MO, USA, auxin, indolebutyric acid, IBA; Sigma-Aldrich, St. Louis, MO, USA, Oasis® 16-4-17 fertilizer, OASIS® Grower Solutions, Kent, OH, USA, ChemGro 4-18-38 fertilizer, ChemGro Hydro-Gardens, Colorado Springs, CO, USA, $Ca(NO_3)_2$, Yara North America, Tampa, FL, USA, and $MgSO_4$, PQ Corp., Valley Forge, PA, USA.

Significance to the Horticulture Industry

Blueberries (*Vaccinium* spp.) are a high-value crop that have cultural requirements of low soil pH and salt loads. Therefore, production using soilless production systems - where the root medium is inert and plant nutrients are supplied solely from fertilizer application - may offer improved management options for producers in regions where soil conditions do not meet these requirements. For easiest establishment in soilless systems, blueberry plants should be propagated in like substrates. Varieties of *Vaccinium* spp. were selected for evaluation because of potential for use in controlled environments or high tunnels. The half-highbush blueberry 'Northland' (*Vaccinium corymbosum* L. X *angustifolium* Aiton 'Northland') is regarded for its compact stature and relatively high fruit yield. The lowbush blueberry 'Brunswick' (*V. angustifolium* L. 'Brunswick') is noted for its high fruit weight and vigor. This research provides new information for propagators who desire to root blueberries in soilless substrates of rockwool or coco coir.

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[2]Graduate research assistant.

[3]Professor of Horticulture and University Distinguished Teaching Scholar. Kansas State University Department of Horticulture and Natural Resources, 1712 Claflin Road, 2021 Throckmorton Plant Sciences Center, Manhattan, KS 66506. Corresponding author. E-mail: kwilliam@ksu.edu.

[4]Professor of Horticulture and Director of the John C. Pair Horticulture Center.

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 foods increases (Conner et. al. 2009), one option is to produce blueberries in protected or 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. Coco coir is also popular in soilless container production systems. Therefore, propagation in alternative soilless substrates was evaluated.

Protocols for asexual propagation of blueberry by stem cuttings are not well defined. Typically, pencil-diameter, 7.5 cm (3 in) 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

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soilless substrates of rockwool or coco coir. 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 improve rooting. Therefore, they do not use it in their commercial operation (personal communication, March, 2018). The rates of IBA applied in this research were selected to hasten and promote uniform rooting of the cuttings (D. Creech, Nacogdoches, TX, personal communication, March, 2018). One aspect of rooting hormone that may affect rooting quality is alcohol toxicity from ethyl alcohol in the carrier solution. This has been shown to negatively impact sensitive species (Dirr and Heuser 2006) while in other species it may aid the uptake of auxin (Stutter and Burger 2008).

The primary objective of this research was to determine the feasibility of rooting two species of blueberry in soilless substrates of shredded rockwool or rockwool cubes and coco coir versus traditional peat-based rooting media. We also evaluated the benefit of auxin and related alcohol toxicity from the carrier solution, determined whether a low rate of fertilizer applied after root initials emerge impacts rooting quality, and assessed the viability of apical versus basal stem cuttings.

Materials and Methods

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

Treatments. Experiment 1 (Expt. 1) consisted of three rooting substrates, four rooting hormones, and two cutting types. Experiment 2 (Expt. 2) consisted of two blueberry species, four rooting substrates, and three fertilizer treatments. Cuttings were collected from two-year-old rooted liners grown in 100% sphagnum peat in 16.5 cm (6.5 in) diameter, 1,930 cm^3 (118 in^3) volume 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 (12 to 18 in) were removed and held with their cut ends in distilled water for no more than two hours. From these stems, experimental cuttings 7 to 10 cm (2.7 to 4 in) were gleaned to maintain three nodes with a bud in the leaf axil and wounded by removing 1 to 2 cm (0.5 to 0.8 in) epidermal tissue at the base of the cutting before dipping in the rooting hormone treatment for 5 sec. Cuttings were then stuck vertically in their respective treatment substrates at a depth of 2 to 3 cm (0.8 to 1.2 in). The experiment was a completely random design (CRD) 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 (Bootstrap Farmer, Ernul, NC, USA), shredded rockwool (Growpito, Kansas City, MO, USA), and 1:3 peat (Pro-Moss Sphagnum Peat Moss, Premier Tech Horticulture, Quakertown, PA, USA): perlite (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 wetted with DI water overhead. Expt. 2 was procedurally the same as Expt. 1 with the addition of coco coir (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 0804 cell packs.

Hormone. In Expt. 1, cuttings were treated with four root promoting hormone treatments. Reverse osmosis water with no IBA (water control), 1:1 95% ethyl alcohol (McCormick Distilling, Weston, MO, USA) : reverse osmosis (RO) water (ethanol control), 1,000 ppm (0.1%) potassium salt indolebutyric acid (K-IBA; Sigma-Aldrich, St. Louis, MO, USA) in RO water, and 1,000 ppm indolebutyric acid (IBA; Sigma-Aldrich, St. Louis, MO, USA) in 1:1 reverse osmosis water : 95% ethyl alcohol. In Expt. 2, all cuttings were treated with 1,000 ppm K-IBA.

Fertilizer. In Expt. 2, the fertilizer treatments included distilled water, 75 ppm N from 16-4-17 (16N-1.7P-14.1K) Oasis® hydroponic fertilizer (0.47 g fertilizer per L) 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) and $Ca(NO_3)_2$ (Yara North America, Tampa, FL, USA) with $MgSO_4$ (PQ Corp., Valley Forge, PA, USA at 0.15 g per L). The cuttings were fertigated with one of the three treatments on days after sticking (DAS) 21, 28, 35, 42, 46, 50, 54, 58, 62, nd 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 repipet at 25 mL per cell.

Cutting type. Apical cuttings were selected as 7 to 10 cm (2.7 to 4 in) stem sections which had a visible apical meristem and two lateral buds. Stem cuttings were any 7 to 10 cm (2.7 to 4 in) stem section which contained three lateral buds between the proximal and distal ends of the cutting. Cuttings for Expt. 2 were all stem cuttings due to limited availability of stock plants.

Cultural practices. Cuttings were placed under overhead intermittent mist (Dramm Misty Mist nozzles; 0.4 gal (1.5 L) per minute; Dramm Corp., Manitowoc, WI, USA) 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. Cuttings were watered overhead once weekly (weeks 4 to

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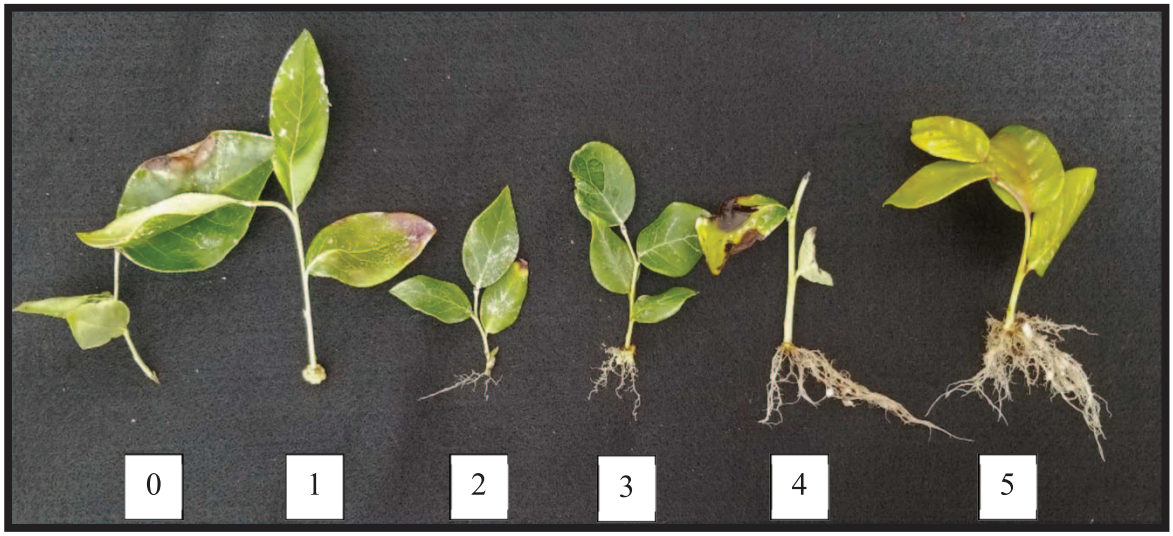

Figure 1. Root rating scale for blueberry cuttings developed for use in this research. 0: unrooted; 1: callus, but no roots; 2: few, small roots; 3: many, small roots; 4: many, elongated roots; and 5: well-rooted.

8) to mitigate any 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 (Fig. 1), 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 (149 F) for seven days, Expt. 1 only). Substrate pH and electrical conductivity (EC) were collected using a pour through method (Expt. 2 only), wherein 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 refrigerator 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

Substrate. Substrate had a significant effect on rooting of both cultivars. In Expt. 1, NL rooted more successfully in traditional peat:perlite (95%) than shredded rockwool (46%) or rockwool cubes (61%, Table 1). In Expt. 2, BW rooted poorly in rockwool substrates (2%, Table 2). Rooting was higher in traditional peat:perlite (27%) and was highest in coco coir (41%, Table 2). The increased rooting for BW in coco coir seems contradictory since it retained more water than the other substrates. The lowbush 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 coco coir. Additionally, Vander Kloet (1988) mentions the native soils of *V. angustifolium* have an average pH of 4.4 which is a stark contrast to coco coir, which had an average pH of 6.2 (Table 3). 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).

Cultivar. Across substrates, lowbush 'Brunswick' rooted poorly (18%) compared to half-high 'Northland' (63%, Table 2). Expt. 2 was longer than Expt. 1 to allow for improved root development of BW; however, the rate of death of BW, 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 change rooting percentage (63% vs 67%, respectively). Rooting percentages for NL exceeded the 45% rooting previously reported by Miller et al. (2004) for this cultivar, but is less than the 85% rooting reported by Badescu et al. (1985). The low rooting success for 'Brunswick' was unexpected as original cultivar release data suggested this cultivar should have near 100% rooting success (Hall et al. 1972). Additionally, Debnath (2007) compared stem cuttings and micropropagation and suggested that "lowbush blueberries rooted readily…" with both methods.

We observed that BW may be more photosensitive than NL based on symptoms of foliar necrosis consistent with photoinhibition. While this was not quantified in this research, it may have contributed to cutting stress 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·m-2 and ~16,600 KJ·m-2 average daily sunlight difference

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Table 1. 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]
1,000 ppm KIBA	67	2.4	0.19	25.28[ab]
1,000 ppm 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 * 1,000 ppm KIBA	61	1.8[c]	0.12[cd]	13.88[c]
Rockwool Cube * 1,000 ppm 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 * 1,000 ppm KIBA	44	1.5[c]	0.20[bcd]	11.33[c]
Shredded Rockwool * 1,000 ppm 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 * 1,000 ppm KIBA	94	3.9[a]	0.24[abc]	50.64[b]
Peat:perlite * 1,000 ppm 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; significant at $p<0.05$.

[z]Root weight is determined as the sum weights from 4 out of 6 cuttings per e.u.

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.

between the native range and Kansas for Expts. 1 and 2, respectively (NLDAS, 2013).

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 1,000 ppm IBA + ethanol compared to water + ethanol (Table 1). 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 for use of a rooting hormone (e.g. Davies et al. 2018), our results do not support the need for hormone application for rooting of blueberry cuttings.

Fertilizer. After Expt. 1, we speculated that lower pH water and/or low-rate fertilizer additions after roots had emerged may promote root development. However, fertilizer application did not improve rooting percentage or root rating in Expt. 2 (Table 2). Rooting percentage was similar whether pH 4.0 water (44% rooting), acid-forming Oasis® fertilizer (41% rooting), or base-forming ChemGro

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Table 2. 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]
Coco coir	64[a]	1.4[a]
Peat:perlite	62[a]	1.6[a]
$HSD_{0.05}$	10.8	0.28
Cultivar * Substrate		
Brunswick * Rockwool Cube	2[c]	1.0[d]
Brunswick * Shredded Rockwool	2[c]	1.0[d]
Brunswick * Coco coir	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 * Coco coir	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 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. Root 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]
Coco coir	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' * Coco coir	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' * Coco coir	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 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.

fertilizer (38% rooting) was supplied. Future research could investigate "priming" of woody cuttings for transplant as hypothesized by Peterson et al. (2018); priming is a positive effect of the fertilizer application on subsequent growth in containers.

The pH of the rockwool substrates was high at 7.1 and lower in the coco coir and peat:perlite treatments (6.2 and 5.5 respectively, Table 3). The EC had a direct relationship with pH across the substrates, where it was highest in the rockwool substrates, lower in coco coir, and lowest in peat:perlite. 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 coco coir or peat:perlite. Interestingly, peat:perlite used for BW had the lowest pH and EC of all treatments, yet still resulted in less rooting success than BW in coco coir, which is contradictory to conditions of its native growing habitat.

The substrate pH may have contributed to rooting success. Given the observation that fertilizer did not improve rooting, different pH levels of the irrigation water may have had an effect, as pH was >4.0 (between 5.3 and 7.2) in all treatments (Table 3). The most successful substrate also maintained the lowest pH across treatments. Additional research could be conducted to evaluate different pH of water applications through the mist system.

Cutting type. Cuttings with shoot apical meristems rooted 25% higher across hormone treatments and substrates (Table 1). 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 a higher rooting percentage. Root weight and length had an inverse relationship between the two cutting types (Table 1). While apical cuttings had higher root percentage than stem cuttings, the latter had higher average root weight. Conversely, apical cuttings generated longer

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root systems on average, suggesting they may have rooted earlier.

Little research has been reported on asexual propagation by stem cuttings of woody species in rockwool substrates. In these studies, we learned that 'Northland' roots well in peat:perlite and coco coir (>80%) substrates and acceptably in two rockwool substrates (~50%). 'Brunswick' rooted acceptably in peat:perlite and coco coir (27% and 41%, respectively), and very poorly in two rockwool substrates (<2%). Rooting of 'Northland' is not improved with application of 0.1% auxin. Apical cuttings of 'Northland' had a higher rooting success than basal stem cuttings. Weekly fertilization did not improve root ratings, and had minimal effect on rooting success. Rooting blueberry cuttings in substrates of rockwool and coco coir requires optimization by propagators, but doing so may contribute to successful establishment in container or hydroponic systems.

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