Impacts of *Vaccinium arboreum* Rootstocks on Vegetative Growth and Yield in Two Southern Highbush Blueberry Cultivars

Rebecca L. Darnell and Jeffrey G. Williamson

Horticultural Sciences Department, University of Florida, Gainesville, FL 32611

Deanna C. Bayo and Philip F. Harmon

Plant Pathology Department, University of Florida, Gainesville, FL 32611

Additional index words. bacterial leaf scorch, fruit quality, grafting, sparkleberry, *Vaccinium corymbosum*, interspecific hybrid

Abstract. *Vaccinium arboreum* Marsh is a small tree adapted to low-organic matter soils and is one of the few ericaceous species that tolerates soil pH greater than 6.0. It has a deep root system and is more drought tolerant than cultivated blueberry. The use of *V. arboreum* as a rootstock for commercial blueberry production has been studied previously in young blueberry plantings. The objective of the current study was to expand on earlier work and evaluate growth, productivity, and tolerance to bacterial leaf scorch (*Xylella fastidiosa*) in established plantings of own-rooted vs. grafted southern highbush blueberry (SHB). Two field plantings of grafted and own-rooted ‘Meadowlark’ and ‘Farthing’ SHB were established in May 2011: one at the University of Florida–Institute of Food and Agricultural Sciences (UF-IFAS) Plant Science Research and Education Unit in Citra, FL, and the other at a commercial blueberry farm in Archer, FL. At both sites, four rootstock–scion combinations were grown in either pine bark-amended or nonamended soil. Canopy volume was greater in grafted compared with own-rooted ‘Meadowlark’ at both locations throughout the 4 years of the study (2015–18), whereas canopy volume in ‘Farthing’ was not consistently different. For both cultivars and both locations, canopy volume was greater on amended compared with nonamended soil. Although canopy growth was not consistently increased in the grafted compared with own-rooted plants, yield was greater in grafted plants of both cultivars at both locations. Cumulative yield over the 4 years was similar between grafted plants grown on both amended and nonamended soil, and was significantly greater than yield of own-rooted plants on nonamended soil, suggesting the use of this rootstock may decrease the requirement for pine bark amendment. In general, grafted plants produced larger berries, with no negative impacts on fruit soluble solids, titratable acidity, or firmness. ‘Meadowlark’—an SHB cultivar that exhibits high sensitivity to bacterial leaf scorch—displayed decreased development of bacterial leaf scorch symptoms when grafted onto *V. arboreum* compared with own-rooted plants. These results indicate the potential benefits of grafting SHB onto *V. arboreum* rootstock, particularly under marginal soil conditions. However, a complete economic analysis that also takes into account any differences in longevity between the two systems must be done to determine whether the benefits of using grafting are feasible financially for the grower.

Rootstocks are commonly used in tree fruit production and, more recently, vegetable production systems (Djidonou et al., 2017; Zhao et al., 2018). However, the use of rootstocks in berry crops (strawberry,

blackberry, raspberry, and blueberry) has not been commonly adopted. Rootstocks offer many advantages to crops, including size control (Basile and DeJong, 2018), increased yields (Xu et al., 2014), increased tolerance to biotic and abiotic stress (Liu et al., 2014), and enhanced soil adaptation (Penella et al., 2015).

Cultivated blueberry (*Vaccinium* species) have strict soil requirements for optimum growth. These include low pH (4.0–5.5), high organic matter, good aeration and drainage (Williamson et al., 2018), and readily available iron and ammonium (Darnell and Hiss, 2006; Nunez et al., 2015). As a result of these requirements, soil amendments and other modifications (e.g., sulfur applications) are used to increase organic matter, lower pH,

and increase iron and ammonium availability. In the southeastern United States, pine bark is the common soil amendment used to increase soil organic matter and is typically incorporated into the top soil layer (Williamson et al., 2018). Without soil amendments, blueberry growth and yields decrease, and plants become chlorotic and nonproductive. However, soil amendments required for establishment and maintenance of blueberry plantings are costly (Julian et al., 2012) and may not be sustainable in the long term.

Vaccinium arboreum is a wild blueberry native to the southeastern United States. It is a single-trunk, small tree that is adapted to low-organic matter mineral soils. Furthermore, this species tolerates soil pH up to 6.5 and—contrary to cultivated *Vaccinium*—can assimilate nitrogen in the nitrate form (Darnell and Hiss, 2006), which is the predominant nitrogen form at higher pH. Because of the broader soil adaptation of *V. arboreum* compared with cultivated *Vaccinium* species, studies have examined the use of *V. arboreum* as a rootstock to increase soil adaptability of commercial blueberry production. Ballington (1996, 1998) found that grafting rabbiteye blueberry (*V. virgatum*) onto *V. arboreum* rootstocks increased plant growth and yield compared with own-rooted plants. More recently, Casamali et al. (2016) reported that SHB (*V. corymbosum* interspecific hybrid) grafted onto *V. arboreum* had increased yields compared with own-rooted plants when grown on nonamended soil, and similar yields compared with own-rooted plants on amended soil during the first 2 years of production. Thus, the use of *V. arboreum* as a rootstock for grafted SHB cultivars has the potential to decrease the use of pine bark (or other soil amendments) needed for optimal blueberry production, expand production areas to different soil types, and increase sustainability.

Although results from short-term research trials indicate the potential of using *V. arboreum* as a rootstock for blueberry, data from longer term trials are still needed. The current research continues the work initiated by Casamali et al. (2016) and examines the use of *V. arboreum* as a rootstock for SHB during 4 years after the establishment period. The hypothesis tested in the current research is that SHB grafted onto *V. arboreum* rootstocks have increased growth and yield compared with own-rooted SHB in both pine bark-amended and nonamended soils. The objectives were to evaluate the effects of soil treatment (amended vs. nonamended) and root system (own-rooted vs. grafted onto *V. arboreum*) on canopy growth, yield, berry weight, and berry quality in two cultivars of SHB. In addition, during the course of the experiment, root system differences in susceptibility to bacterial leaf scorch (*Xylella fastidiosa*) were observed; thus, incidence and severity of this disease were also evaluated.

Materials and Methods

Two field plantings of grafted and own-rooted ‘Meadowlark’ and ‘Farthing’ SHB were established in May 2011: one at the

Received for publication 23 Sept. 2019. Accepted for publication 21 Oct. 2019.

Published online 12 December 2019.

This material is based on work supported by the Florida Department of Agriculture and Consumer Services (Award 024045).

R.L.D. is the corresponding author. E-mail: rld@ufl.edu.

This is an open access article distributed under the CC BY-NC-ND license (<https://creativecommons.org/licenses/by-nc-nd/4.0/>).

UF-IFAS Plant Science Research and Education Unit in Citra, FL, and the other at a commercial blueberry farm (Straughn Farms LLC, Archer, FL). These cultivars have high yield potential (Williamson et al., 2014) and were widely planted by the industry at the initiation of this project. At each site, four scion–root system combinations were grown (‘Meadowlark’ and ‘Farthing’ on their own roots or grafted onto *V. arboreum*). Details on the propagation, grafting, and sources of *V. arboreum* rootstocks are given in Casamali et al. (2016). Plants were spaced 0.9 m in the row, with 3 m between rows at the Citra location; and 0.9 m in the row, with 3.3 m between rows at the Archer location. At both locations, the soil is Arrendondo sand, pH $\approx$ 6.0, and organic matter $\approx$ 1.4%. Each scion–root system combination was grown in either pine bark-amended or nonamended soil. The amended treatment consisted of soil amended by incorporating a 10-cm layer of pine bark into the top 20 cm of soil, whereas the nonamended soil did not have any soil amendments incorporated. Experiments were arranged in a split-plot design, with soil treatment as the main plot and the scion–root system treatments as the subplots. Main plots were different rows with six replicates in Citra and eight replicates in Archer. The subplots consisted of eight plants; the first and last plants in the subplots were guard plants, and two data plants were selected from the remaining six plants in the subplot. During the course of the experiment, some of the original data plants lost productivity as a result of disease, including bacterial leaf scorch (discussed later). In those cases, new data plants were selected for growth measurements.

Drip irrigation, fertigation, pest management, and pruning followed the recommendations for Florida blueberry production (Williamson et al., 2018). Soil pH was maintained between 5.0 and 6.0 using 38% sulfuric acid injected through the irrigation system. During the 4 years postestablishment period (2015–18) reported here, plants received 180N–40P–75K kg·ha⁻¹ and 1790 L irrigation water annually per plant in Citra, and 180N–35P–75K kg·ha⁻¹ and 1830 L irrigation water annually per plant in Archer. In both locations, plants received $\approx$ 27% of the fertilizer between 15 Feb. and 15 Apr., $\approx$ 13% between 15 Apr. and 1 June, $\approx$ 56% between 1 June and 30 Sept., and $\approx$ 4% between 30 Sept. and 15 Nov. Hydrogen cyanamide (1.5% v/v) was applied in late December of each year in both locations to improve vegetative budbreak per standard commercial practice. After harvest each year, plants were top-pruned to $\approx$ 1.5 m with a handheld hedger (PP2822; Poulan PRO, Charlotte, NC), and any canes protruding into the row aisle were hedged.

Plant canopy volume was measured at the end of each growing season from 2015 through 2018 in both locations, except Archer in 2018. After fruit harvest in 2018, glyphosate was applied inadvertently to the plants at Straughn Farms in Archer, thus no

further data were available from that location. Canopy volume was determined by measuring plant height and plant diameter in two directions. Because of cultivar differences in canopy shape, a half-ellipsoid equation, Eq. [1], was used to estimate canopy volume in ‘Farthing’ and an elliptic cylinder equation, Eq. [2], was used to estimate volume in ‘Meadowlark’.

$$\begin{aligned} \text{Canopy volume 'Farthing'} \\ &= \frac{2}{3} \times \pi \times \text{Height} \\ &\times \frac{1}{2} \text{Diameter 1} \times \frac{1}{2} \text{Diameter 2} \end{aligned} \quad [1]$$

$$\begin{aligned} \text{Canopy volume 'Meadowlark'} \\ &= \pi \times \text{Height} \times \frac{1}{2} \text{Diameter 1} \\ &\times \frac{1}{2} \text{Diameter 2} \end{aligned} \quad [2]$$

Fruit yield and mean berry weight at both locations were determined throughout the harvest period each year. Berries were hand-harvested two to three times per week, depending on the season. Total seasonal yield was determined at the end of each harvest season and total cumulative yield was calculated for 2015 through 2018. Twenty-five berry subsamples were selected randomly from each plot at each harvest and were weighed to determine mean berry weight. The harvest season was divided into three periods (early-, mid-, and late-season harvest), and the harvest dates of each period were combined to estimate mean berry weight for that period. Seasonal berry weight was then calculated using a weighted average according to the yield of each period.

Fruit quality was determined two or three times during the harvest season from 2015 through 2018 at each location. Berry firmness was measured using a fruit firmness tester (Model Firmtech 2; BioWorks, Wamego, KS) on the subsample used to calculate mean berry weight. Firmness measurements were done on the day of harvest or the following morning after fruit that was stored in a cooler at 4 °C was brought to room temperature. After firmness measurements were taken, berries were frozen at –30 °C until total soluble solids (TSS) and total titratable acidity (TTA) were measured. For analysis, berries were thawed, macerated, and centrifuged at 14,000 g_n for 20 min (Model Sorvall Legend XTR; Thermo Scientific, Waltham, MA). The supernatant was filtered through cheesecloth and TSS was measured with a refractometer (Model AR200; Reichert, Depew, NY). TTA was measured using an automated titrator (Model 719 S Tritino; Metrohm, Riverview, FL) and results are expressed as the percentage of citric acid.

Data from each year (except cumulative yield), each cultivar, and each location were analyzed separately. Treatment means and interactions were compared using PROC GLIMMIX in SAS 9.4 (SAS Institute Inc., Cary, NC). Means were separated using Tukey’s honestly significant difference test at $P \leq 0.05$.

Bacterial leaf scorch symptoms were quantified in ‘Meadowlark’ experimental plots in Citra five times between Aug. 2016 and Nov. 2018. Data were acquired on ‘Meadowlark’ only, because that cultivar exhibits high sensitivity to the disease. Disease incidence was recorded as a percentage of the live plants per plot that had two or more leaves showing characteristic marginal scorch. Disease severity was quantified visually on a 0% to 100% scale for each of the three most symptomatic living plants per plot. For symptoms to be considered caused by bacterial leaf scorch, and therefore quantified, yellow, defoliated stems and dieback had to be associated with leaf scorch and not a result of abiotic factors or fungal diseases. In addition, before symptom ratings, the presence of *X. fastidiosa* in symptomatic leaves and stems was confirmed via real-time polymerase chain reaction at the University of Florida Plant Diagnostic Center, Gainesville, FL. Incidence data were analyzed using PROC NPAR1WAY in SAS 9.4 (SAS Institute Inc.). The Kruskal-Wallis non-parametric test for differences in groups was used, with a Steel Dwass multiple comparison procedure to compare which groups were different. Severity data were analyzed using PROC GLIMMIX in SAS 9.4 (SAS Institute Inc.). Means were separated using Tukey’s honestly significant difference test at $P \leq 0.05$. All ratings were performed by the same individual throughout the duration of the experiment.

Results

Canopy volume. Canopy volume of ‘Meadowlark’ was greater in grafted compared with own-rooted plants and greater on amended compared with nonamended soil at both locations for all years (Table 1). For ‘Farthing’, canopy volume was similar between grafted and own-rooted plants in Citra, except in 2018, when canopy volume was greater in grafted compared with own-rooted plants. In Archer, grafted plants of ‘Farthing’ exhibited greater canopy volume in 2016 and 2017 compared with own-rooted plants, and plants grown on amended soil had greater volume compared with plants on nonamended soil in all years. There were no biologically significant interactions between root system and soil treatment on canopy volume for either cultivar at either location.

Yield. Total yield of ‘Meadowlark’ was significantly greater in grafted compared with own-rooted plants for all years and both locations, except Archer in 2015, where there were no differences (Table 2). ‘Meadowlark’ grown on amended soil had greater yield than plants grown on nonamended soil in Citra for all years and in Archer in 2015 and 2016. There were significant interactions between root system and soil treatment for ‘Meadowlark’ grown in Archer in 2015 and 2016, where yields of own-rooted plants on nonamended soil were significantly less (1758 g/plant) than that of the other three treatments, whereas yields of own-rooted and grafted

Table 1. Effect of root system and soil treatment on canopy volume of ‘Meadowlark’ and ‘Farthing’ southern highbush blueberry from 2015 to 2018, Citra and Archer, FL.

Treatment ^z	Canopy volume (m ³)							
	Meadowlark				Farthing			
	2015	2016	2017	2018	2015	2016	2017	2018
<i>Citra</i>								
Root system								
Grafted	2.33 ^{xy}	2.58*	2.40*	1.95*	1.03	1.08	1.13	1.07*
Own-rooted	1.76	1.54	1.49	1.25	1.09	1.17	1.08	0.94
Soil								
Amended	2.30*	2.36*	2.09*	1.73*	1.19*	1.29*	1.22*	1.10*
Nonamended	1.79	1.78	1.79	1.47	0.93	0.96	1.00	0.92
<i>Archer</i>								
Root system								
Grafted	1.44*	1.83*	1.55*	nd	1.14	0.97*	1.01*	nd
Own-rooted	1.04	1.26	0.96	nd	1.00	0.84	0.79	nd
Soil								
Amended	1.48*	1.77*	1.41*	nd	1.32*	1.03*	1.02*	nd
Nonamended	1.00	1.31	1.10	nd	0.82	0.78	0.78	nd

^zGrafted = cultivars grafted onto *V. arboreum* rootstock; own-rooted = cultivars grown on their own roots; amended = pine bark amended soil; nonamended = native soil.

^yMeans represent main effects.

*Significant differences between treatments within soil or root system, Tukey’s honestly significant difference, $P \leq 0.05$.

nd = data not taken.

Table 2. Effect of root system and soil treatment on yield of ‘Meadowlark’ and ‘Farthing’ southern highbush blueberry from 2015 to 2018, Citra and Archer, FL.

Treatment ^y	Yield (g/plant) ^z							
	Meadowlark				Farthing			
	2015	2016	2017	2018	2015	2016	2017	2018
<i>Citra</i>								
Root system								
Grafted	6,482 ^{xy}	5,928*	3,501*	4,664*	3,234	5,773*	3,719*	6,260*
Own-rooted	4,437	2,137	828	1,802	3,724	2,260	1,488	3,861
Soil								
Amended	6,409*	4,804*	2,654*	3,575*	3,816	5,319*	3,229*	5,634
Nonamended	4,510	3,261	1,675	2,712	3,142	2,714	1,979	4,486
<i>Archer</i>								
Root system								
Grafted	3,999	7,205*	1,794*	2,089*	4,419	6,642*	2,743*	3,782*
Own-rooted	3,563	5,772	473	555	3,762	5,002	1,288	1,918
Soil								
Amended	4,798*	7,271*	1,233	1,302	4,966*	6,724	2,456*	3,092
Nonamended	2,764	5,706	1,033	1,342	3,215	4,920	1,575	2,609

^zPlants that became nonproductive during the experiment were replaced with new data plants, from which subsequent yield data were taken.

^yGrafted = cultivars grafted onto *V. arboreum* rootstock; own-rooted = cultivars grown on their own roots; amended = pine bark amended soil; nonamended = native soil.

^xMeans represent main effects.

*Significant differences between treatments within soil or root system, Tukey’s honestly significant difference, $P \leq 0.05$.

plants on amended soil were similar (5369 and 4226 g/plant, respectively) and greater than yields of own-rooted on nonamended soil (3073 g/plant). In ‘Farthing’, yields were greater in grafted compared with own-rooted plants at both locations for all years except 2015, when there were no differences. ‘Farthing’ grown in amended soil had increased yields compared with those grown in non-amended soil in 2016 and 2017 in Citra, and 2015 and 2017 in Archer. There were no significant interactions between root system and soil treatment in ‘Farthing’.

Cumulative yield from 2015 to 2018 in both locations and both cultivars was significantly less in own-rooted plants grown in nonamended soil compared with the other three treatments (Fig. 1). In Citra, grafted plants on amended soil had greater yields

than own-rooted plants on amended soil for both cultivars, whereas in Archer, cumulative yields were similar between the two.

Berry weight. In Citra, seasonal berry weight was significantly greater for grafted compared with own-rooted plants for both cultivars and all years (Table 3). In Archer, seasonal berry weight was greater in grafted compared with own-rooted ‘Meadowlark’ in 2016 and 2017, and greater in grafted compared with own-rooted ‘Farthing’ in all years except 2015. Soil treatment had minimal effect on seasonal berry weight, and interactions between soil treatment and root system were nonsignificant.

Berry quality. There was no consistent effect of either soil treatment or root system on berry firmness for either cultivar. Firmness was greater in own-rooted compared

with grafted ‘Meadowlark’ grown in Archer in 2016 and 2018 (267 vs. 245 g·mm⁻¹ in 2016 and 270 vs. 257 g·mm⁻¹ in 2017 for own-rooted and grafted, respectively), but was less in own-rooted compared with grafted ‘Meadowlark’ fruit grown in Citra in 2017 (291 vs. 312 g·mm⁻¹, respectively). Similar results were found for ‘Farthing’ (data not shown). There were no consistent effects of treatments on TSS or TTA throughout years or locations for either cultivar. For ‘Meadowlark’ across years and locations, TSS ranged from 11.0% to 11.6% and TTA ranged from 0.41% to 0.44% citric acid, whereas for ‘Farthing’, TSS ranged from 11.7% to 12.5% and TTA ranged from 0.68% to 0.74% citric acid.

Bacterial leaf scorch ratings. Symptom development—as quantified by incidence and severity—was significantly less in grafted compared with own-rooted ‘Meadowlark’ at all sampling dates except those in 2017 (Table 4). There was no significant interaction between soil treatment and root system on disease symptom development.

Discussion

In general, the hypothesis that SHB grafted onto *V. arboreum* rootstocks exhibit increased growth and yield compared with own-rooted SHB in both pine bark-amended and nonamended soils was supported, with a few exceptions depending on cultivar, year, or location. In the two locations, both canopy volume and yield were greater in grafted compared with own-rooted ‘Meadowlark’, except for the 2015 season in Archer. ‘Farthing’, on the other hand, did not exhibit a consistently increased canopy volume in grafted plants, but did exhibit increased yields compared with own-rooted plants in both locations except for the 2015 season. Cultivar differences in the canopy volume response to grafting are likely a result of the different architectures of the two cultivars. ‘Meadowlark’ has long, upright canes and shoots whereas ‘Farthing’ is a bushier plant, with new growth consisting of many internal shoots (Lyrene, 2008, 2010) that would contribute to yield without contributing to canopy volume. Increases in canopy volume, plant height, and/or yield have been reported previously in northern highbush (*V. corymbosum*), rabbiteye (*V. virgatum*), and SHB when grafted onto various *Vaccinium* rootstocks compared with the own-rooted control (Casamali et al., 2016; Galletta and Fish, 1971; Kunitake et al., 2006; Xu et al., 2014).

The lack of significant differences in yield in 2015 may reflect the time required for grafted plants to reach their full yield potential. In the establishment years of this study, Casamali et al. (2016) found that yields the first fruiting year after grafting (2013) were less compared with own-rooted plants, but by the second fruiting year (2014), yields between the two root systems were similar. They attributed the decreased yield in the first fruiting year to an initial reduction in growth resulting from the grafting process. Our

Fig. 1. Effect of root system and soil treatment on cumulative yield of (A) ‘Meadowlark’ and (B) ‘Farthing’ southern highbush blueberry from 2015 through 2018, Citra and Archer, FL. Means represent root $\times$ soil interaction. Means followed by the same letter within location are not significantly different by Tukey’s honestly significant difference, $P \leq 0.05$.

subsequent work suggests that this initial reduction in yield may be followed by 1 or 2 years of similar yields between grafted and own-rooted plants before grafted plants begin to out-yield own-rooted plants.

The cumulative yield between 2015 and 2018 supports the finding that grafting SHB onto *V. arboreum* rootstocks increases yield

compared with own-rooted plants, regardless of soil amendment, although location affected this. In Citra, cumulative yields in both cultivars were greater in grafted compared with own-rooted plants, whether the soil was amended with pine bark or remained nonamended. In Archer, however, grafting increased yields compared with own-rooted

plants only in nonamended soil. The reason for the different responses in the two locations is unclear. It could reflect differences in management practices, irrigation water quality, or soil properties—any of which may have interacted with the two soil treatments, resulting in different responses. Nonetheless, these results indicate that using *V. arboreum* as a rootstock not only has the potential to increase blueberry yield in amended soils, but also increases the tolerance of blueberry to nonamended soils, suggesting that the use of rootstocks could decrease—although not eliminate—the requirement for soil amendments in commercial blueberry production. This increased tolerance may be a result of the lower organic matter requirement (Lyrene, 1997), more efficient nitrate and iron uptake (Darnell and Hiss, 2006), and/or increased tolerance to drought resulting from the deeper root system (Lyrene, 1997) of *V. arboreum* compared with cultivated *Vaccinium*.

Although grafting onto *V. arboreum* rootstocks likely increased yields compared with own-rooted plants by one or more of the mechanisms mentioned earlier, the yield increase in grafted compared with own-rooted ‘Meadowlark’ may also be the result of the apparent increased tolerance of the grafted plants to bacterial leaf scorch, as evidenced by decreased symptom development compared with own-rooted ‘Meadowlark’. Although the healthiest plants were chosen as data plants each year to minimize the confounding effects of bacterial leaf scorch on yield, it is likely that yield of own-rooted ‘Meadowlark’ was decreased to a much greater extent as a result of bacterial leaf scorch than was yield of grafted ‘Meadowlark’. Bacterial leaf scorch disease has been identified in blueberry plantings in the southeastern United States (Brannen et al., 2016, Harmon and Hopkins, 2009) and causes marginal leaf burn that may initially be confined to an individual cane. As the disease progresses, new shoots exhibit decreased diameter, stems become yellowed, leaf abscission occurs, and the plant eventually dies. Blueberry cultivars vary in their susceptibility to the disease (Brannen et al., 2016), as observed in our study, in which ‘Meadowlark’ exhibited much greater susceptibility than ‘Farthing’. Regular insecticide sprays used to kill the insect vector of this disease have been largely ineffective as preventative measures, and there are no postinfection chemical management options (Brannen et al., 2016). Thus, cultural practices that alleviate stress, removal of infected plants from the planting, and selection of tolerant cultivars are the primary means of disease management. Our work suggests that the use of *V. arboreum* rootstocks also imparts increased tolerance to the susceptible cultivar ‘Meadowlark’ and could be a useful tool for controlling the disease. Additional research is needed to elucidate the nature and durability of the resistance conferred by using the *V. arboreum* rootstock.

Table 3. Effect of root system and soil treatment on seasonal mean berry weight of ‘Meadowlark’ and ‘Farthing’ southern highbush blueberry from 2015 to 2018, Citra and Archer, FL.

Treatment ^z	Meadowlark				Farthing			
	2015	2016	2017	2018	2015	2016	2017	2018
<i>Citra</i>								
Root system								
Grafted	2.21* ^y	2.24*	2.66*	2.46*	1.48*	2.22*	2.47*	1.93*
Own-rooted	1.84	1.69	1.67	2.04	1.27	1.97	1.98	1.70
Soil								
Amended	2.08*	1.96	2.05	2.24	1.39	2.13	2.29	1.81
Nonamended	1.98	1.97	2.28	2.25	1.37	2.08	2.15	1.81
<i>Archer</i>								
Root system								
Grafted	2.00	1.78*	2.05*	2.10	1.91	2.10*	2.23*	1.97*
Own-rooted	1.89	1.43	1.57	2.05	2.02	1.88	1.61	1.72
Soil								
Amended	1.88	1.60	1.88*	2.10	1.89	2.06	2.01	1.83
Nonamended	2.01	1.61	1.73	2.04	2.05	1.92	1.83	1.85

^zGrafted = cultivars grafted onto *V. arboreum* rootstock; own-rooted = cultivars grown on their own roots; amended = pine bark amended soil; nonamended = native soil.

^yMeans represent main effects.

*Significant differences between treatments within soil or root system, Tukey’s honestly significant difference, $P \leq 0.05$.

Table 4. Bacterial leaf scorch (*Xylella fastidiosa*) symptom incidence and severity in ‘Meadowlark’ southern highbush blueberry from 2016 to 2018, Citra, FL.

Treatment ^z	<i>Xylella fastidiosa</i> symptoms									
	Incidence (%) ^y					Severity (%) ^x				
	Aug. 2016	Nov. 2016	June 2017	Nov. 2017	Nov. 2018	Aug. 2016	Nov. 2016	June 2017	Nov. 2017	Nov. 2018
Own-rooted/amended	55.6 a	88.3 a	47.3 a	69.4 a	90.0 a	65.0 a	85.7 a	42.9 a	51.2 a	81.1 a
Own-rooted/nonamended	49.3 a	100.0 a	16.5 a	43.6 ab	97.7 a	49.2 a	90.5 a	23.8 a	37.5 ab	75.9 a
Grafted/amended	2.1 b	2.1 b	21.4 a	24.7 ab	12.3 b	4.8 b	4.4 b	12.2 a	10.4 ab	5.8 b
Grafted/nonamended	8.3 b	6.3 b	15.9 a	16.4 b	8.9 b	6.3 b	9.6 b	7.6 a	0.1 b	6.8 b

^zOwn-rooted = cultivars grown on their own roots; grafted = cultivars grafted onto *V. arboreum* rootstock; amended = pine bark-amended soil; nonamended = native soil.

^yData were analyzed using PROC NPAR1WAY and the Kruskal-Wallis nonparametric test for differences in groups, with the Steel Dwass multiple comparison procedure, $P \leq 0.05$. Means followed by the same letter within a column and date are not significantly different.

^xData were analyzed using PROC GLIMMIX. Means followed by the same letter within a column and date are not significantly different by Tukey’s honestly significant difference, $P \leq 0.05$.

Regardless of the mechanism behind increased yields in grafted compared with own-rooted plants, the increase was likely largely a result of increased mean berry weight, which was significantly greater in grafted plants for all years and both cultivars at the Citra location, and generally greater at the Archer site. ‘Meadowlark’ exhibited similar berry weights in grafted and own-rooted plants the last year of the study, suggesting that increased fruit number was also a factor in the observed yield increase. The increase in berry weight in the grafted compared with own-rooted plants was attributed previously to increased drought tolerance of the deeper *V. arboreum* root system compared with *V. corymbosum* (Ballington, 1998). In our study, both grafted and own-rooted plants were irrigated similarly, and no symptoms of water deficit were observed. Thus, improved water status may not be the reason for the increased berry weight in grafted plants.

Although berry weight was generally greater in grafted compared with own-rooted plants, this did not lead to consistent decreases in fruit firmness, contrary to the findings by Casamali et al. (2016) in the establishment years of this study. The reason for the difference is unclear, although many factors, including environment, affect cultivar berry firmness from year to year (Ehlenfeldt and Martin, 2002).

Using *V. arboreum* as a rootstock for SHB did not affect fruit quality consistently com-

pared with own-rooted plants. This is similar to previous work using several species of *Vaccinium* as rootstocks for cultivated blueberry (Ballington, 1998; Casamali et al., 2016; Xu et al., 2014), and further supports results showing positive impacts of using *V. arboreum* as a rootstock on the growth and yield of cultivated blueberry with few, if any, negative impacts after the establishment years.

Using *V. arboreum* as a rootstock for SHB increased yields and decreased development of bacterial leaf scorch symptoms, with no negative impacts on fruit quality. Plants grafted onto *V. arboreum* exhibited increased tolerance to nonamended soils compared with own-rooted plants, suggesting that the use of soil amendments in SHB blueberry plantings in areas where soils are marginal could be reduced. We are currently evaluating *V. arboreum* selections to identify those that have superior attributes in terms of impacts on yield and planting longevity. The performance of these selections under planting systems with decreased soil amendments also needs to be assessed. Finally, though, a complete economic analysis must be done to determine whether the biological and sustainability benefits of using *V. arboreum* rootstocks are feasible financially for growers. The longevity of grafted vs. own-rooted plantings must be included in any

analysis. In the southeast United States, for example, own-rooted blueberry plantings may begin to decline as early as 6 to 7 years after planting; grafting onto *V. arboreum* rootstocks may increase the longevity. In other areas under good growing conditions, where own-rooted plantings are much longer lived, the use of grafting onto a single *V. arboreum* trunk may limit mature plant yield compared with own-rooted plants.

Literature Cited

- Ballington, J.R. 1996. Performance of own-rooted ‘Premier’ rabbiteye blueberry vs. ‘Premier’ grafted on *V. arboreum* through three harvest seasons on a Fuquay soil. HortScience 31:749–750.
- Ballington, J.R. 1998. Performance of own-rooted ‘Premier’ rabbiteye blueberry (*Vaccinium ashei* Reade) compared to ‘Premier’ grafted on *Vaccinium arboreum* Marsh (Sparkleberry) through four harvest seasons. Proceedings of the 8th North American Blueberry Research and Extension Workers Conference. p. 178–181.
- Basile, B. and T.M. DeJong. 2018. Control of fruit tree vigor induced by dwarfing rootstocks. Hort. Rev. 46:39–97.
- Brannen, P., G. Krewer, B. Boland, D. Horton, and C.J. Chang. 2016. Bacterial leaf scorch of blueberry. Circular 922. <<https://extension.uga.edu/publications/detail.html?number=C922&title=Bacterial%20Leaf%20Scorch%20of%20Blueberry>>.
- Casamali, B., R. L. Darnell, A.P. Kovalski, J.W. Olmstead, and J.G. Williamson. 2016. Vegetative

- and reproductive traits of two southern highbush blueberry cultivars grafted onto *Vaccinium arboreum* rootstocks. HortScience 51:880–886.
- Darnell, R.L. and S.A. Hiss. 2006. Uptake and assimilation of nitrate and iron in two *Vaccinium* species as affected by external nitrate concentration. J. Amer. Soc. Hort. Sci. 131:5–10.
- Djidonou, D., X. Zhao, J.K. Brecht, and K.M. Cordasco. 2017. Influence of interspecific hybrid rootstocks on tomato growth, nutrient accumulation, yield, and fruit composition under greenhouse conditions. HortTechnology 27:868–877.
- Ehlenfeldt, M.K. and R.B. Martin. 2002. A survey of fruit firmness in highbush blueberry and species-introgressed blueberry cultivars. HortScience 37:386–389.
- Galletta, G.J. and A.S. Fish, Jr. 1971. Interspecific blueberry grafting, a way to extend *Vaccinium* culture to different soils. J. Amer. Soc. Hort. Sci. 96:294–298.
- Harmon, P. and D. Hopkins. 2009. First report of bacterial leaf scorch caused by *Xylella fastidiosa* on southern highbush blueberry in Florida. Plant Dis. 93:1220.
- Julian, J.W., B.C. Strik, H.O. Larco, D.R. Bryla, and D.M. Sullivan. 2012. Costs of establishing organic northern highbush blueberry: Impact of planting method, fertilization, and mulch type. HortScience 47:866–873.
- Kunitake, H., H. Tsuda, R. Takagi, Y. Ohno, Y. Kurori, K. Yoshioka, T. Kage, T. Ito, and H. Komatsu. 2006. Possibility of wild blueberry Shashanbo (*Vaccinium bracteatum* Thunb.) as rootstock for cultivation of northern highbush blueberry in warm region. Engeigaku Kenkyuu 5:105–110.
- Liu, J., J. Li, X. Su, and Z. Xia. 2014. Grafting improves drought tolerance by regulating antioxidant enzymes activities and stress-responsive gene expression in tobacco. Environ. Exp. Bot. 107:173–179.
- Lyrene, P.M. 1997. Value of various taxa in breeding tetraploid blueberries in Florida. Euphytica 94:15–22.
- Lyrene, P.M. 2008. Southern highbush blueberry plant named ‘Farthing’. Patent PP19341. 14 Oct. 2008.
- Lyrene, P.M. 2010. Southern highbush blueberry plant named ‘FL01-173’. U.S. Patent 21553. 7 Dec. 2010.
- Nunez, G.H., J.W. Olmstead, and R.L. Darnell. 2015. Rhizosphere acidification is not part of the strategy I iron deficiency response of *Vaccinium arboreum* and the southern highbush blueberry. HortScience 50:1064–1069.
- Penella, C., S.G. Nebauer, A. Quinones, A. San Bautista, S. Lopez-Galarza, and A. Calatayud. 2015. Some rootstocks improve pepper tolerance to mild salinity through ionic regulation. Plant Sci. 2390:12–22.
- Williamson, J.G., J.W. Olmstead, G.K. England, and P.M. Lyrene. 2014. Southern highbush blueberry cultivars from the University of Florida. Univ. Fla. Coop. Ext. Serv., HS 1245.
- Williamson, J.G., J.W. Olmstead, and P.M. Lyrene. 2018. Florida’s commercial blueberry industry. Univ. Fla. Coop. Ext. Serv., HS 742.
- Xu, C., Y. Ma, and H. Chen. 2014. Technique of grafting with Wufanshu (*Vaccinium bracteatum* Thunb.) and the effects on blueberry plant growth and development, fruit yield and quality. Scientia Hort. 176:290–296.
- Zhao, X., Q. Liu, M.T. Sanchez, and N.S. Dufault. 2018. Performance of grafted seedless watermelon plants with and without root excision under inoculation with *Fusarium oxysporum* f.sp. *niveum* race 2. HortScience 53:1340–1346.