Influence of Perlite in Peat- and Coir-based Media on Vegetative Growth and Mineral Nutrition of Highbush Blueberry

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Abstract. Peat and coir are commonly used for substrate production of highbush blueberry (*Vaccinium* sp.). Perlite is also typically added to improve drainage and stability of the media. The purpose of the present study was to determine how various combinations of each affect growth and nutrition in highbush blueberry. Two cultivars, ‘Liberty’ northern highbush blueberry (*V. corymbosum* L.) and ‘Jewel’ southern highbush blueberry (interspecific hybrid of *V. corymbosum* L. and *V. darrowii* Camp.), were grown for 3 months in media containing 0%, 10%, 20%, or 30% perlite, by volume, and a 1:0, 2:1, 1:2, or 0:1 ratio of peat and coir. At 95 days after transplanting, total dry weight of the ‘Liberty’ plants was greatest in pure peat and progressively less as more coir or perlite was added to the media. Total dry weight of ‘Jewel’ also declined with increasing amounts of perlite but, in this case, was unaffected by the ratio of peat and coir. The response of the plants to perlite did not appear to be a function of pH or nutrition and was most likely related to the effects of perlite on media water relations. Response to peat and coir, on the other hand, may have been due to nutrition and salinity of the media. In both cultivars, a higher amount of peat in the media improved uptake of N, P, Mg, and S and decreased uptake of K, B, Zn, and Na. Coir, on the other hand, contained higher concentrations of Na and Cl than peat. These findings suggest that the use of high amounts of perlite in the media could be detrimental when growing highbush blueberry in substrate, and some cultivars may grow better in peat than in coir.

Container production is becoming an important competitive growing system for highbush

blueberry (Brazelton, 2017), but information on the best practices for the process is limited. For example, it is unknown which substrates are optimal for regional use in blueberry and whether there are cultivar-specific responses to different components of the media. Successful production of blueberry in a wide range of substrates would give growers flexibility in choosing media and mix ratios based on availability and economics (Mann, 2015).

Previously, we investigated how growth and nutrition of blueberry was influenced by altering the ratios of three common substrates, including peat, coir, and douglas fir bark, in media containing 10% perlite, by volume (Kingston et al., 2017). We found that the plants grew better in media with high proportions of peat or coir in the mix. However, it was unclear whether varying the amount of perlite in the media would have altered the response of the plants to peat and coir. Perlite has a much lower water holding capacity (WHC) than most organic materials and is often added to soilless media to increase drainage and porosity (Grillas et al.,

2001; Heiskanen, 1995a, 1995b; Londra, 2010; Londra et al., 2012). The amount of water retained by perlite will vary with particle size and is generally much higher for the coarse fraction (0.5–1.0 mm) than the finer fraction (0.25–0.50 mm) of expanded perlite used for horticulture (Burés et al., 1997).

Perlite is mined from rhyolitic volcanic minerals and, when used in media, is heated to 800 to 1100 °C to evaporate the water inside and expand the particles (Alkan and Doğan, 1998). Once expanded, the particles are very porous and light and provide a stable component in the media that is resistant to decomposition (Bar-Tal et al., 2019; Bilderback et al., 2005). Peat and coir, on the other hand, decompose and settle over time, eventually reducing the volume of the media (Bar-Tal et al., 2019). Economically, container production of blueberries requires that the plants remain in the same media for at least 4 years (B. Strik, personal observation). Therefore, growers are interested in media with high proportions of stable ingredients such as perlite for container production of highbush blueberry. The stability of perlite is relatively unaffected by acid or microorganisms, and therefore it can last for many years in the media (Bar-Tal et al., 2019). However, the use of high amounts of it can increase nutrient leaching from containers, decrease efficiency of fertilizer use, and negatively impact plant nutrition and growth (Bugbee and Frink, 1986; Munoz et al., 1993). There is also risk of toxic release of Al from perlite in media with low pH (Bar-Tal et al., 2019).

The objective of the present study was to evaluate the effects of using different amounts of perlite in peat- and coir-based media on growth and mineral nutrition of newly potted blueberry plants. We chose two cultivars for the study, including one northern highbush and one southern highbush blueberry. Both types of blueberry are commonly used for substrate production.

Materials and Methods

Experimental setup. Two cultivars, ‘Liberty’ northern highbush blueberry and ‘Jewel’ southern highbush blueberry, were obtained from a commercial nursery (Fall Creek Farm and Nursery, Lowell, OR) as 70-mL plugs and transplanted on 8 Apr. 2016 into 4.4-L pots [19.7 cm in diameter and 16.5 cm in height (#2 Short); Anderson Pots, Portland, OR] filled with one of 16 different media treatments (one plant/pot). The treatments consisted of four rates of perlite (coarse expanded grade; Supreme Perlite Co., Portland, OR), including 0%, 10%, 20%, and 30%, by volume, each of which were combined in a cement mixer with different organic substrates, including sphagnum peat (Sun Gro Horticulture, Hubbard, OR), coir (coconut fiber; Pro Gro Mixes, Sherwood, OR), or a 2:1 or 1:2 mix of peat and coir. Each treatment was replicated five times for a total of 160 plants (2 cultivars × 4 perlite treatments × 4 organic substrate treatments × 5 replicates). The plants were in a temperature-controlled glasshouse at the USDA–ARS–Horticultural

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Crops Research Unit in Corvallis, OR (lat. 44°34'3" N, long. 123°17'19" W) and arranged in a randomized complete block design on two adjacent wire benches. Each bench was illumi-

nated with two 1000-W high-pressure sodium lamps from 0700 to 2100 HR. A thermostat was set to cool the glasshouse at temperatures >27 °C and to heat it at temperatures <15 °C.

Temperature and relative humidity were measured near the top of the canopy of the plants using a shielded temperature/humidity sensor (Humitter 50 YC; Vaisala, Woburn, MA). Solar radiation ($\text{kW}\cdot\text{m}^{-2}$) was also measured using a light meter (LI200X-L; LI-COR Environmental, Lincoln, NE) and converted to photosynthetically active radiation (PAR ; $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$) (Biggs, 1986). Readings from each sensor were recorded every 15 min using a data logger (CR10X; Campbell Scientific, Logan, UT). Mean daily temperature averaged 22.8 °C and ranged from 14.8 to 28.5 °C. Relative humidity and PAR averaged 59% and $28 \text{ mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$, respectively.

Each pot was fertigated daily after transplanting with 100 mL of modified Hoagland's nutrient solution (Hoagland and Arnon, 1938). The solution was adjusted to pH 5.2 with sulfuric acid and contained 5.5 mM N from $(\text{NH}_4)_2\text{SO}_4$, and $(\text{NH}_4)_2\text{HPO}_4 + 1.14 \text{ mM N}$ as a chelating agent used to deliver Ca; 0.51 mM P from $(\text{NH}_4)_2\text{HPO}_4$; 3.07 mM K from K_2SO_4 ; 2 mM Ca from chelated Ca product (ProNatural Calcium; Wilbur Ellis, Aurora, CO); 0.74 mM Mg from $\text{MgSO}_4\cdot 7\text{H}_2\text{O}$; 25 μM Fe from Fe-DTPA; 25 μM B from H_3BO_3 ; 3 μM Mn from $\text{MnCl}_2\cdot 4\text{H}_2\text{O}$; and 4 μM Zn from $\text{ZnSO}_4\cdot 7\text{H}_2\text{O}$. Extra irrigation water was added to maintain drainage at $\approx 25\%$ of the total volume of solution applied. Plants were also irrigated twice on warm and sunny days, as needed, to prevent the pots from drying out.

Measurements. A 100-g air-dry sample of media from each treatment was submitted to a commercial laboratory (Soil Control Laboratory, Watsonville, CA) for initial analysis (before planting) of physical and chemical properties, including bulk density, porosity, particle size distribution, pH, electrical conductivity (EC), organic matter content, available N ($\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$), and other extractable nutrients (P, K, Ca, Mg, $\text{SO}_4\text{-S}$, B, Cu, Fe, Mn, Zn, Na, and Cl). See Kingston et al. (2017) for a description of the procedures used for each analysis.

Leachate was collected every 2 weeks after transplanting, using a modified pour-through method (Wright, 1986). To do so, pots were irrigated with 67 mL of water at $\approx 1 \text{ h}$ after fertigation, and 50 mL of leachate was collected from saucers placed under the pots. Samples from three pots per treatment were then stored in glass vials at 3 °C and later analyzed for pH and EC using a pH/ion/conductivity meter (model SevenGo Duo pro with an InLab Expert Pro-ISM-IP67 probe

Fig. 1. (A) Bulk density and (B) particle size distribution in media with 0%, 10%, 20%, or 30% perlite, by volume ($n = 16$). Means are pooled across treatments with different ratios of peat and coir in the media (peat, 2 peat : 1 coir, 1 peat : 2 coir, and coir). Spearman Rank Order correlations indicate that bulk density and larger particles (2–4 and >4 mm) were positively related to percent perlite in the media ($\rho = 0.47, 0.86$, and 0.67 , respectively), while smaller particles (<2 mm) were negatively related to percentage of perlite ($\rho = -0.85$) ($P < 0.05$).

Fig. 2. (A) Physical [solids, water holding capacity (WHC), and air space] and (B) chemical (pH and EC) properties of peat and coir-based media ($n = 16$). Means are pooled across treatments with different percent perlite in the media (0%, 10%, 20%, or 30%, by volume). Spearman Rank Order correlations indicate that percent solids were positively related to the relative proportion of peat in the media ($\rho = 0.73$), while air space, pH, and EC were negatively related to the relative proportion of peat ($\rho = -0.85, -0.91$, and -0.78 , respectively) ($P < 0.05$).

Table 1. Extractable nutrients in peat- and coir-based media.^a

Organic substrate	Extractable nutrients (mg·L ⁻¹)												
	NH ₄ -N	NO ₃ -N	P	K	Ca	Mg	SO ₄ -S	B	Cu	Fe	Mn	Zn	Na
Peat	1.8	13.4	2	106	1081	563	10	0.3	0.2	102	23	3.0	116
2 peat: 1 coir	2.0	1.8	11	864	938	459	10	0.4	0.4	80	16	2.9	249
1 peat: 2 coir	1.6	0.8	23	1469	778	377	11	0.6	0.5	55	12	2.9	372
Coir	1.5	0.5	34	1829	535	259	12	0.7	0.5	19	10	5.0	448
Spearman's ρ^y	0.64	0.81	-0.97	-0.88	0.81	0.92	NS	-0.93	-0.90	0.95	0.94	NS	-0.98

^aMeasured before planting using a 100-g sample of each media ($n = 16$). Means are pooled across treatments with different percentages of perlite in the media (0%, 10%, 20%, or 30%, by volume).

^bValues indicate a significant positive or negative relationship between nutrient concentration and the relative proportion of peat in the media ($P \leq 0.05$).

NS = nonsignificant.

for pH, and an InLab 738 ISM conductivity probe for EC; Mettler-Toledo, Columbus, OH). The vials were placed in a water bath during the measurements and maintained at 25 °C.

The plants were harvested destructively at 95 d after transplanting. Five additional plants were harvested before transplanting (day 0). The shoots were cut off at the surface of the media on each date, rinsed with distilled water, and separated into stems (canes) and leaves. The media was then removed from the pots (or plug trays at day 0) and washed under running water to collect the roots. Each plant component was oven-dried at 60 °C, weighed, and ground to pass a 1-mm screen. About 1 g of the ground samples was analyzed for N using a combustion analyzer (TruSpec CN; Leco Corp., St. Joseph, MI), and another 1 g of each sample was digested in a microwave using 70% (v/v) nitric acid and analyzed for P, K, S, Ca, Mg, Fe, B, Cu, Mn, Zn, and Na using an inductively coupled plasma-optical emission spectrometer (Perkin Elmer Optima 3000DV; Wellesley, MA) (Gavlak et al., 2005; Jones and Case, 1990). Reference standard apple [*Malus × sylvestris* (L.) Mill. var. *domestica* (Borkh.) Mansf.] leaves (no. 151, National Institute of Standards and Technology) were included in each set of samples to ensure accuracy of the instruments and digestion procedures. Total content of each nutrient in the plants was calculated by multiplying tissue dry weight by the concentration of the nutrient and taking the sum of each tissue (leaves, stems, and roots). Total uptake of each nutrient was then calculated as the difference between total content at 0 and 95 d after transplanting.

Data analysis. All data were analyzed using Statistica analytical software (ver. 13; Dell, Inc., Tulsa, OK). Spearman Rank Order correlation (ρ) was used to estimate correlative relationships between physical and chemical properties of the media mixtures with the various ingredient proportions and plant dry weight ($n = 16$). Total dry weight was evaluated by analysis of variance (ANOVA). Cultivar and the percentage of perlite and peat in the media were treated as fixed effects. The percentage of coir in the media was inversely related to the percentage of peat, and therefore was not included in the model. Total uptake of each nutrient in the plants was also evaluated by ANOVA, but in this case, total dry weight was used as a covariate to account for differences in plant growth among the treatments (Scagel et al., 2008). Likewise, leachate volume was used as a covariate in the analysis of leachate pH and EC. Contrast analysis was used to examine significant responses of the variables to the percentage of peat or perlite in the media. To meet statistical assumptions for variance of residuals and normal distribution, data on total uptake of B and Cu in the plants were transformed using a natural logarithm and back-transformed for presentation.

Results and Discussion

Initial physical and chemical properties of the media. Perlite increased bulk density and the proportion of larger particles in the media (Fig. 1). It also had a slight effect on the concentration of extractable Zn in the

media (5.1, 3.1, 2.9, and 2.7 ppm Zn with 0%, 10%, 20%, and 30% perlite; $\rho = -0.55$) but had no effect on air space, WHC, pH, EC, or concentration of the other nutrients in the media, including available $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ and extractable P, K, Ca, Mg, $\text{SO}_4\text{-S}$, B, Cu, Mn, or Na ($P > 0.05$). Usually, coarse substrates such as perlite increase porosity and drainage and reduce WHC of the media (Fields et al., 2014; Kingston et al., 2017). However, Rhie and Kim (2017) found that it took at least 40% perlite to reduce WHC in substrate mixes with coir dust. Fields et al. (2014) suggested that small particles in the media can settle into large pore spaces in perlite and, thereby, reduce potential differences in porosity and WHC.

Water holding capacity was also unaffected by the organic substrates, which averaged 62%, regardless of the proportion of peat or coir in the mix (Fig. 2A). However, coir increased air space, pH, and EC relative to peat (Fig. 2A and B) and resulted in higher concentrations of P, K, B, Cu, and Na and lower concentrations of $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, Ca, Mg, Fe, and Mn (Table 1). Despite rinsing the substrate before use, coir also resulted in much higher concentrations of Cl, particularly when little or no perlite was added to the media (Fig. 3). Salinity is variable among different sources of coir and, therefore, can be problematic when coir is used as a primary substrate for container production (Konduru et al., 1999).

Leachate pH and EC. The pH and EC of leachate from the pots decreased over time ($P < 0.0001$) and were affected by perlite ($P = 0.0250$) and peat and coir ($P < 0.0001$) in the mix. However, neither were affected by cultivar or interactions among the treatments. On average, pH and EC were lower with 30% perlite than with 20% perlite or less (Fig. 4A)

and were higher with increasing amounts of coir in the mix (Fig. 4B). In most treatments, pH was within a range of 4.5–5.5, which is recommended for northern and southern highbush blueberry (Retamales and Hancock, 2018). However, pH dropped to 4.0 with 30% perlite in the mix and to 3.8 with peat. Aluminum becomes more available at low pH (Bar-Tal et al., 2019), which could damage the roots and impede plant uptake of immobile nutrients such as $\text{NH}_4\text{-N}$, P, and Fe (Marschner, 2012). Leachate EC, on the other hand, was somewhat high initially in many treatments but, within a few weeks, dropped to $<2 \text{ dS m}^{-1}$, which is considered safe for salt-sensitive crops such as blueberry (Machado et al., 2014).

Plant growth. Total dry weight of the plants was significantly affected by a three-way interaction among cultivar, perlite, and the

Fig. 3. Concentration of extractable Cl in media with 0%, 10%, 20%, or 30% perlite, by volume, and different organic substrates, including peat, 2 peat: 1 coir, 1 peat: 2 coir, or coir ($n = 16$). Spearman Rank Order correlations indicate that the concentration of Cl was negatively related to percent perlite ($\rho = -0.58$) and the relative proportion of peat ($\rho = -0.88$) in the media ($P < 0.05$).

Fig. 4. Leachate pH and EC from pots of ‘Jewel’ and ‘Liberty’ blueberry grown in media containing 0%, 10%, 20%, or 30% perlite, by volume, and different organic substrates, including peat, 2 peat: 1 coir, 1 peat: 2 coir, or coir. Means are pooled across (A) cultivars and peat:coir ratios or (B) cultivars and percent perlite in the media. Error bars represent 95% confidence intervals.

proportion of peat and coir in the media ($P = 0.0158$). In terms of dry weight, ‘Liberty’ grew best in pure peat and had progressively less growth as more coir or perlite was added to the media (Fig. 5A). ‘Jewel’ also had less growth with more perlite in the media, but unlike ‘Liberty’, it was unaffected by the proportion of peat and coir in the mix (Fig. 5B). Apparently, ‘Liberty’ was sensitive to high pH and/or high salinity in the coir, whereas ‘Jewel’ was not. In general, southern highbush cultivars such as Jewel appear to be more tolerant to high salinity than northern highbush cultivars such as Liberty (J. Umble, personal communication). However, it is unclear why both cultivars had a negative response to perlite. As mentioned, perlite had no measurable effect on porosity, WHC, or essential nutrients in the media. Bunt (1983) observed that perlite reduced easily available water (defined as the quantity of water released at -1 to -5 kPa) in peat, particularly when used at volumes $>25\%$ in the mix. Perhaps perlite led to water stress between irrigations in the present study. Water stress is frequently observed at relatively high water potentials in potted

plants due to a strong increase in hydraulic resistance at the interface between the roots and the growing media (Allaire-Leung et al., 1999; Caron et al., 1998; da Silva et al., 1993; Heiskanen, 1995a, 1995b; Naasz et al., 2005, 2008). Adding large particles of perlite would likely exacerbate this problem and further increase hydraulic resistance between the roots and the media (Londra et al., 2018).

In both cultivars, total dry weight of the plants was positively correlated with initial measures of organic matter content ($\rho = 0.52$ in ‘Jewel’ and ‘Liberty’) and total available N ($\rho = 0.60$ in ‘Jewel’ and 0.68 in ‘Liberty’) in the media. Total dry weight was also positively correlated with small particle sizes in the media ($0-2$ mm, $\rho = 0.69$) in ‘Jewel’ and was negatively correlated with the concentration of Cu, Na, and Cl in the media in ‘Liberty’ ($\rho \geq -0.51$).

Nutrient uptake. Total uptake of numerous nutrients in the plants was affected by cultivar and the proportion of peat and coir in the media (Table 2). However, total uptake of each nutrient was unaffected by the percent perlite in the media or, with the exception of

Mn, by interactions among the treatments. On average, both cultivars took up more N, P, Mg, and S and less K, B, Zn, and Na when they were grown in substrates with more peat than coir. Handreck (1993) observed that N availability declined in coir and attributed it to N immobilization by the substrate. In contrast, adding more peat to the media increased N in the present study, including availability of $\text{NH}_4\text{-N}$ (Table 1), which is considered preferable over $\text{NO}_3\text{-N}$ in blueberry (Rosen et al., 1990). However, peat reduced the amount of P in the substrate and had no effect on S or Zn. In this case, greater P uptake in peat may have been a function of the pH of the media (Marschner, 2012). As mentioned, leachate pH was initially lower with peat (Fig. 4B), and low pH can increase the availability of P in substrate (Altland and Buamscha, 2008). Peat also reduced pH and increased uptake of P relative to coir in our previous study on ‘Snowchaser’ blueberry (Kingston et al., 2017).

Much like N, differences in uptake of other nutrients, including K, Mg, B, and Na, appeared to be related to the initial concentration of each in the media. Plant uptake of these nutrients is driven largely by the concentration in the root zone (Silber et al., 2003). For example, peat contained much less K than coir in the present study (Table 1). In fact, the initial concentration of K in peat-based media was in a range considered deficient for soil-grown blueberry plants (i.e., <150 ppm K; Hart et al., 2006). The initial concentration of K in coir, on the other hand, was very high. Consequently, K uptake was greater when the plants were grown with coir than with peat (Table 2). Clearly, the use of coir in the media would reduce the need for K fertilizer initially, but it might increase the need for Ca and Mg (Handreck, 1993). High levels of K in either soil or potting media have been shown to limit uptake of Ca and Mg in many plants, including blueberry (Kingston, 2017; Strik et al., 2019). In the present study, Mg uptake was inversely related to the initial

Fig. 5. Effect of media composition on total dry weight of (A) ‘Liberty’ and (B) ‘Jewel’ blueberry. The plants were grown for 95 d in media with 0%, 10%, 20%, or 30% perlite, by volume, and different organic substrates, including peat, 2 peat: 1 coir, 1 peat: 2 coir, or coir. L_p indicates the response to perlite in the media is linear within a given peat:coir ratio, while L_{os} indicates the response to the relative proportion of peat in the media is linear within a given percentage of perlite ($P \leq 0.05$).

Table 2. Nutrient uptake by ‘Liberty’ and ‘Jewel’ blueberry grown for 95 d in media with 0%, 10%, 20%, or 30% perlite, by volume, in combination with different organic substrates, including peat, 2 peat: 1 coir, 1 peat: 2 coir, or coir ($n = 5$).

Treatment ^z	Nutrient uptake (mg/plant)									
	N	P	K	Ca	Mg	S	B	Cu	Zn	Na
Cultivar										
Liberty	472	56	264	140	63	119	1.4	0.37	1.3	6.4
Jewel	444	49	267	135	64	96	1.6	0.31	1.1	7.8
Significance	***	***	NS	NS	NS	***	**	*	**	*
Perlite										
No perlite	463	52	258	142	62	106	1.5	0.38	1.1	6.1
10% perlite	458	51	259	137	62	107	1.5	0.33	1.1	6.5
20% perlite	453	54	267	132	64	108	1.5	0.32	1.2	7.7
30% perlite	457	54	276	139	65	109	1.6	0.34	1.1	6.9
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Organic substrate										
Peat	492	56	257	137	66	114	1.4	0.33	1.1	4.7
2 peat: 1 coir	471	53	260	136	65	111	1.5	0.34	1.1	5.9
1 peat: 2 coir	442	50	264	136	60	103	1.5	0.35	1.2	7.7
Coir	425	48	278	140	58	100	1.6	0.35	1.2	10.0
Significance ^y	L***	L***	L*Q***	NS	L**	L*	L*	NS	L*	L***Q***

^zData were analyzed by ANCOVA using plant dry weight as a covariate (see Fig. 5). Two- and three-way interactions among the treatments were nonsignificant ($P > 0.05$).

^yL and Q indicate the response to the relative proportion of peat in the media is linear or quadratic.

NS, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01 , or 0.001 , respectively.

Fig. 6. Effect of media composition on uptake of Mn in (A) 'Liberty' and (B) 'Jewel' blueberry. Plants were grown for 95 d in media containing 0%, 10%, 20%, or 30% perlite, by volume, and different organic substrates, including peat, 2 peat: 1 coir, 1 peat: 2 coir, or coir. L_p indicates the response to perlite in the media is linear within a given peat:coir ratio, while L_{OS} indicates the response to the relative proportion of peat in the media is linear within a given percentage of perlite ($P \leq 0.05$).

Table 3. Concentration of Na in the leaves, canes, and roots of 'Liberty' and 'Jewel' blueberry grown for 95 d in media with 0%, 10%, 20%, or 30% perlite, by volume, in combination with different organic substrates, including peat, 2 peat: 1 coir, 1 peat: 2 coir, or coir ($n = 5$).

Treatment ^z	Na concn (ppm)		
	Leaves	Canes	Roots
Cultivar			
Liberty	121	346	354
Jewel	130	276	351
Significance	NS	**	NS
Perlite			
No perlite	77	276	327
10% perlite	117	292	340
20% perlite	207	358	376
30% perlite	101	318	368
Significance ^y	Q*	NS	NS
Organic substrate			
Peat	74	199	264
2 peat: 1 coir	90	273	302
1 peat: 2 coir	140	327	358
Coir	197	445	487
Significance ^y	L*	L***	L***

^zInteractions among cultivar, perlite, and organic substrate are nonsignificant.

^yL and Q indicate the response to percent perlite or the relative proportion of peat in the media is linear or quadratic.

NS, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

concentration of K in the media and was positively correlated with the initial concentration of Mg in the media, which was greater in peat than in coir.

Manganese was the only nutrient in which uptake was affected by an interaction among cultivar, perlite, and the proportion of peat and coir in the media ($P = 0.0108$). 'Liberty' took up progressively more Mn when the plants were grown in media with more peat and took up progressively less Mn when they were grown in media with more perlite (Fig. 6A). 'Jewel' also took up slightly less Mn with more perlite in the media, but in this case, it was only in peat, and uptake was unaffected by the proportion of peat and coir in the mix (Fig. 6B). Any differences in uptake were likely related to pH of the media. Typically, Mn uptake increases as pH declines in soil or growing media (Marschner, 2012). In

our case, pH was lower in media with less perlite and more peat (Fig. 4). However, the concentration of Mn in recently expanded leaf tissue was similar among treatments (131–167 ppm) and well within the range recommended for northern highbush blueberry (30–350 ppm; Hart et al., 2006).

The effect of the media on Na uptake was particularly noteworthy. Sodium uptake was higher in 'Jewel' than in 'Liberty' and two times greater in coir than in peat (Table 2). Plants grown with coir had elevated concentrations of Na in each plant tissue, including the leaves, canes, and roots (Table 3). Interestingly, the plants also had higher concentration of Na in the leaves when they were grown with perlite. However, leaf Na was lower with 30% than with 20% perlite, and there was no evidence of salt damage (e.g., marginal leaf necrosis) in any treatment. Addition of high amounts of perlite can dilute salts such as Na in the media (Rhie and Kim, 2017). Muralitharan et al. (1992) observed that >200 ppm Na in the leaves was needed to cause damage in 'Bluecrop' northern highbush blueberry. Salt sensitivity has also been reported in rabbiteye blueberry (*V. virgatum* Aiton) but at much higher concentrations of leaf Na (>700 ppm) than observed in northern highbush blueberry (Spiers, 1983).

Conclusion

In most cases, adding perlite to the media resulted in less plant growth in highbush blueberry. However, perlite had little effect on nutrient composition of the media or on plant nutrient uptake. This suggests that the influence of perlite on plant growth was largely unrelated to plant nutrition and more likely due to its influence on irrigation and water relations of the media. In contrast, peat increased plant growth relative to coir in one of the two cultivars tested, which was apparently due to its effect on plant nutrition and salinity in the media. Peat contained much less salt than the coir used in the study and improved plant uptake of nutrients such as N, P, Mg, and S. Currently, most substrate production of blueberry is done in arid regions such as southern California, Mexico, Spain,

and Portugal. Unless reverse osmosis water is used, irrigation water quality is often high in salts such as NaCl and carbonates and bicarbonates in these locations (J. Umble, personal communication). Coir would compound this problem by contributing to salinity. The next step is to evaluate the long-term effects of different substrates on fruit production and quality in highbush blueberry.

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