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Research Report

Influence of Biochar Amendment on Herb Growth in a Green Roof Substrate

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Abstract. The objectives of this research were: 1) to assess the effect of biochar incorporation on the growth of basil (*Ocimum basilicum* 'Genovese Compact, Improved') and peppermint (*Mentha* × *piperita*) and, 2) to determine the physical characteristic differences in heat-expanded clay (HEC) substrate following incorporations of biochar at 5%, 10%, or 15% (by volume). A commercially-available green roof substrate, Rooflite Intensive Ag (IA) substrate, was included for comparison. The IA substrate had the highest total porosity (TP), container capacity (CC), and air-filled porosity (AP). The HEC substrate showed a linear increase in TP and CC and a linear decrease in dry bulk density with increasing amounts of biochar. The commercially available IA substrate had the highest water retention (CC = 25.0%). Overall, there was a maximum increase of peppermint shoot dry weight (g/shoot) response in the HEC substrate using 15% biochar. Coverage area measurements indicated that peppermint benefited more than basil from the incorporation of biochar. Biochar alone did not influence stomatal conductance, although basil or peppermint grown in the IA substrate had higher stomatal conductance than plants grown on HEC with all three biochar incorporation rates at 3 and 4 d after irrigation, probably due to the lower aboveground biomass of the IA-grown plants. In conclusion, the addition of biochar amendment to HEC substrate had a minor influence on peppermint growth and no influence on stomatal conductance of either basil or peppermint.

***Additional key words*:** basil, heat-expanded clay, peppermint, roof garden

Introduction

Biochar is a product of the pyrolysis of organic material and is becoming increasingly popular as a soil amendment. Different biochars impart varying properties to the soil in which they are added; some increase pH and macronutrients while others contribute more significantly to enhanced carbon sequestration and contaminant absorption (Dai et al., 2013). The reported benefits of biochar incorporation were reviewed by Sohi et al. (2010), and include carbon sequestration, microbial stimulation, and improved soil chemical and physical characteristics. The latter two potential benefits are commonly attributed to enhanced nutrient availability and increased water retention within soil. Nonetheless, exact mechanisms for improved plant growth through biochar additions are not well-defined. Bean (*Phaseolus vulgaris* L.) yield increased with biochar soil additions due to higher biological nitrogen fixation (Rondon et al., 2007). Applications of biochar to a sand-based substrate increased water retention following 25% (by volume) incorporations and higher biochar concentrations increased electrical conductivity (EC), pH, and total organic carbon content. Increasing biochar concentrations also resulted in a reduction of nitrogen leaching (Brockhoff et al., 2010). Amendments of biochar contribute significant amounts of nutrients to media, particularly phosphate and potassium (Atland and Locke, 2013), and in soilless media, biochar additions affected nitrate, phosphate, and potassium concentrations and leaching rates (Atland and Locke, 2012). Different types of biochar impart different beneficial properties to the soil in which they are added; some biochars increase pH while others contribute to nutrient retention, carbon sequestration, and/or contaminant absorption (Dai et al., 2013). A wood-derived biochar resulting from fast-pyrolysis increased microbial biomass and changed microbial composition to one dominated by gram-negative bacteria (Gomez et al., 2014). Huang et al. (2013) concluded that biochar amendments increased soil quality and rice (*Oryza sativa* L.) yield under nitrogen fertilizer regimes. Additional research by Huang et al. (2014) indicated that biochar: (1) increased grain yield of rice by 8-10%, (2) increased fertilizer uptake of rice by 23-27%, and (3) decreased nitrogen loss by 9-10%. Observed changes in soil properties resulting from biochar incorporation included decreased soil bulk density, increased saturated hydraulic conductivity, increased soil organic matter, and increased microbial activity; differences between wood-derived biochar versus dairy manure-derived biochar included higher water content in the former (Lei and Zhang, 2013). Biochars derived from high-temperature pyrolysis had relatively high pH values; woodchip-derived biochars had a higher carbon-to-nitrogen ratio than did dairy manure-derived biochar (Lei and Zhang, 2013). Addition of 7% biochar (by weight) to a green roof substrate containing gravel, sand, silt, clay, and screened pumice resulted in increased water retention and reduced leaching of total nitrogen, total phosphorous, nitrate, phosphate, and organic carbon (Beck et al., 2011).

Biederman and Harpole (2013) conducted a meta-analysis of 371 different studies to assess the effects of biochar application on plant productivity and nutrient cycling. They found that on average, biochar application increased above-ground productivity, crop yield, soil microbial biomass, and nutrient concentrations in both plant tissues (K) and soil (total N, P, K, and total C). The effects of biochar on herb growth is variable, possibly due to the different potting substrates used in the different experiments. In a study investigating the effects of the combined application of biochar and chemical fertilizer, Pandey et al. (2016) found that the applications increased biomass and essential oil yield in basil (*Ocimum basilicum*). While this study used air-dried soil with low organic carbon content, a different study by Goldy and Wendzel (2014) used a potting mix with a high organic matter content. They found that the addition of biochar at varying volumes (0.5-8.0%) to Morgan's 301 soil mix in a high tunnel, polybag growth system did not increase yield or quality of cucumber, tomato, spinach, basil, Swiss chard, lettuce, or snap dragon (Goldy and Wendzel, 2014).

Two of the most critical factors for sustaining plant health on a vegetated roof are green roof substrate composition and substrate depth, and increasing depth of green roof substrate improved plant growth and survival (Durhman et al., 2007; Getter and Rowe, 2008; Getter and Rowe, 2009). Substrate depth and associated water availability were vital to the survival of herbaceous plants on green roofs and these types of plants may require deeper substrate, increased organic matter, and/or supplemental irrigation compared to commonly planted succulents (Rowe et al., 2006). Two herbaceous perennials had increased survivability in heat-expanded clay (HEC) rather than heat-expanded shale media when subjected to early drought in 60 mm of media and to late drought in 30 mm of media (Thuring et al., 2010).

Optimal physical and chemical characteristics of green roof media are summarized by Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e. V. (FLL, 2008). Optimal container capacity (water storage ability) varies from ≥ 35% or ≥ 45%, respectively, for extensive/shallow-depth and intensive/deep depth green roofs; aeration porosity should be > 10%, or ≥ 20% at an applied suction pressure of -6.3 kPa (FLL, 2008). The pH values for all green roofs should be between 6.0 and 8.5 (FLL, 2008). A variety of substrate components have been studied for use on green roofs including gravel and soil with organic matter including biochar (Beck et al., 2011), HEC granules with compost and loam (Dunnett and Nolan, 2004), heat-expanded slate with compost and hydrogel (Olszewski et al., 2010), heat-expanded slate with sand, Michigan peat and compost (Rowe et al., 2006), heat-expanded shale with sand and compost (Whittinghill et al., 2013), sandy loam soils amended with urea-formaldehyde resin foam, peat moss and/or perlite (Panayiotis et al., 2003), and other selective materials (reviews by Friedrich, 2008; Skinner, 2005). HEC medium is commonly used in green roof substrates and has been evaluated for both physical and chemical properties (Olszewski and Young, 2011).

Growing horticultural crops on roof tops presents unique challenges and there have been few research studies concerning crop growth on green roofs. Typically, plants are selected for installation on extensive (shallow) green roofs based on the characteristics of low-maintenance and drought tolerance. Perennials, including succulent evergreen species of *Delosperma* N.E.Br., *Sedum* L., and *Sempervivum* L., and herbaceous perennials, like *Allium* L. and *Dianthus* L., are the most commonly used for their ability to survive under harsh conditions (Durhman et al., 2007). While the goals of green roof installations may vary from region to region (Getter and Rowe, 2006), these systems are not typically aimed at quick production of plant biomass. Installation, management issues, and cost to grow food on green roofs are all important factors to consider; however, basic information such as suitable crop species and issues related to repeated yearly plantings are largely unknown (Whittinghill and Rowe, 2011). It is possible to grow vegetables and herbs on a green roof, although there may be yearly variations in yield (Whittinghill et al., 2013).

The present experiment was conducted to assess the effects of biochar application as an amendment in HEC green roof substrate. Two high-value herbs, basil and peppermint, were selected for the trial. Basil is an annual species with an erect habit, while peppermint is a rhizomatous perennial with a more spreading habit. Both species are adapted to moist environments and therefore would serve as good indicators of water stress (Simon et al., 1992; Alkire and Simon, 1993; Ekren et al., 2012). The objectives of the following research were: 1) to determine the physical characteristics of green roof substrate amended with different amounts of biochar, and 2) to determine the effect of biochar additions on the growth and water relations of basil and peppermint.

Materials and Methods

Plant Materials

Seeds of 'Genovese Compact, Improved' basil (*Ocimum basilicum*; Johnny's Selected Seeds, Fairfield, ME, USA) and peppermint (*Mentha* × *piperita*; Park Seed, Hodges, SC) were sown into Sunshine Redi-Earth Professional Growing Mix (55-65% Canadian *Sphagnum* peat moss with vermiculite and dolomite; Sun Gro Horticulture; Agawam, MA, USA) contained in six-pack inserts. After germination, plants were fertilized alternating every two weeks with 100 or 150 ppm N using 20N-3.2P-16.6K and 13N-0.6P-10.8K (Peter's Professional; Everris, Dublin, OH, USA). Twelve-week-old plants were transplanted into green roof substrate contained in 11.7 cm-tall × 10.5 cm-wide squared plastic pots containing test substrate and grown for nine weeks.

Substrate Treatments

Blended substrates were prepared in 10-liter batches consisting of fine-grade heat-expanded clay (HEC, < 3.2 mm particle size; Garick Corp., Cleveland, OH, USA), a commonly used green roof substrate, and biochar (< 3 mm grade; product of slow pyrolysis; Biochar Now, Loveland, CO); the biochar was added at 5%, 10%, and 15% (by volume) to the HEC. Rooflite Intensive Ag commercial substrate (IA substrate; Skyland USA, Landenberg, PA, USA) was included for comparative purposes. IA is marketed as consisting of blended materials designed for the purpose of growing food crops on green roofs. Initial moisture content was estimated using an IR-35 moisture analyzer (Denver Instrument Company, Denver, CO, USA) and was determined to be 29.3% ± 3.2, 6.2% ± 1.5, and 26.1% ± 1.6 (mean ± standard deviation; $n = 4$) for the IA substrate, Biochar, and HEC, respectively (%, by weight following 110°C drying until no further water loss occurred). Controlled-release fertilizer (CRF) 14.0N-6.1P-11.6K fertilizer (Scotts-Sierra Horticultural Products Company, Marysville, OH, USA) was added to each substrate blend at a concentration of 5.04 $kg \cdot m^{-3}$. Then, each substrate was hand-mixed followed by five minutes of additional blending in a cement mixer. CRF used in this study (2 to 3 months longevity at 26.7°C) contained 8.2% ammoniacal nitrogen, 5.8% nitrate-nitrogen, potassium sulfate, ammonium phosphate, and calcium phosphate. The CRF concentration was selected based on labelled recommendations for use in landscapes.

Substrate Physical and Chemical Property Determination

The physical properties of the green roof substrates were determined using four replications. For testing the physical properties of the blended green roof substrates, 17-cm tall × 17-cm diameter modified Buchner funnel removable cylinders (volume = 3,419.1 to 3,435.1 cm^3) were filled with substrate and subjected to the procedures described by Wang and Gregg (1990) and Spomer (1990). Substrate-filled cylinders were placed in a large container and sub-irrigated with distilled water until the top of the substrate was 'glistening', indicating complete saturation. Following saturation, the cylinder and substrate were removed and weighed. Total porosity was determined from the amount of water needed to saturate the substrate divided by cylinder volume, then multiplied by 100. Cylinders with substrate were covered and allowed to drain for one day before weighing again. Container capacity equaled the amount of water retained after drainage divided by cylinder volume, followed by multiplication by 100. Air-filled porosity equaled total porosity minus container capacity. Dry bulk density was determined by methods described by Tan (2005).

Particle size distribution was determined by screening using four air-dried 100 g samples of each mix placed into the top of a sieve series with mesh diameters of 9.5 mm, 4 mm, 2 mm, 1 mm, 0.5 mm, and 0.053 mm. Samples were shaken for three minutes with a Ro-Tap shaker (W.S. Tyler, Mentor, OH, USA). Particles in each sieve and receiver pan were weighed and percentages were determined based on the total weight of the sample.

Plant Growth Responses

Greenhouse photosynthetically active radiation (PAR) at mid-day averaged 301 $\mu mol \cdot m^{-2} \cdot s^{-1}$, with natural light supplemented with high-pressure sodium lamps. Stomatal conductance (g_s) was measured using a portable leaf porometer (Model SC-1, Decagon Devices, Pullman, WA, USA). The porometer was calibrated according to manufacturer directions (Decagon Devices, Inc. 2014) and readings were taken for four successive days following the final irrigation event at the end of the plant growth experiment (16 Feb. 2015 through 19 Feb. 2015). The measurements were made at mid-day between 12:00 and 14:00 local time with average temperatures of 21, 23, 23, and 20°C on 16 Feb. 2015, 17 Feb. 2015, 18 Feb. 2015, and 19 Feb. 2015, respectively. Each g_s measurement was taken from an expanded, non-shaded leaf located two leaves below the apical meristem.

Plant coverage area was determined via a photograph of each single plant replicate using a 55-mm EOS Rebel XT digital camera (Canon Inc., Tokyo, Japan). A 25.52 cm^2 standard was photographed, printed, cut out, and weighed, and coverage area was determined relative to the standard. Shoots were cut at the surface of the medium, dried at 70°C for 48 h, and weighed.

Determinations of initial and final pH (pH Testr20, Oakton Instruments, Vernon Hills, IL, USA) and electrical conductivity (EC; EC Testr11 plus, Oakton Instruments, Vernon Hills, IL, USA) for each medium were made by a 1:2 dilution test [1 substrate: 2 distilled water (by volume)].

Statistical Analysis

Averaged values for plant growth and physiological parameters were calculated and standard deviation was used as a measure of variation. The plant growth experiment was arranged in a randomized complete block design with four single-pot replications for each of the five treatments (media types). Plants and pots were hand-watered with an irrigation wand two times per week with two passes per pot until leaching occurred. Data, where appropriate, were subjected to analysis of variance using PROC GLM (SAS 9.1; SAS Institute Inc., Cary, North Carolina, USA). Percentage data were transformed according to Gomez and Gomez (1984) and means were separated by Fisher's protected least significance difference (LSD) at $p < 0.05$. Physical property data were analyzed for linear trends.

Results and Discussion

All substrate particle size percentages were within the lower and upper limits for extensive green roof construction defined by FLL (2008). However, there were substantial differences between the IA media and the HEC-based media (Table 1). Although there was some particle size variation for 5% biochar compared to the other HEC-based substrates (Table 1), these differences were not considered of practical significance since 10 and 15% biochar substrates had the same particle sizes as 100% HEC substrate; seemingly, this eliminates the possibility that increased water retention in 15% biochar compared to 100% HEC (Table 2) was due solely to particle size substitution. There was a linear decrease in dry bulk density as biochar concentration increased (Table 2). Overall, substitutions of up to 15% biochar did not significantly alter particle size proportions compared to the 100% HEC control, and most substrate particles were less than 2.0 mm. Bulk density values are inversely related to the ratio of

Table 1. Particle size distribution of green roof media (mean ± standard deviation)

Media components (%)			Percentage of particle sizes (%)						
Intensive Ag	Biochar	Heat-expanded clay	> 9.50 mm	4.00-8.49 mm	2-3.99 mm	1.00-1.99 mm	0.50-0.99 mm	0.053-0.49 mm	< 0.053 mm
Controls									
100%	0%	0%	1.2 ± 2.3	28.1± 4.4	23.3 ± 1.3	16.3 ± 1.5	12.0 ± 1.7	17.9 ± 3.9	1.1 ± 0.1
0%	0%	100%	-	6.9 ± 2.1	25.4 ± 1.8	28.7 ± 1.1	17.2 ± 1.2	16.2 ± 1.5	5.6 ± 0.3
Biochar-HEC substrate									
0	5%	95%	-	11.4 ± 0.4	32.1 ± 2.2	29.4 ± 0.8	14.6 ± 0.7	9.6 ± 1.8	2.9 ± 0.3
0	10%	90%	-	6.5 ± 1.1	26.5 ± 1.7	29.7 ± 1.1	18.2 ± 0.5	15.2 ± 2.2	4.0 ± 0.5
0	15%	85%	-	7.9 ± 2.0	25.0 ± 2.9	28.6 ± 1.6	18.2 ± 1.4	15.6 ± 3.9	4.7 ± 1.1

Table 2. Physical properties of green roof substrates including dry bulk density, total porosity, container capacity, and air-filled porosity

Substrate components						
Intensive Ag[z] (%, by volume)	Biochar (%, by volume)	Heat-expanded clay (HEC) (%, by volume)	Dry bulk density (g·L-1)	Total porosity (%)	Container capacity [% (√%)]	Air-filled porosity [% (√%)]
Controls						
100	-	-	0.48 e[y]	49.9 a	25.0 (5.0) a	24.9 (5.0) a
-	-	100	0.77 a	29.5 e	16.4 (4.0) d	13.1 (3.6) bc
Biochar-HEC substrate						
-	5	95	0.75 b	30.9 d	18.1 (4.2) c	12.8 (3.6) c
-	10	90	0.71 c	34.1 c	21.5 (4.6) b	12.7 (3.6) c
-	15	85	0.66 d	36.3 b	22.3 (4.7) b	14.0 (3.7) b
Significances/clay-biochar trend						
Linear			***	***	***	ns

[z]Rooflite Intensive Ag (IA) substrate was obtained from Laural Valey Soils (Landenberg, PA, USA).
[y]Means followed by a similar letter are not significantly different ($p < 0.05$). deg., angular transformation of percentage data (arcsin √%); √% , square root transformation of percentage data; ***, $p < 0.001$; ns, not significant.

Table 3. Stomatal conductance (g_s) of basil and peppermint growing in five green roof media for four consecutive days (1-d, 2-d, 3-d, or 4-d) after irrigation

Media components			Herb species							
			Basil				Peppermint			
Intensive Ag[z]	Biochar	Heat-expanded clay	g_s (mmol·m^{-2}·s^{-1} ± standard deviation)							
(%, by volume)	(%, by volume)	(%, by volume)	1-d	2-d	3-d	4-d	1-d	2-d	3-d	4-d
Controls										
100	-	-	204 ± 27[y]	215 ± 65	188 ± 87	108 ± 61	426 ± 26	629 ± 54	509 ± 169	254 ± 232
-	-	100	224 ± 73	174 ± 45	49 ± 11	31 ± 9	514 ± 32	600 ± 216	237 ± 293	80 ± 104
Biochar plus heat-expanded clay media										
-	5	95	229 ± 55	266 ± 131	53 ± 14	41 ± 14	516 ± 68	645 ± 202	171 ± 133	93 ± 83
-	10	90	202 ± 29	191 ± 28	121 ± 92	56 ± 15	482 ± 73	675 ± 101	174 ± 103	106 ± 37
-	15	85	235 ± 43	242 ± 56	59 ± 15	42 ± 8	471 ± 11	736 ± 168	125 ± 60	55 ± 28

[z]Intensive Ag media obtained from Laural Valey Soils (Landenberg, PA).
[y]Average of four single-plant replicates for each species.

pores-to-solids (Brady and Weil, 2008). Dry bulk density values for organic (0.51 g·cm^{-3}) and inorganic-based extensive substrates (0.67 g·cm^{-3}) used in green roof construction (Friedrich, 2008) were similar to those determined for IA (0.48 g·cm^{-3}) and HEC (0.66 to 0.77 g·cm^{-3}) substrates, respectively. Additions of biochar resulted in a linear increase of total porosity and container capacity. However, there was no influence of biochar addition on air-filled porosity (Table 2). Panayiotis et al. (2003) tested sandy loam soils (SLS) for use on green roofs; total porosity for the SLS and SLS-blends ranged from 45.9% to 57.4%. In the current study, TP was 49.9% for the IA substrate, 29.5% for 100% HEC, and 30.0%, 34.1%, and 36.3% for 5%, 10%, and 15% biochar added to HEC, respectively. The CC was greatest in the IA substrate (25.0%), lowest in the 100% HEC substrate (CC = 16.4%), and increased to 22.3% with 15% biochar additions. Green roof conditions are generally dry and enhanced CC is important to maintain plant turgor. The minimum AP of 10% that was recommended by FLL (2008) is also thought to be the minimum content for gaseous diffusion in mineral soils (Wallach, 2008). All substrates tested had adequate AP. Since green roofs can lose most of their water within one day after an irrigation event (VanWoert et al., 2005), CC is assumed to be the more important physical property and limiting factor in terms of plant survival. Additions of 7% biochar (by weight) to green roof substrate resulted in increased water retention of the medium and reduced runoff of nitrogen, phosphorous, and organic carbon (Beck et al., 2011).

Three days after irrigation (3 DAI), g_s values indicated that the g_s of basil plants in the IA substrate were significantly greater than all others except for 10% biochar. Peppermint grown in the IA or 100% HEC substrate had greater g_s than all biochar incorporated substrates at 3 DAI. Three and four DAI, respectively, basil and peppermint approached 50 mmol·m^{-2}·s^{-1}; after four days, some basil treatments fell below 50 mmol·m^{-2}·s^{-1} (Table 3). Plants with less biomass exhibited higher g_s than those with greater biomass. This was indicated by higher g_s values at 3 and 4 DAI for the IA substrate and for 10% biochar. For the IA substrate, the g_s at 3 and 4 DAI was 188 and 108 mmol·m^{-2}·s^{-1} for basil and 509 and 254 mmol·m^{-2}·s^{-1} for peppermint, respectively. The data on g_s indicate a complex array of stomatal and non-stomatal responses to drought (Flexas and Medrano, 2002). During early drought development, at relatively high g_s levels of >150 mmol·m^{-2}·s^{-1}, there is decreased ribulose bisphosphate and adenosine triphosphate content, while at < 50 mmol·m^{-2}·s^{-1}, an indicator of severe drought, permanent photoinhibition may occur (Flexas and Medrano, 2002). At < 100 to 150 mmol·m^{-2}·s^{-1} g_s in grapevine (*Vitis vinifera*), non-stomatal limitations occur (Medrano et al., 2002). The herbs grown in the IA substrate exhibited less drought stress, which can be attributed to the higher container capacity of the substrate, as well as the lower water requirements of plants with lower biomass.

Biochar additions had an effect on coverage area of peppermint, but not basil (Table 4). Peppermint coverage area was affected by biochar incorporations of 5 to 15% (by volume). There was a 25 to 33% increase of peppermint coverage area following biochar additions when compared to HEC substrate without biochar (control). At the 15% biochar incorporation rate, shoot dry weight was 23% higher than that of the control (HEC without biochar). For basil coverage area, there was no significant difference between any HEC treatments. Plants in the IA substrate had the lowest shoot dry weight and coverage area among any of the substrates. Two important limiting factors for growing agronomic crops on green roofs are substrate depth and amount of irrigation supplied (Whittinghill et al., 2013). Similar to Beck et al.

Table 4. Shoot dry weight and coverage area (mean ± standard deviation) of basil and peppermint following transplanting and growth for nine weeks in Rooflite Intensive Ag (IA) substrate, heat-expanded clay (HEC), and HEC plus biochar. Controlled release fertilizer (14.0N-6.1P-11.6K) was added to each substrate and no supplemental nutrients were provided during the experiment

Substrate components			Herb species			
			basil		peppermint	
Intensive Ag[z] (%, by volume)	Biochar (%, by volume)	Heat-expanded clay (%, by volume)	Dry weight (g/shoot)	Coverage area (cm^2)	Dry weight (g/shoot)	Coverage area (cm^2)
Controls						
100	-	-	4.2 ± 1.0	350.7 ± 70.5	4.8 ± 1.4	489.6 ± 136.5
-	-	100	5.1 ± 0.6	391.7 ± 83.2	6.4 ± 0.9	460.0 ± 61.3
Biochar-HEC substrate						
-	5	95	5.6 ± 0.9	419.3 ± 86.0	7.3 ± 0.8	610.0 ± 28.5
-	10	90	4.5 ± 1.1	380.7 ± 98.3	6.2 ± 0.7	597.4 ± 96.7
-	15	85	5.4 ± 0.3	442.9 ± 54.1	7.9 ± 0.9	575.0 ± 52.5

[z]Rooflite intensive Ag substrate was obtained from Laural Valey Soils (Landenberg, PA, USA).

Table 5. Initial and final pH and EC nine weeks after transplanting basil and peppermint into container media containing Intensive Ag, heat-expanded clay (HEC), or HEC with biochar. Slow-release fertilizer was pre-incorporated into each media type prior to experimentation (5.04 $kg \cdot m^{-3}$; 14.0N-6.1P-11.6K).

Media components			Initial		Final, basil		Final, peppermint	
Intensive Ag[z] (%, by volume)	Biochar (%, by volume)	Heat-expanded clay (%, by volume)	pH	EC[y]	pH	EC[w]	pH	EC
Controls								
100	-	-	7.55[v]	2.52	7.33	0.79	7.24	1.00
-	-	100	7.16	0.91	6.60	0.22	6.44	0.37
Biochar-HEC substrate								
-	5	95	7.45	0.53	6.27	0.35	6.48	0.35
-	10	90	7.44	0.65	6.36	0.28	6.28	0.29
-	15	85	7.62	0.56	6.44	0.28	6.60	0.31
$LSD_{0.05}$ (one-way)[w]			0.15	0.25	0.32	0.20	0.23	0.21
$LSD_{0.05}$ (two-way)[v]			-	-	0.27	0.20	-	-

[z]Rooflite intensive Ag substrate was obtained from Laural Valey Soils (Landenberg, PA, USA).
[y]Values for EC were $mS \cdot cm^{-1}$.
[w]Means separation within columns by media by Fisher's protected least significant difference at $p < 0.05$.
[v]This value is for comparison of all possible final pH or EC values, respectively.

(2011) biochar additions used in this study resulted in increased water retention. While neither species used in this experiment is considered drought tolerant, our results indicate that basil is more susceptible to water deficit stress than peppermint. Green roof medium with increased water holding capacity is critical for the successful growth of herbs with significant water requirements. Additions of 15% biochar to HEC resulted in a 36% increase in water retention. This is more than the 4.4% increase in water retention in saturated soils determined by Beck et al. (2011). Overall, as plant dry weight decreased, g_s increased and this was most evident on the third day after an irrigation event (Tables 3 and 4). It is worth noting that peppermint has a spreading habit while basil has an upright growth habit. It is possible that ground-spreading plants perform better on green roofs, although this has not been studied; a tall, vigorous, large-leaved plant may require more water in a similar depth substrate and be more susceptible to excessive dehydration. Lower-growing cultivars of basil may be more suitable for green roof agriculture than the taller, large-leaved one used in this study. 'Spicy bush fine-leaf' basil (*O. basilicum* var. *minimum*) may be more drought tolerant than 'Genovese Compact, Improved' basil, a large-leaved basil, as determined by leaf wilting observations (data not shown). Although it would be ideal to conduct research on roof tops, it is commonly infeasible to alter an established green roof for that purpose; additionally, in evaluating and selecting vegetation for ornamental purposes, there may be a species bias in green roof studies towards the production of aboveground biomass (Sutton, 2013).

Green roof substrate pH values should be between 6.0 to 8.5 (FLL, 2008). Following blending, the CRF addition initially decreased initial pH and increased initial EC of all substrates (Table 5). The pH of biochar and HEC alone was 8.53 ± 0.07 and 8.58 ± 0.23, respectively, while the EC was 245 ± 35 $\mu S \cdot cm^{-1}$ and 134 ± 38 $\mu S \cdot cm^{-1}$, respectively (mean ± standard deviation, n = 4; data not shown). For the HEC substrate with or without biochar, there were no practical differences for final pH or EC among basil (pH range = 6.27 to 6.60; EC range = 0.22 to 0.35 $\mu S \cdot cm^{-1}$) or peppermint (pH range = 6.28 to 6.60; EC range = 0.29 to 0.37 $\mu S \cdot cm^{-1}$). However, the change from initial to final pH was noticeably impacted by the addition of biochar. The pH decreased by 0.22 and 0.56 in the IA and HEC substrates, respectively, while the pH change in the biochar treatments ranged from 0.97 to 1.18. Although Beck et al. (2011) determined that biochar decreased nutrient leaching, we found no differences in final EC or pH for the substrates amended by biochar versus the HEC substrate without biochar.

In conclusion, adding 15% biochar to green roof substrate had a small but significant effect on peppermint coverage area but no effect on basil. Also, there was a linear increase in container capacity with increasing proportions of biochar. Other variables, such as below-ground biomass, long-term survivability, ecological function, or even photosynthetic rate, may be more appropriate for evaluating green roof plants for their potential ecological services.

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