Gasified Rice Hull Biochar is a Source of Phosphorus and Potassium for Container-Grown Plants[1,2]

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Abstract

Biochar materials have been reported to improve the chemical, physical, and biological properties of mineral soils and soilless substrates. The objective of this research was to determine the effect of gasified rice hull biochar (GRHB) on available nutrients in a container substrate. Two experiments were conducted in a glasshouse with geranium (*Pelargonium* x*hortorum* 'Maverick Red') in 10 cm (4 in) pots. Geranium were potted in commercial soilless medium (Sunshine Mix #2) amended with 0 to 10% GRHB. Control pots were fertilized with a commercial complete liquid fertilizer (20N-4.4P-16.6K-0.15Mg-0.02B-0.01Cu-0.1Fe-0.05Mn-0.01Mo-0.05Zn), while GRHB-amended crops were fertilized with ammonium nitrate. Additional GRHB substrates were amended with either 0 or 0.9 $kg \cdot m^{-3}$ (1.5 $lb \cdot yd^{-3}$) micronutrient package (Micromax). The GRHB amendment had little or no effect on substrate pH. Amendment with GRHB increased available phosphate and potassium in substrate leachates compared to the commercially fertilized controls. Substrates amended with GRHB alone were chlorotic and grew less than those amended with GRHB and micronutrients. These data demonstrate that GRHB provides sufficient P and K to support a six week production cycle of geranium, but lacks either the correct concentration or balance of micronutrients for healthy growth.

Index words: bedding plants, nitrate, phosphorus, potassium, leaching.

Significance to the Nursery Industry

Fertilizer costs and nutrient use efficiency are important issues for greenhouse and nursery producers. Research has shown that some forms of biochar provide an abundant source of nutrients and other possible benefit when used as part of the container substrate. The objective of this research was to determine the potential nutritional value of gasified rice hull biochar (GRHB) when amended to a typical greenhouse substrate. Our data show that GRHB amendment rates up to 10% (by volume) have little or no effect on substrate pH. Gasified rice hull biochar provided sufficient phosphorus (P) and potassium (K) to the substrate to grow a geranium crop for six weeks without any additional P or K fertilizers. It was necessary to provide a micronutrient fertilizer source in addition to the GRHB to avoid chlorosis in geranium foliage. It was concluded that GRHB provides a source of readily available P and K, but lacks the correct concentration or balance of micronutrients for adequate container nutrition. Gasified rice hull biochar could be an important source of P and K for greenhouse and nursery container crops in the future.

Introduction

Container crops are generally fertilized such that all macro- and micro-nutrients are provided in a manufactured controlled-release or liquid formulation. Nitrogen (N), phosphorus (P), and potassium (K) are often applied in the highest quantity and concentration. Nitrogen and P have been highly scrutinized due to the adverse effects these two nutrients have on surface and ground waters when over-application leads to offsite movement.

In addition to adverse environmental effects of excess P released into surface and ground waters, there is a looming global shortage of P fertilizers. Phosphate fertilizer is a nonrenewable resource mined almost exclusively in a few countries, primarily Morocco, China, and the United States. (3). It is predicted that phosphate reserves will be depleted in 50 to 100 years (3), during a time when phosphate demand will only increase for agricultural purposes to feed an increasing world population. As the price of phosphate increases over this time period, use of alternative phosphate sources will become prudent. Evans et al. (6) demonstrated a high P concentration in parboiled rice hulls, a byproduct of rice production that is already utilized as a component in many commercial greenhouse and nursery substrates. Gasified rice hull biochar (GRHB) has a similarly high P concentration (unpublished data), thus could serve as an amendment to alleviate the need for P fertilizers.

The influence of biochar on soilless substrates used in greenhouse and nursery containers has been studied little, and only a few citations tangentially related to greenhouse and nursery production are available. Papers published thus far have addressed the effects of biochar on plant growth (8, 9), microbial populations (8), calcium nutrition (15), substrate hydraulic properties (5), as well as chemical properties including pH, cation exchange capacity, and carbon to nitrogen ratio (5). None of these aforementioned papers addressed the influence of biochar on P or K in soilless substrates. Beck et al. (2) showed that amendment of an unspecified greenroof substrate with 7% biochar increased water retention and decreased total N and P, nitrate, phosphate, and organic carbon in runoff. More recently, Altland and Locke (1) demonstrated a temporary retention and subsequent release of nitrate and phosphate with a peat moss based substrate amended with 10% saw dust biochar. These papers did not address the influence of nitrate and phosphate retention on plant growth or fertility. Biochar elemental nutrient properties tend to reflect the properties of the original feedstock, only in higher concentration as a percentage of the carbon, hydrogen, and oxygen have been burned off during pyrolysis (11). Biochar used in the Beck et al. (2) and Altland and Locke (1) studies

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[2] Mention of proprietary products or company is included for the reader's convenience and does not imply any endorsement or preferential treatment by USDA/ARS.

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had low N, P, and K concentrations, and thus showed some capacity to absorb and retain nitrates and phosphates. In contrast, Wells and Bush (16) reported that poultry litter ash, inherently high in P and K due to the poultry manure feedstock, provided sufficient P and K for production of several greenhouse crops. Considering the inherently high concentration of P and K in parboiled rice hulls (6), the objective of this research was to determine if GRHB could provide sufficient P, K, and micronutrients to support production of geranium over a period of six weeks.

Materials and Methods

General conditions and materials. Two experiments were conducted in a glasshouse at the Ohio Agricultural Research and Development Center, Wooster, OH. Throughout the experiments, natural light was supplemented with high pressure sodium vapor lights for 13 hr daily from 6 am to 7 pm. Thermostat heat and cool points were set at 21 and 27C (70 and 80F), respectively.

Gasified rice hull biochar (GRHB) (CharSil, Riceland Food, Inc, Stuttgart, AR) was used as an amendment with particle size distribution and chemical properties shown in Tables 1 and 2. Particle size distribution was determined by passing approximately 45 g (1.6 oz) of oven dried [55C (131F)] GRHB through 2.8, 2.0,1.4, 1.0, 0.71, 0.50, 0.35, 0.25, 0.18, and 0.11 mm (0.75, 0.5, and 0.25 in, and nos. 5, 7, 10, 14, 18, 25, 35, 45, 60, 80, and 140) soil sieves. Particles ≤ 0.11 mm (no. 140 screen) were collected in a pan. Sieves and pan were shaken for 3 min with a RX-29/30 Ro-Tap® test sieve shaker (278 oscillations·min^{-1}, 150 taps·min^{-1}) (W.S. Tyler, Mentor, OH). Biochar percent carbon (C) and N were determined with a PerkinElmer Series II CHNS/O Analyzer (PerkinElmer Instruments, Shelton, CT). Other macronutrients and micronutrients were determined with a Thermo Iris Intrepid ICP-OES (Thermo Electron Corp., Waltham, MA).

Geranium (*Pelargonium* x*hortorum* 'Maverick Red') seedling transplants were produced in Oasis cubes (276 cells per flat, Kent, OH) and grown for four weeks prior to transplant. The base substrate for the study was a standard commercial soilless medium (Sunshine Mix #2, Sun Gro Horticulture Canada Ltd.), composed of a proprietary and unspecified mixture of sphagnum peat moss, coarse perlite, and amended with dolomitic limestone and gypsum.

Experiment 1. Four treatments were designed to compare GRHB with standard fertilizer practices as follows. A group of geraniums were transplanted into the base substrate without amendment and were fertilized with a commercial complete fertilizer with micronutrients (Jack's 20N-4.4P-16.6K-0.15Mg-0.02B-0.01Cu-0.1Fe-0.05Mn-0.01Mo-0.05Zn, JR Peters, Inc., Allentown, PA) at a rate of 100 mg·L^{-1} N (100 ppm N), and hereafter referred to as the NPK-control group. Two additional treatments consisted of the base substrate amended with GRHB at 1 or 10% (v/v), fertilized with 100 mg·L^{-1} N (100 ppm N) using ammonium nitrate, and subsequently described as 1 or 10% GRHB, respectively. A final treatment was included with the base substrate amended with 10% GRHB and a commercial micronutrient package (Micromax, The Scotts Co., Marysville, OH) at 0.9 kg·m^{-3} (1.5 lb·yd^{-3}) fertilized with 100 mg·L^{-1} N (100 ppm N) ammonium nitrate, and hereafter referred to as 10% GRHB-M. Geraniums were transplanted as a single plug per pot on May 11, 2012, into 10 cm (4 in) wide pots (approx. 600 cm^3 (0.6 qt) volume). Geraniums were irrigated or fertigated by pouring from a glass beaker. Fertigation and irrigation was done as needed, with approximately three fertigation and one irrigation events each week. A 15 cm (6 in) wide clear vinyl saucer (Hummert Int., Earth City, MO) was placed beneath each container to capture leachate and allow it to be re-absorbed by the substrate, thus avoiding any nutrient loss via leaching. There were 12 single pot replications per treatment arranged in a completely randomized design.

Substrate physical properties were determined for each substrate immediately after mixing. Substrates were packed in 347 cm^3 (0.37 qt) aluminum cores [7.6 cm (3 in) tall by 7.6 cm (3 in) i.d.] according to methods described by Fonteno and Bilderback (7). There were three replications for each substrate. Aluminum cores were attached to North Carolina State University Porometers™ (Horticultural Substrates Laboratory, North Carolina State University, Raleigh, NC) for determination of air space (AS). Cores were weighed, oven dried for four days at [72C (162F)], and weighed again to determine container capacity (CC). Total porosity (TP) was calculated as the sum of AS and CC. Bulk density (D_b) was determined using oven dried [72C (162F)] substrate in 347 cm^3 (0.37 qt) cores.

Table 1. Chemical properties of gasified rice hull biochar. All analyses (except pH) are expressed on a percent or concentration of oven dried biochar (n = 3).

	units	Value
pH		10.54
Carbon	(%)	17.68
Nitrogen		0.18
Phosphorus		0.30
Potassium		0.98
Calcium		0.35
Magnesium		0.15
Sulfur		0.03
Silicon		11.72
Boron	mg·kg^{-1}	10.36
Copper		8.42
Iron		197.3
Manganese		541.0
Molybdenum		ND[z]
Zinc		46.34

[z]Not detectable.

Table 2. Particle size distribution of gasified rice hull biochar used as a greenhouse substrate amendment (n = 3).

Sieve size (mm)	Percent of sample	Standard deviation
< 0.106	25.8	1.34
0.106	20.2	0.86
0.18	13.9	0.11
0.25	15.5	0.33
0.35	12.1	0.51
0.5	9.5	0.96
0.71	1.9	0.29
1	0.5	0.07
1.4	0.5	0.11
2	0.1	0.06
2.8	0.0	0.01

At 3 and 6 WAP (weeks after potting), six replicates from every treatment were destructively harvested for the following analyses. Containers were subjected to the pour-through technique (16) in order to collect a 50 mL (1.7 oz) sample of the substrate solution for measurement of pH, electrical conductivity (EC), and nutrient analysis. Substrate solutions were immediately measured for pH and EC then frozen until a nutrient analysis was performed. At the time of nutrient analysis, samples were thawed, filtered through GF/F binder-free borosilicate glass fiber filter paper (Whatman Ltd., Kent, UK) to remove particles greater than 0.7 μm (0.000028 in). The filtrate was then poured into 5 mL (1 tsp) autosampler vials, capped, and analyzed on an ICS 1600 (Ion Chromatography System, Dionex, Bannockburn, IL) for concentrations of nitrate (NO_3^-), ammonium (NH_4^+), phosphate (PO_4^{2-}), and potassium (K). Following pour-through analysis, leaf greenness was determined with a SPAD chlorophyll meter (Minolta-502 SPAD meter, Spectrum Technologies, Inc., Plainfield, IL) by taking a measurement on five leaves per pot and recording the mean. Recently matured foliage was harvested for foliar nutrient analysis (12), rinsed with deionized water, then oven dried at 55C (131F) for 3 d. Samples were ground in a Tecator Cyclotec mill (Tecator AB, Hogenas, Sweden) through a 0.5 mm (0.02 in) screen. Foliar N was determined with a Vario Max CN analyzer (Elementar Americas, Mt. Laurel, NJ). Other macronutrients and micronutrients were determined with a Thermo Iris Intrepid ICP-OES (Thermo Fisher Scientific, Waltham, MA). Immediately after leaf tissue harvests, shoot dry weight (SDW) was determined by removing the shoot portion of the plant, oven drying at 55C (131F) for 3 days, and weighing.

Data were subjected to analysis of variance (ANOVA) and repeated measures ANOVA, when appropriate, using SAS 9.1 (SAS Systems, Inc, Carey, NC). Means were separated using Fisher's protected least significant difference (LSD) test with the LSD value presented.

Experiment 2. A second experiment was conducted similarly to the previous experiment with the following exceptions. The treatment design was an augmented 2 × 2 factorial arrangement with two GRHB amendment rates (5 and 10%) and two micronutrient (Micromax) rates [0 and 0.9 $kg \cdot m^{-3}$ (0 and 1.5 $lb \cdot yd^{-3}$)] which were all fertilized with 100 $mg \cdot L^{-1}$ N (100 ppm N) from ammonium nitrate. These factorial treatments were augmented with a control treatment using the non-amended substrate fertilized with the same commercial complete NPK fertilizer used in Expt. 1. Geranium plugs were potted July 25, 2012, and data were collected 3 and 6 WAP. There were 14 single plant replications per treatment arranged in a completely randomized design, with seven replications destructively harvested on each date.

Results and Discussion

Physical properties of the substrates used in the experiment differed slightly (Table 3). Air space was reduced in substrates amended with 10% GRHB compared to those with 0 or 1% GRHB. Conversely, CC was greater in substrates amended with 10% GRHB. Dumroese et al. (5) reported amendment with 25% pelletized biochar increased water holding capacity and decreased air-filled porosity of a peat moss substrate, while Beck et al. (2) showed greater water retention in greenroof substrates amended with biochar. Total porosity of the substrates was not affected by GRHB amendment. Total porosity is the sum of AS and CC, and because amendment with 10% GRHB caused a slight decrease in AS and a concomitant increase in CC, the net effect was no change in TP. Unavailable water decreased slightly with each level of additional GRHB. Gasified rice hull biochar amended at 10% increased bulk density slightly. The GRHB used in this study has a published bulk density of 0.2 $g \cdot cm^{-3}$ (12.5 $lb \cdot ft^{-3}$), roughly twice that of the commercial substrate with a bulk density of 0.096 $g \cdot cm^{-3}$ (6 $lb \cdot ft^{-3}$). Bulk density of substrates made from multiple components are additive, in that increasing percentages of higher-density materials will increase the bulk density of the composite material (14). With increased CC and reduced unavailable water, it is conceivable that GRHB-amended substrates would increase water availability to plants. Although there were measurable differences in physical properties caused by substrate type and GRHB amendment, it is unlikely such minor differences had any impact on the growth or performance of plants in this experiment, nor would such differences likely impact commercial production of a crop if GRHB were adopted by industry and used at rates similar to or less than those used in this experiment.

Table 3. Physical properties of a commercial substrate (Sunshine Mix #2) amended with 0, 1, or 10% gasified rice hull biochar (GRHB) (n = 4).

GRHB rate	Air space	Container capacity	Total porosity	Unavailable water	Bulk density
	(%)				($g \cdot cm^{-3}$)
0	15.5	68.5	84.1	18.6	0.096
1	15.4	68.7	84.1	16.7	0.097
10	12.5	72.2	84.7	15.0	0.113
$LSD_{0.05}^{z}$	2.7	3.4	NS	0.9	0.002

^{z}LSD is Fisher's least significant difference where α = 0.05.

Substrate pH was affected by GRHB treatment (Table 4). At 3 WAP, amendment of 10% GRHB, with or without micronutrients, depressed pH compared to substrates amended with 1% GRHB. While biochar in general has been shown to influence and generally increase pH of soil and soilless systems (5, 13, 16), rates used in these experiments had the opposite effect. Amendment with 10% GRHB-M had the lowest pH, and although it was similar to containers with just 10% GRHB, it was lower than all other treatments. By 6 WAP, pH within a treatment changed little. Substrates with 10% GRHB (with or without micronutrients) had lower pH than containers with 0% or 1% GRHB.

At 3 WAP, EC was similar among containers with 0, 1, or 10% GRHB, and highest in containers amended with 10% GRHB-M (Table 4). By 6 WAP, substrates with 10% GRHB, with or without the micronutrient package, had higher EC than those with 0 or 1% GRHB. Despite using a no-leach system of irrigation, EC of substrates with 10% GRHB, with or without micronutrients, were within the optimum range of 2 to 3.5 dS (4).

Nitrate levels were high at 3 WAP in all containers except those amended with 10% GRHB-M (Table 4). The differences in nitrate concentration in the leachate solution might in part be due to plant mass, which was weakly correlated to nitrate concentration (R = –0.5564, P = 0.0058, n = 23) 3 WAP. By 6 WAP, nitrate concentration was lower and similar across all treatments. Neither phosphate nor potassium was

Table 4. **Substrate pH, electrical conductivity (EC), and nitrate, phosphate, and potassium concentration in leachates from a commercial substrate (Sunshine Mix #2) amended with either 0, 1, or 10% gasified rice hull biochar (GRHB) and fertilized with a commercial complete fertilizer (Jack's 20N-4.4P-16.6K), ammonium nitrate (AN), or AN and a micronutrient package (Micromax) (M).**

Treatment	GRHB rate (%)	Fertilizer	pH		EC ($dS \cdot m^{-1}$)		Nitrate ($mg \cdot liter^{-1}$)		Phosphate ($mg \cdot liter^{-1}$)		Potassium ($mg \cdot liter^{-1}$)	
			3 WAP^z	6 WAP	3 WAP	6 WAP	3 WAP	6 WAP	3 WAP	6 WAP	3 WAP	6 WAP
Control	0	20N-4.4P-16.6K	6.83	6.90	1.69	1.70	482.3	6.7	8.3	3.8	11.8	5.5
GRHB-1	1	AN	6.89	7.10	1.37	1.94	558.3	17.5	8.8	1.8	11.0	1.8
GRHB-10	10	AN	6.68	6.55	1.81	3.23	753.1	36.0	123.2	252.6	87.7	117.1
GRHB-M	10	AN + M	6.55	6.62	2.97	3.39	35.7	24.8	168.7	92.4	143.7	48.9
$LSD_{0.05}$^{y}			0.16	0.14	0.76	1.04	371.9	NS	46.3	74.3	38.0	47.9

^{z}WAP is weeks after potting, which occurred on May 11, 2012.

^{y}LSD is Fisher's least significant difference where α = 0.05.

correlated to SDW throughout the experiment. Phosphate and potassium at both dates were much higher in leachates from containers that received 10% GRHB, with or without micronutrients, compared to those receiving 0 or 1% GRHB.

At 3 WAP, geranium amended with 10% GRHB-M had higher SPAD chlorophyll readings than those receiving 10% GRHB alone (Table 5). Plants receiving just 1% or 10% GRHB had slight interveinal chlorosis on new growth. By 6 WAP, there was greater separation among treatments. Geranium receiving the complete NPK fertilization program and those amended with 10% GRHB-M had the highest SPAD readings and were completely free of chlorosis symptoms. Those in containers amended with either 1 or 10% GRHB in had the lowest SPAD readings and were uniformly characterized by interveinal chlorosis on both mature and juvenile foliage. Despite clear signs of chlorosis in two treatments and seemingly healthy vigorous growth in two other treatments, none of the foliar nutrient concentrations determined at 3 and 6 WAP suggested a cause for the chlorosis (Table 6). Foliar N was low across all treatments relative to minimum recommendations (10) for geranium. Fertilizer N rates were assigned based on the local greenhouse industry practice of 100 $mg \cdot L^{-1}$ N constant feed. Although foliar N levels were low compared to the recommended sufficiency range, treatment differences did not explain the presence or lack of chlorosis symptoms by treatment. Among other macronutrients, foliar P, K, Ca, Mg, and S were generally higher than published sufficiency ranges across all treatments, and again, minor differences that did occur would not explain differences in chlorosis among treatments in our experiment. Foliar micronutrients were more variable with greater differences among treatments. But none of the treatment patterns in foliar micronutrient levels could explain chlorosis patterns observed in this experiment.

Shoot dry weight of plants harvested 3 WAP were least with plants amended with 10% GRHB alone (Table 5). By 6 WAP, geranium receiving 10% GRHB-M were greater than all other plants, with those receiving the complete NPK fertilizer second greatest, and those receiving 1% or 10% GRHB similar in size and least.

Experiment 2. At 3 WAP, substrate pH was higher in the NPK fertilized control than all GRHB-amended substrates (Table 7). Within the factorial arrangement of GRHB-amended substrates, only GRHB rate affected substrate pH with slightly higher pH in the 10% rate compared to the 5% rate (6.69 vs. 6.50, respectively). By 6 WAP, substrate pH was still higher in the NPK-fertilized controls compared to all GRHB-amended substrates; however, by this time all GRHB-amended substrates had similar pH. The pH of the GRHB used in these experiments is 10.4 (Table 1). Other experiments have shown an increase in substrate pH due to biochar amendment (5, 16). However, rates used in these studies seem to have little effect on substrate pH. While containers with 10% GRHB amendment had slightly higher pH than those with 5% amendment at 3 WAP, all GRHB-amended plants had lower pH than the NPK-fertilized controls throughout the study. Lower pH in GRHB-amended substrates is likely due to the fertilizer applied. The commercial fertilizer formulation used in the NPK-fertilized controls has a potential acidity of 200 $kg \cdot ton^{-1}$ (440 $lb \cdot ton^{-1}$)

Table 5. **Foliar chlorophyll (SPAD) readings and shoot dry weight of geranium (*Pelargonium* x*hortorum* 'Maverick Red') in a standard substrate (Sunshine Mix #2) amended with either 0, 1, or 10% gasified rice hull biochar (GRHB) and fertilized with a commercial complete fertilizer (Jack's 20N-4.4P-16.6K), ammonium nitrate (AN), or AN and a micronutrient package (Micromax) (M).**

Treatment	GRHB rate	Fertilizer	SPAD		Shoot dry weight (g)	
			3 WAP^z	6 WAP	3 WAP	6 WAP
Control	0	20N-4.4P-16.6K	30.6	40.7	0.66	4.74
GRHB-1	1	AN	28.4	23.1	0.83	2.46
GRHB-10	10	AN	26.5	29.0	0.55	2.80
GRHB-M	10	AN + M	30.4	38.2	0.83	7.67
$LSD_{0.05}$^{y}			3.0	4.9	0.21	1.04

^{z}WAP is weeks after potting, which occurred on May 11, 2012.

^{y}LSD is Fisher's least significant difference where α = 0.05.

Table 6. Foliar nutrient concentrations of geranium (*Pelargonium* x*hortorum* 'Maverick Red') in a standard substrate (Sunshine #2) amended with either 0, 1, or 10% gasified rice hull biochar (GRHB) and fertilized with a commercial complete fertilizer (Jack's 20N-4.4P-16.6K), ammonium nitrate (AN), or AN and a micronutrient package (Micromax) (M).

Harvest	Treatment	GRHB rate (%)	Fertilizer	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
3 WAP[z]	Control	0	20N-4.4P-16.6K	3.0	0.5	3.1	1.0	0.8	0.25	40.3	6.3	77.4	118.4	37.7
	GRHB-1	1	AN	2.7	0.6	3.0	1.1	0.9	0.24	40.2	5.1	58.9	157.7	34.3
	GRHB-10	10	AN	2.7	0.8	4.5	0.9	0.7	0.20	55.9	3.4	159.1	339.6	54.8
	GRHB-M	10	AN + M	2.7	0.8	4.5	0.9	0.7	0.23	57.2	8.3	114.7	492.9	72.7
	$LSD_{0.05}$[y]			0.2	0.1	0.4	0.1	0.1	0.02	10.3	1.3	NS	45.5	13.7
6 WAP	Control	0	20N-4.4P-16.6K	2.4	0.4	2.6	1.2	0.8	0.19	25.0	1.9	51.1	88.2	38.5
	GRHB-1	1	AN	3.0	0.4	2.4	1.6	1.0	0.23	30.6	1.6	54.9	237.2	53.9
	GRHB-10	10	AN	2.7	0.8	4.5	1.3	0.8	0.22	35.5	1.9	52.4	452.8	80.4
	GRHB-M	10	AN + M	1.4	0.5	3.0	0.9	0.5	0.13	31.9	4.8	45.2	380.4	53.7
	$LSD_{0.05}$			0.3	0.1	0.4	0.1	0.1	0.02	2.4	0.9	NS	30.2	10.1
Recommended minimum[x]				3.7	0.3	2.5	0.8	0.2	0.18	35.0	5.0	70.0	110.0	36.0

[z] WAP is weeks after potting, which occurred on May 11, 2012.

[y] LSD is Fisher's least significant difference where α = 0.05.

[x] Krug, B.A., B.E. Whipker, and I. McCall. 2010. Geranium leaf tissue nutrient sufficiency ranges by chronological age. J. Plant Nutr. 33:339–350.

according to the manufacturer, while ammonium nitrate has a potential acidity of 591 kg·ton^{-1} (1303 lb·ton^{-1}). Thus the ammonium nitrate fertilizer has a greater acidifying effect than the commercial NPK fertilizer used, and this acidifying effect overwhelmed any alkaline pH effect that might have been caused by the GRHB. Electrical conductivity was similar among all GRHB-amended substrates at 3 WAP, and all of these were higher than the NPK-fertilized control. By 6 WAP, GRHB-amended substrates with the micronutrient package had lower EC than those without, while EC for GRHB-amended substrates as a whole remained higher than NPK-fertilized controls.

Nitrate and phosphate levels in leachates were affected primarily by micronutrient amendment in the substrate (Table 7). At 3 WAP, nitrate concentration in leachates of NPK-fertilized controls was similar to those amended with GRHB and micronutrients, all of which were less than those amended with GRHB alone. This pattern held at 6 WAP, but was exacerbated further in that nitrate concentrations among containers amended with GRHB increased while those for all other treatments decreased. A similar pattern was observed in phosphate concentration at both 3 and 6 WAP. Potassium concentration at 3 WAP was lowest in the NPK-fertilized controls. Among the GRHB-amended substrates, potassium increased with increasing GRHB rate, and was not affected by micronutrient amendment. By 6 WAP, potassium concentration in leachates followed the same pattern found in nitrate and phosphate concentrations.

Foliar SPAD readings for NPK-fertilized controls were higher than all other treatments at 3 WAP except those in containers with 10% GRHB-M (Table 8). Among GRHB-amended containers, those amended with micronutrients had higher SPAD readings than those without (33.8 vs. 29.2). By 6 WAP, NPK-fertilized controls were similar to containers amended with GRHB and micronutrients, and greater than those without micronutrients. Considering only the GRHB-

Table 7. Substrate pH, electrical conductivity, and nitrate, phosphate, and potassium concentration in leachates of containers with a commercial substrate (Sunshine Mix #2) amended with either 0, 5 or 10% gasified rice hull biochar (GRHB) and fertilized with a commercial complete fertilizer (20N-4.4P-16.6K), ammonium nitrate (AN), and/or a commercial micronutrient fertilizer (M).

		Substrate pH		Electrical cond.		Nitrate (mg·L^{-1})		Phosphate (mg·L^{-1})		Potassium (mg·L^{-1})	
GRHB rate (%)	Fertilizer	3 WAP[z]	6 WAP	3 WAP	6 WAP	3 WAP	6 WAP	3 WAP	6 WAP	3 WAP	6 WAP
0	20N-4.4P-16.6K	7.07	6.97	1.32	1.75	54.7	4.4	4.7	3.7	7.2	1.4
5	AN	6.52	6.57	2.61	3.26	133.6	286.7	156.7	136.0	119.8	68.0
	AN+MM	6.47	6.59	2.99	2.23	45.2	29.2	72.7	17.3	100.6	8.5
10	AN	6.74	6.63	3.19	3.73	180.2	275.3	228.9	214.9	266.8	124.8
	AN+MM	6.64	6.58	3.16	2.51	46.8	18.9	121.3	42.5	246.3	13.2
$LSD_{0.05}$[y]		0.12	0.16	0.70	0.73	80.6	141.7	49.3	54.7	90.4	42.2
GRHB rate		0.0001	NS[x]	NS	NS	NS	NS	0.0013	0.0101	0.0001	0.0437
Micronutrient		NS	NS	NS	0.0001	0.0004	0.0001	0.0001	0.0001	NS	0.0001
Interaction		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] WAP is weeks after potting, which occurred on July 25, 2012.

[y] LSD is Fisher's least significant difference where α = 0.05.

[x] NS is not significant.

Table 8. **Foliar chlorophyll (SPAD) readings and shoot dry weight of geranium (*Pelargonium* x*hortorum* 'Maverick Red') in a commercial substrate (Sunshine #2) amended with either 0, 5 or 10% gasified rice hull biochar (GRHB) and fertilized with a commercial complete fertilizer (20N-4.4P-16.6K), ammonium nitrate (AN), and/or a commercial micronutrient fertilizer (M).**

GRHB rate (%)	Fertilizer	SPAD		Dry weight (g)	
		3 WAP[z]	6 WAP	3 WAP	6 WAP
0	20N-4.4P-16.6K	37.4	43.5	1.5	7.6
5	AN	30.9	39.8	1.6	4.6
	AN+MM	33.7	42.8	2.0	12.0
10	AN	27.5	36.8	1.5	5.7
	AN+MM	33.9	40.2	1.7	11.2
LSD$_{0.05}$[y]		3.6	3.5	NS	1.2
GRHB rate		NS	0.0306	NS	NS
Micronutrient		0.0009	0.0145	NS	0.0001
Interaction		NS	NS	NS	0.0290

[z] WAP is weeks after potting, which occurred on July 25, 2012.

[y] LSD is Fisher's least significant difference where α = 0.05.

amended geraniums, those with micronutrients had greater SPAD values than those without (41.5 vs. 38.3), and those receiving 5% GRHB had higher SPAD values than those with 10% (41.3 vs. 38.5). Although the magnitude of the difference in SPAD values was less in Expt.2 than Expt. 1, the severity of interveinal chlorosis was as severe among geranium amended with GRHB alone. The SPAD measurement was not as useful in providing a quantitative measure to reflect the degree of differentiation we observed in these groups of treatments. Similar to Expt. 1, foliar nutrient concentrations fail to explain SPAD or chlorosis patterns (Table 9). At 3 WAP, amendment with micronutrients was shown to affect foliar N, Mg, B, Cu, Mn, and Zn. While concentrations of the six aforementioned nutrients were higher in geranium amended with micronutrients (with the exception of Mg) compared to those not amended, in each case the NPK-fertilized control had similar or lower concentrations, yet NPK-fertilized controls lacked chlorosis and had high SPAD values. At 6 WAP, all nutrients with the exception of B, Fe, and Mn were affected by micronutrient amendment. But similar to 3 WAP, no foliar nutrient concentration displayed a pattern where the nutrient was deficient or lower among geranium fertilized with GRHB alone and sufficient or higher with GRHB and micronutrients as well as the NPK-fertilized controls.

All plants had similar SDW 3 WAP. By 6 WAP, geranium amended with GRHB and micronutrients were larger than NPK-fertilized controls, which in turn were larger than GRHB-amended geranium without micronutrients. Among containers amended with GRHB, containers also amended with micronutrients had more than twice the mass of those without micronutrients. This is likely the reason that EC levels in containers with micronutrients were lower than those without. It might be expected that a micronutrient amendment to container substrates would increase the EC levels of a substrate, but after 6 weeks with plants that had more than twice the shoot mass, containers with micronu-

Table 9. **Foliar nutrition of geranium (*Pelargonium* x*hortorum* 'Maverick Red') grown in a commercial substrate (Sunshine Mix #2) amended with either 0, 5% or 10% gasified rice hull biochar (GRHB) and fertilized with a commercial complete fertilizer (20N-4.4P-16.6K), ammonium nitrate (AN), and/or a commercial micronutrient fertilizer (M).**

WAP[z]	GRHB rate (%)	Fertilizer	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
3	0	20N-4.4P-16.6K	3.49	0.41	2.85	1.11	0.85	0.24	27.61	2.75	80.98	114.98	54.84
	5	AN	3.22	0.63	4.14	1.13	0.80	0.26	36.53	2.09	61.21	345.16	74.86
		AN+MM	3.43	0.58	4.10	1.09	0.67	0.25	43.64	10.91	67.87	499.68	102.03
	10	AN	2.91	0.59	4.69	1.06	0.77	0.25	34.48	1.89	74.30	418.56	70.94
		AN+MM	3.19	0.59	4.55	1.04	0.70	0.26	41.66	6.38	98.23	481.26	95.07
	LSD$_{0.05}$[y]		0.24	0.07	0.27	NS	0.06	0.02	5.47	1.55	NS	79.32	11.31
	GRHB rate		0.0032	NS	0.0001	0.0193	NS	NS	NS	0.0001	NS	NS	NS
	Micronutrient		0.0067	NS	NS	NS	0.0001	NS	0.0007	0.0001	NS	0.0004	0.0001
	Interaction		NS	NS	NS	NS	NS	0.0346	NS	0.0004	NS	NS	NS
6	0	20N-4.4P-16.6K	1.96	0.22	1.68	0.97	0.68	0.16	16.22	2.81	39.45	83.61	34.30
	5	AN	2.72	0.73	3.68	1.38	0.84	0.23	27.80	1.90	24.42	341.93	85.21
		AN+MM	1.54	0.40	1.65	1.02	0.58	0.16	24.09	5.08	24.19	374.01	69.53
	10	AN	2.41	0.62	4.38	1.28	0.81	0.20	26.48	2.11	16.09	435.37	91.55
		AN+MM	1.67	0.55	2.98	1.12	0.61	0.17	26.97	6.51	14.65	480.67	81.22
	LSD$_{0.05}$		0.37	0.05	0.40	0.11	0.06	0.02	3.48	1.11	NS	68.76	10.57
	GRHB rate		NS	NS	0.0001	NS	NS	NS	NS	0.0430	NS	0.0002	0.0202
	Micronutrient		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	NS	0.0001	NS	NS	0.0014
	Interaction		NS	0.0001	0.0322	0.0168	NS	0.0201	NS	NS	NS	NS	NS
	Recommended minimum[x]		3.7	0.3	2.5	0.8	0.2	0.18	35	5	70	110	36

[z] WAP is weeks after potting, which occurred on July 25, 2012.

[y] LSD is Fisher's least significant difference where α = 0.05.

[x] Krug, B.A., B.E. Whipker, and I. McCall. 2010. Geranium leaf tissue nutrient sufficiency ranges by chronological age. J. Plant Nutr. 33:339–350.

trient amendment would be more depleted of fertilizer salts than those without. Differences in plant growth also partially explain nitrate, phosphate, and potassium concentration in container leachates. At 3 WAP, there were no differences in plant growth and only leachate concentrations of nitrate were correlated to plant size (R = –0.5175, P = 0.0015, n = 35). However, by 6 WAP when plant size responded to treatment, nitrate (R = –0.7103, P = 0.0001, n = 35), phosphate (R = –0.6523, P = 0.0001, n = 35) and potassium (R = –0.6546, P = 0.0001, n = 35) were all negatively correlated to plant size. Lack of correlation for phosphate and potassium at 3 WAP suggests that while plants were similar in size, those in substrates amended with GRHB and micronutrients or fertilized with the NPK-control solution were accumulating more nitrate and phosphate compared to those amended with GRHB alone. This suggests that some chemical factor in substrates amended with GRHB alone was inhibitory to phosphate and potassium uptake. This inhibitory compound could have been a single nutrient or combination of nutrients (12) in either deficient or toxic concentration. Addition of a micronutrient fertilizer to the substrate alleviated the factor inhibiting phosphate and potassium uptake.

The objective of this research was to determine if GRHB could provide sufficient P, K, and micronutrients to support production geranium for six weeks. In both experiments, substrate solutions from containers amended with 10% GRHB (with or without micronutrients) had elevated levels of both soluble reactive phosphate and potassium relative to geranium receiving the NPK-control fertilizer solution. Furthermore, foliar P and K concentration in geranium growing in substrates amended with 10% GRHB (with or without micronutrients) were similar and often higher than those receiving the NPK-fertilizer control. Containers amended with GRHB were fertilized with ammonium nitrate only, thus all P and K must have originated primarily from the GRHB. These data suggest that GRHB can provide sufficient P and K for container-grown geranium over a 6-week production cycle. Considering the high levels of phosphate and K in the substrate solution at 6 WAP, it is likely there would be sufficient P and K for a period considerably longer than 6 weeks. Amendment with GRHB does not satisfy the micronutrient needs of container-grown geranium. In both experiments, micronutrient levels in foliage were either above the recommended minimum range, or at least greater than levels in the apparently healthy NPK-fertilized controls. Micronutrient levels in foliage do not explain the clear pattern of chlorosis among treatments. Despite this, in both experiments, amendment of the substrate with a micronutrient package in addition to GRHB alleviated all signs of chlorosis and resulted in significantly larger plants compared to other plants receiving the same rate of GRHB but no micronutrient package. Additional research will be needed to determine which micronutrient, or combination of micronutrients, are either deficient or in toxic concentration. These data demonstrate that GRHB provides a source of readily available P and K, but lacks the correct con-centration or balance of micronutrients for adequate container nutrition.

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