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Physical Properties of and Plant Growth in Peat-based Root Substrates Containing Glass-based Aggregate, Perlite, and Parboiled Fresh Rice Hulls

Michael R. Evans[1]

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SUMMARY. Aggregates produced from finely ground waste glass [Growstones (GS); Earthstone Corp., Santa Fe, NM] have been proposed to adjust the physical properties of peat-based substrates. The GS had a total pore space (TPS) of 87.4% (by volume), which was higher than that of sphagnum peat and perlite but was similar to that of parboiled fresh rice hulls (PBH). The GS had an air-filled pore space (AFP) of 53.1%, which was higher than that of sphagnum peat and perlite but lower than that of PBH. At 34.3%, GS had a lower water-holding capacity (WHC) than sphagnum peat but a higher WHC than either perlite or PBH. The bulk density of GS was 0.19 g·cm^{-3} and was not different from that of the perlite but was higher than that of sphagnum peat and PBH. The addition of at least 15% GS to sphagnum peat increased the AFP of the resulting peat-based substrate. Substrates containing 25% or 30% GS had a higher AFP than substrates containing equivalent amounts of perlite but a lower AFP than substrates containing equivalent PBH. Substrates containing 20% or more GS had a higher WHC than equivalent perlite- or PBH-containing substrates. Growth of 'Cooler Grape' vinca (*Catharanthus roseus*), 'Dazzler Lilac Splash' impatiens (*Impatiens walleriana*), and 'Score Red' geranium (*Pelargonium* ×*hortorum*) was similar for plants grown in GS-containing substrates and those grown in equivalent perlite- and PBH-containing substrates.

Root substrates (substrates) are formulated from various inorganic and organic components to provide suitable physical and chemical properties as required by the specific crop and growing conditions (Bunt, 1988; Nelson, 2003). Important substrate physical properties include TPS, AFP, WHC, and bulk density. Air-filled pore space is particularly important because air-filled pores allow for gas exchange between the root environment and the outside atmosphere (Bunt, 1988). Various materials have been used to provide AFP in substrates, with two of the most common being perlite (Bunt, 1988) and PBH (Evans and Gachukia, 2007).

Perlite is an inorganic expanded aluminosilicate of volcanic origin (Nelson, 2003) produced by mining the ore, grinding the crude ore to the desired particle size, and heating it up to 982 °C. Heating causes the ore to expand from 4 to 20 times its original volume, resulting in a lightweight white porous particle (Hanan, 1998). Parboiled fresh rice hulls are a milling coproduct of the rice industry and comprise ≈20% of the rice grain at harvest (Kamath and Proctor, 1998). Parboiled fresh rice hulls are obtained as a result of a steaming process and are therefore sterile and free of viable weed seed when initially produced. Because of their large elongated shape, PBH creates large pores in the substrate that become air-filled after irrigation and drainage (Evans and Gachukia, 2004, 2007).

Although these two components are the dominant components used in substrates in the United States to increase AFP, they both have disadvantages and limitations. Because of the costs associated with mining, transportation, and heating, perlite has been a relatively expensive substrate component. In addition to its cost, in its dry state, perlite produces a siliceous dust, which is an eye and lung irritant. PBH are produced in specific areas of the United States; therefore, shipping costs impact the economics of using PBH. Additionally, because it is a plant-based component, PBH may have limitations with respect to its use in long-term crops because of softening and decomposition of the particle.

Some potential alternative components designed to provide drainage and AFP in a substrate (e.g., shredded rubber, ground bovine bone) had undesirable chemical properties (Evans, 2004; Evans and Harkess, 1997; Handrek, 1996) such as high pH, high ammonium, high electrical conductivity, or phytotoxic levels of one or more mineral elements. Other materials evaluated were either too expensive or had unacceptably high bulk densities (e.g., calcined clay aggregates, gravel), which resulted in unacceptably high shipping costs for most horticultural uses.

Growstones have been successfully used as a hydroponic substrate and proposed as an aggregate to adjust the physical properties of peat-based substrates. Growstones were produced from finely ground waste glass. The ground glass powder was combined with calcium carbonate and heated in a kiln. The heat resulted in the production of carbon dioxide as the glass particles were heated and fused together trapping air spaces inside the glass. This resulted in an expanded light weight product. After cooling, the product was ground to produce the desired particle size.

The objectives of this study were to determine the physical properties of GS compared with those of perlite and PBH, to determine how GS

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
28.3495	oz	g	0.0353
1.7300	oz/inch³	g·cm⁻³	0.5780
1	ppm	mg·L⁻¹	1
(°F − 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

Professor, Department of Horticulture, 318 Plant Sciences Building, University of Arkansas, Fayetteville, AR 72701

[1]Corresponding author. E-mail: mrevans@uark.edu.

affected root substrate physical properties compared with those of perlite and PBH, and to evaluate plant growth in GS-, perlite-, and PBH-containing substrates.

Materials and methods

Physical properties of GS, perlite, PBH, and peat-based root substrates amended with these aggregates. Parboiled fresh rice hulls were obtained from Riceland Foods (Stuttgart, AR). Horticultural perlite and sphagnum peat were obtained from Sun Gro Horticulture (Bellevue, WA). Growstones were obtained from Earthstone Corp. (Santa Fe, NM). Particle size distributions were determined for GS, PBH, and perlite by sieving 100-g samples on a rotary shaker (CSC Scientific, Fairfax, VA) for 5 min using screens with openings of diameters 8.0, 6.3, 2.8, and 2.0 mm. Five random samples were screened for each material. The weight of the material collected in each screen was determined. The percent weight retained in each screen size and standard errors were plotted for GS, perlite, and PBH.

Fifteen substrates were formulated by blending GS, perlite, and PBH in a rotary mixer for 1 min at 50 rpm to produce root substrates that contained either 10%, 15%, 20%, 25%, or 30% (by volume) GS, perlite, or PBH, with the remainder being sphagnum peat. All substrates were air-dried in a greenhouse at 32 to 35 °C until they no longer lost weight over a 24-h period. The composite substrates were re-wetted with deionized water to a moisture content of 50% (by weight). All substrates were placed into sealed plastic bags and allowed to equilibrate for 1 d to attain moisture uniformity. In addition to these 15 composite root substrates, the physical properties of 100% sphagnum peat, GS, perlite, and PBH were determined. The 100% GS, perlite, and PBH had no water added. Substrates and components were packed into 350-mL porometers (7.6 × 7.6 cm aluminum core), and total porosity (v/v), AFP (v/v), WHC (v/v), and bulk density were determined using procedures described by Bilderback and Fonteno (1993), Byrne and Carty (1989), and Evans and Gachukia (2007).

Five replications of each root substrate were tested. Single-df contrasts were conducted for each of the physical properties to determine if significant differences occurred between GS and perlite or PBH, as well as substrates containing GS and those containing equivalent amounts of perlite or PBH.

Plant growth in substrates containing GS, perlite, or PBH. Fifteen substrates containing 10%, 15%, 20%, 25%, or 30% GS, perlite, or PBH were formulated as described earlier. Substrates were placed into 4.5-inch-diameter plastic (600 mL volume) containers. 'Cooler Grape' vinca, 'Dazzler Lilac Splash' impatiens, and 'Score Red' geranium plugs (#277 plugs with four expanded true leaves) were transplanted into the containers filled with the substrates. Containers were transferred to a glass-glazed greenhouse. Air temperatures were maintained between 20 and 25 °C under ambient light levels (350 to 525 $\mu mol \cdot s^{-1} \cdot m^{-2}$ at 1200 HR) and natural photoperiods occurring from 15 Sept. to 7 Nov. at latitude 36°3′36″N. Plants were irrigated with a 200 ppm nitrogen nutrient solution using a 15N–2.2P–12.5K water-soluble fertilizer (Excel 15–5–15 Cal Mag fertilizer; Scotts, Marysville, OH) as required to maintain moist root substrates for all containers. However, plants were irrigated at least twice per week.

Shoot and root dry weights were determined 8 weeks after transplanting. The study was a randomized complete block design with 10 blocks, and each species and root substrate combination appeared once per block. An analysis of variance was conducted to determine if significant differences in shoot dry or root dry weights occurred among the substrates. Where significant differences occurred, single-df contrasts were conducted to determine the significant differences between GS-containing substrates vs. equivalent perlite- and PBH-containing substrates.

Results and discussion

Physical properties of GS, perlite, PBH, and peat-based root substrates amended with these aggregates. About 92% of GS particles were more than 2.8 mm in diameter (Fig. 1), and the GS had a significantly higher percentage (62%) of particles larger than 6.3 mm than either perlite or PBH, which had a majority of particles in the 2.8 to 6.3 mm particle size range. The GS also had a lower percentage of particles in the less than 2.0 mm diameter particle size than either perlite or PBH.

The GS had a TPS of 87.4%, which was higher than that of sphagnum peat and perlite but was similar to that of PBH (Table 1). The substrate containing 10% GS had a lower TPS than the substrates containing 10% perlite and PBH. There was no difference in TPS between root substrates containing 15% to 30% GS and equivalent perlite- and PBH-containing root substrates.

The GS had an AFP of 53.1%, which was higher than that of sphagnum peat and perlite but lower than that of PBH (Table 1). Substrates containing 10% and 15% GS had lower AFP than equivalent perlite-containing substrates. The substrate containing 20% GS had a similar AFP as the substrate containing 20%

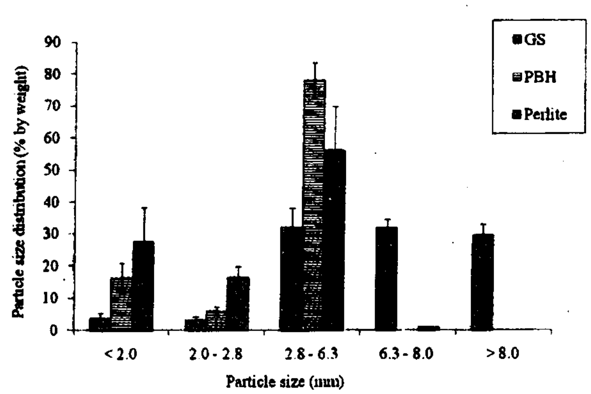

Fig. 1. Particle size distributions of glass-based aggregates [Growstones (GS); Earthstone Corp., Santa Fe, NM], parboiled fresh rice hulls (PBH), and perlite used in trials. Means are for five replications. Error bars represent the SE; 1 mm = 0.0394 inch.

Table 1. Physical properties of sphagnum peat, glass-based aggregates [Growstones (GS); Earthstone Corp., Santa Fe, NM], perlite, parboiled fresh rice hulls (PBH), and peat-based root substrates containing different proportions of these aggregates.[z]

Root substrate[y]	Total pore space (% v/v)	Air-filled pore space (% v/v)	Water-holding capacity (% v/v)	Bulk density (g·cm^{-3})[x]
Sphagnum peat	82.0	12.5	69.5	0.10
GS	87.4	53.1	34.3	0.19
Perlite	61.8	29.8	31.9	0.17
PBH	88.6	68.1	20.5	0.10
10% GS	76.5	11.0	65.5	0.13
15% GS	88.1	14.7	73.5	0.12
20% GS	87.9	14.9	73.0	0.12
25% GS	87.6	20.3	67.3	0.12
30% GS	86.4	19.7	66.7	0.13
10% perlite	85.8	13.7	77.8	0.10
15% perlite	85.8	16.8	69.0	0.08
20% perlite	84.3	15.4	66.0	0.10
25% perlite	83.9	17.4	66.4	0.09
30% perlite	83.3	18.5	64.7	0.10
10% PBH	87.5	16.5	71.0	0.11
15% PBH	87.8	18.1	69.7	0.12
20% PBH	84.6	22.8	61.8	0.10
25% PBH	83.9	25.5	58.4	0.09
30% PBH	84.3	26.5	57.9	0.09
Overall significance	***	***	***	***
GS vs. peat	***	***	***	***
Perlite vs. peat	***	***	***	***
PBH vs. peat	***	***	***	NS
GS vs. perlite	***	***	**	NS
GS vs. PBH	NS	***	**	**
10% GS vs. 10% perlite	*	*	*	*
10% GS 10 vs. 10% PBH	*	***	*	NS
15% GS vs. 15% perlite	NS	***	***	**
15% GS 15 vs. 15% PBH	NS	***	**	NS
20% GS vs. 20% perlite	NS	NS	***	NS
20% GS vs. 20% PBH	NS	***	***	NS
25% GS vs. 25% perlite	NS	***	**	*
25% GS vs. 25% PBH	NS	***	**	*
30% GS vs. 30% perlite	NS	***	**	*
30% GS vs. 30% PBH	NS	***	***	***

[z]Physical properties were determined using porometers with a column height of 7.6 cm (2.99 inches) and a volume of 350 mL (11.83 fl oz). Means are for five replications.
[y]Numbers preceding substrate components indicate the percentage of the component in the substrate with the remainder of the volume being sphagnum peat.
[x]1 g·cm^{-3} = 0.5780 oz/inch^3.
NS, *, **, *** Nonsignificant or significant at $P = 0.05$, 0.01, or 0.001, respectively.

perlite, but substrates containing 25% or 30% GS had a higher AFP than equivalent perlite-containing substrates. All GS-containing substrates had lower AFP than equivalent PBH-containing substrates.

The GS had a WHC of 34.3%, which was lower than that of sphagnum peat but higher than that of either perlite or PBH. Substrates containing 10% GS had a lower WHC than equivalent perlite- or PBH-containing substrates. Substrates containing 15% to 30% GS had a higher WHC than equivalent perlite- or PBH-containing substrates.

At 0.19 g·cm^{-3}, the bulk density of GS was not different from that of the perlite but was higher than that of sphagnum peat and PBH (Table 1). The bulk density of substrates containing 10%, 15%, 25%, and 30% GS was higher than that of equivalent perlite-containing substrates. The bulk density of substrates containing 20% GS was not different from that of the substrate containing 20% perlite. The bulk density of substrates containing 10% to 20% GS was not different from equivalent PBH-containing substrates, but substrates containing 25% and 30% GS had a higher bulk density than those containing 25% and 30% PBH, respectively.

The addition of at least 15% GS to sphagnum peat provided for increased AFP in the resulting substrates, and as the amount of GS was increased in the substrate, the AFP of the resulting substrate increased. Therefore, GS had a similar role in the substrate as perlite and PBH in relation to providing increased AFP.

Evans and Gachukia (2007) reported that at concentrations of 20% or less, perlite- and PBH-containing substrates had a similar AFP, but as the amount of perlite and PBH were increased, the PBH had an increased effect on the AFP than perlite. This was also the case with GS because the addition of at least 25% GS to the substrate resulted in a higher AFP than equivalent amounts of perlite. Evans and Gachukia (2007) attributed the greater impact of PBH on AFP to the long and angular shape of the PBH vs. the more rounded shape of the perlite. Growstones particles were more angular than perlite, and this shape difference may explain why 25% and 30% GS substrates had a higher AFP than equivalent perlite substrates. This may also explain why substrates containing at least 20% PBH had a higher AFP than perlite or GS because PBH were the longest and most angular of the aggregates.

Interestingly, substrates that contained at least 15% GS had a higher WHC than equivalent perlite- or PBH-containing substrates. The GS particles were very porous and the openings in the particles were larger than those of the perlite. Growstones particles were able to absorb water whereas most of the pores of perlite were considered closed and did not, at least in the short term, absorb water. This may be the reason that GS-containing substrates had a higher WHC than equivalent perlite- and PBH-containing substrates.

For substrates to be used in greenhouse crop production, Arnold Bik (1983) and Boertje (1984) recommended a minimum of 85% TPS and at least 45% water-filled pore space. Bunt (1988) recommended an AFP of at least 10% to 20%. Jenkins and Jarrell (1989) proposed optimal ranges of 60% to 75% for TPS, 50% to 65%

for WHC, and 10% to 20% for AFP. All the GS-containing substrates were within the recommended ranges for these parameters.

Plant growth in substrates containing GS, perlite, or PBH. There was no difference in shoot dry or root dry weights of impatiens and vinca grown in substrates containing 10% to 30% GS and those grown in equivalent perlite- or PBH-containing substrates (Table 2). There was no difference in shoot dry weight of geranium plants grown in substrates containing 10% to 25% GS and equivalent perlite- and PBH-containing substrates or substrates containing 30% GS and 30% PBH. However, geranium plants grown in the substrate containing 30% GS had lower shoot dry weight than those grown in the substrate containing 30% perlite. Geranium plants grown in 10% GS had higher root dry weight than plants grown in substrates containing 10% perlite or 10% PBH. Geranium plants grown in 15% GS had lower root dry weight than geranium plants grown in the substrate containing 15% PBH but had a similar root dry weight as those grown in 15% perlite. There was no difference in root dry weights of geranium plants grown in substrates containing 20% or more GS and those containing equivalent amounts of perlite or PBH.

No differences were observed in plant growth for vinca and impatiens. Although some differences in shoot and root growth of geranium were observed for plants grown in GS-containing substrate as compared with plants grown in perlite- or PBH-containing substrates, the differences were not large enough to be of practical or commercial significance and all plants were of marketable size and quality. Therefore, in addition to having recommended physical properties, substrates amended with GS could be used to grow crops similar to those grown in equivalent perlite- and PBH-containing substrates.

Table 2. Growth of geranium, impatiens, and vinca after 8 weeks in peat-based substrates containing varying proportions of glass-based aggregates [Growstones (GS); Earthstone Corp.], perlite, and parboiled fresh rice hulls (PBH).

	Vinca		Impatiens		Geranium	
Root substrate	Shoot dry wt (g)[z]	Root dry wt (g)	Shoot dry wt (g)	Root dry wt (g)	Shoot dry wt (g)	Root dry wt (g)
10% GS	2.6	0.6	3.0	0.8	12.0	1.9
15% GS	2.8	0.7	2.7	0.9	11.4	1.6
20% GS	2.7	0.6	3.0	0.9	10.7	1.7
25% GS	2.7	0.7	2.8	0.8	11.4	1.8
30% GS	2.7	0.6	2.9	0.8	10.6	1.7
10% perlite	2.3	0.5	2.9	0.8	11.3	1.5
15% perlite	2.5	0.6	2.9	0.9	11.3	1.5
20% perlite	2.7	0.6	3.1	0.9	12.1	1.7
25% perlite	3.2	0.8	2.9	0.9	11.3	1.7
30% perlite	3.0	0.8	3.0	0.8	12.3	1.9
10% PBH	2 6	0.6	2.9	0.9	10.5	1.6
15% PBH	3.0	0.7	2.9	0.9	11.5	2.0
20% PBH	3.0	0.7	3.1	1.0	10.1	1.7
25% PBH	2.2	0.5	2.9	0.9	11.1	1.9
30% PBH	2.3	0.7	3.0	0.8	10.6	1.9
Overall significance	NS	NS	NS	NS	*	*
GS vs. perlite	NS	NS	NS	NS	*	*
GS vs. PBH	NS	NS	NS	NS	NS	*
10% GS vs. 10% perlite	NS	NS	NS	NS	NS	*
10% GS 10 vs. 10% PBH	NS	NS	NS	NS	NS	*
15% GS vs. 15% perlite	NS	NS	NS	NS	NS	NS
15% GS 15 vs. 15% PBH	NS	NS	NS	NS	NS	*
20% GS vs. 20% perlite	NS	NS	NS	NS	NS	NS
20% GS vs. 20% PBH	NS	NS	NS	NS	NS	NS
25% GS vs. 25% perlite	NS	NS	NS	NS	NS	NS
25% GS vs. 25% PBH	NS	NS	NS	NS	NS	NS
30% GS vs. 30% perlite	NS	NS	NS	NS	*	NS
30% GS vs. 30% PBH	NS	NS	NS	NS	NS	NS

[z]Means are for 10 blocks; 1 g = 0.0353 oz.
[NS],* Nonsignificant or significant at $P = 0.05$ level.

Conclusions

Growstones had an AFP higher than that of both peat and perlite and when added to peat at a concentration of at least 15% increased the AFP of the resulting peat-based substrate. Therefore, GS could be used in a similar manner to perlite and PBH as an aggregate to increase AFP of peat-based substrates. The three primary differences were that, at concentrations of 25% or more, GS resulted in a higher AFP than equivalent perlite-containing substrates, substrates containing 20% or more GS had a higher WHC than equivalent perlite- and PBH-containing substrates, and GS-containing substrates had a higher bulk density than equivalent perlite- and PBH-containing substrates. All GS-containing substrates had physical properties within recommended ranges, and plants grown in GS-containing substrates were similar to plants grown in equivalent perlite- and PBH-containing substrates. Therefore, GS were successfully used as a component for substrates to be used for the production of greenhouse crops.

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