Physical Properties of Sphagnum Peat-based Root Substrates Amended with Perlite or Parboiled Fresh Rice Hulls

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SUMMARY. **Ten substrates were formulated by blending perlite or parboiled fresh rice hulls (PBH) to produce root substrates (substrates) that contained either 20%, 30%, 40%, 50%, or 60% (by volume) perlite or PBH, with the remainder being sphagnum peatmoss. All substrates containing PBH had higher total pore space than substrates containing an equivalent amount of perlite. As the percentage perlite increased from 20% to 60%, the total pore space decreased. The total pore space increased as the amount of PBH increased to 50% and then decreased as the amount of PBH increased from 50% to 60%. The air-filled pore space was not different between substrates containing 20% perlite or PBH. However, the air-filled pore space was higher in PBH-containing substrates than in equivalent perlite-containing substrates when the amount of PBH or perlite was at least 40%. As the amount of perlite or PBH was increased, the air-filled pore space increased, but the rate of increase was higher for PBH-containing substrates. The 20% PBH-containing substrate had a higher water-holding capacity than the 20% perlite-containing substrate. However, at 30% or higher PBH, the PBH-containing root substrates had a lower water-holding capacity than equivalent perlite-containing substrates. As the percentage perlite or PBH was increased, the water-holding capacity decreased, but at a higher rate in PBH-containing substrates than in perlite-containing substrates. For all substrates except those containing 40% PBH or perlite, substrates containing PBH had lower bulk densities than equivalent perlite-containing substrates. The differences in bulk densities were not great enough to be of practical significance. Inclusion of PBH in the substrate provided for drainage and air-filled pore space as did perlite. However, less PBH would be required in a substrate to provide the same air-filled pore space as perlite when more than 20% perlite or PBH is used.**

Root substrates (substrates) are commonly used in the production of containerized greenhouse and nursery crops (Nelson, 2003). 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). An important physical property of substrates is air-filled pore space. Air-filled pores allow for drainage and gas exchange between the root environment and the outside atmosphere (Bunt, 1988). Various materials are used to provide, at least in part, for air-filled pore space in substrates, with one of the most common being perlite (Boertje and Arnold Bik, 1975; Bunt, 1988).

Perlite is an inorganic, expanded aluminosilicate of volcanic origin (Nelson, 2003) and it is produced by mining the ore, grinding the crude ore to the desired particle size, and heating it to temperatures of up to 982 °C. Heating causes the ore to expand from four to 20 times its original volume, resulting in a lightweight white porous particle (Hanan, 1998). Because of the costs associated with mining, transportation, and heating, perlite is a relatively expensive substrate component. In addition to its cost, in its dry state perlite produces a siliceous dust that is classified as an eye and lung irritant. Substrate components that are lower in cost, do not have potential health issues, and could provide for air-filled pore space in the substrate would be beneficial to the nursery and greenhouse crops industries.

Some potential alternative components to perlite (e.g., shredded rubber, ground bovine bone) have undesirable chemical properties (Evans, 2004; Evans and Harkess, 1997) such as high pH, high electrical conductivity, or phytotoxic levels of one more mineral nutrients. Other materials evaluated as potential alternatives to perlite are either too expensive or have unacceptably high bulk densities (e.g., calcined clay aggregates, gravel), which resulted in unacceptably high shipping costs.

Parboiled fresh rice hulls (PBH) are a milling coproduct of the rice industry and comprise ≈20% of the rice grain at harvest. Parboiled fresh rice hulls are obtained as a result of a steaming process and are therefore free of viable weed seed. Evans and Gachukia (2004) demonstrated that PBH could be successfully used as an alternative to perlite in the root substrate for the production of several ornamental species. However, the physical properties of PBH-amended sphagnum peat-based substrates compared with those amended with perlite have not been reported. Additionally, how increasing amounts of PBH in the substrate affects the physical properties of the substrate has not been reported.

The objectives of this study were to determine and compare total pore space (% by volume), air-filled pore space (% by volume), water-holding capacity (% by volume and weight per weight), and bulk density (weight per volume) of sphagnum peat-based substrates amended with various amounts of PBH or perlite, and to determine how the amount of PBH or perlite affects these physical properties.

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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
2.5400	inch(es)	cm	0.3937
1.7300	oz/inch^3	g·cm^{-3}	0.5780
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

Materials and methods

Parboiled fresh rice hulls were obtained from Riceland Foods (Stuttgart, Ark.). Parboiled fresh rice hulls were dried and bagged immediately after parboiling and drying without being stored outside. Horticultural perlite and sphagnum peat were obtained from Sun Gro Horticulture (Bellevue, Wash.). Ten substrates were formulated by blending perlite or PBH in a rotary mixer for 1 min at 50 rpm to produce root substrates that contained either 20%, 30%, 40%, 50%, or 60% (v/v) perlite or PBH, with the remainder being sphagnum peat.

The root substrates were air-dried in a greenhouse at 32 to 35 °C until they no longer lost weight over a 24-h period. The samples were rewetted with deionized water to a moisture level of 60% (wt/wt). They were then placed into sealed plastic bags and allowed to equilibrate for 1 d to attain moisture uniformity. Substrates were packed into 350-mL porometers (3 × 3-inch aluminum core), and total porosity (by volume), air-filled pore space (by volume), water-holding capacity (by volume), and bulk density (weight per volume) were determined using procedures described by Bilderback and Fonteno (1993) and Byrne and Carty (1989).

Five replications of each root substrate were evaluated. Single-df contrasts were conducted for each of the physical properties to determine whether significant differences occurred between root substrates containing equivalent amounts of perlite or PBH. Regression analysis was performed to determine how increasing amounts of perlite or PBH affected the root substrate physical properties. The best models describing the parameters were determined by evaluating a combination of the data values versus predicted values, residual values versus a zero reference line, and the R^2 values for each model.

Results and discussion

Total pore space in perlite-containing substrates ranged from 71.5% to 79.4% whereas total pore space in PBH-containing substrates ranged from 82.1% to 86.7% (Table 1). All substrates containing PBH had more total pore space than substrates containing an equivalent amount of perlite. As the percentage perlite increased from 20% to 60%, the total pore space decreased (Fig. 1), following the model $y = 77 + 11x - 0.0035x^2$ (R^2 = 0.71). The total pore space increased as the amount of PBH increased to 50%, and then decreased as the amount of PBH increased to 60%. However, the change in total pore space as PBH increased was relatively small and followed the model $y = 70.1 + 0.84x - 0.01x^2$ (R^2 = 0.76).

The decrease in total pore space of perlite-containing substrates could be attributed to perlite having a total pore space of 74%, which was lower than that for sphagnum peat at 84% (Hanan, 1998). Likewise, the small change in total pore space with increasing amounts of PBH could be attributed to PBH having a total pore space of 82%, which was similar to the total pore space of sphagnum peat.

Air-filled pore space ranged from 9.5% to 12.7% for perlite-containing root substrates and 11.5% to 37.8% for PBH-containing substrates (Table 1).

Table 1. Physical properties of sphagnum peat-based root substrates amended with perlite or parboiled fresh rice hulls (PBH).

Substrate composition[z]		Total pore space (% v/v)	Air-filled pore space (% v/v)	Water-holding capacity (% v/v)	Bulk density ($g\cdot cm^{-3}$)[y]
20% perlite		79.4	9.5	67.9	0.108
30% perlite		76.9	10.8	68.9	0.101
40% perlite		73.9	11.4	62.6	0.098
50% perlite		73.9	11.9	62.8	0.115
60% perlite		71.5	12.7	59.0	0.121
20% PBH		83.2	11.5	71.7	0.098
30% PBH		85.5	20.3	64.9	0.098
40% PBH		86.0	28.8	56.9	0.097
50% PBH		86.7	34.0	53.9	0.104
60% PBH		82.1	37.8	45.1	0.112
Significance	df				
Substrate	9	***	***	***	***
Perlite vs. PBH	1	***	***	***	***
20% perlite vs. PBH	1	***	NS	*	***
30% perlite vs. PBH	1	***	***	*	**
40% perlite vs. PBH	1	***	***	***	NS
50% perlite vs. PBH	1	***	***	***	***
60% perlite vs. PBH	1	***	***	***	**

[z]Substrate composition indicates percentage perlite or PBH, with the remainder of substrate being sphagnum peat.
[y]$1\ g\cdot cm^{-3} = 0.5780\ oz/inch^3$.
NS,*,**,***Nonsignificant or significant at P = 0.05, 0.01, or 0.001 respectively.
PBH, parboiled fresh rice hulls.

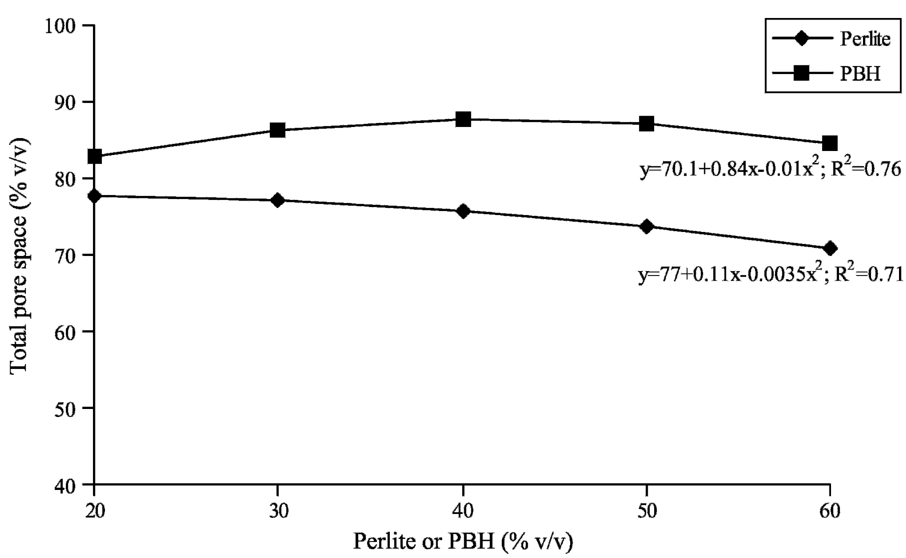

Fig. 1. Total pore space (% by volume) of sphagnum peat-based root substrates containing 20% to 60% perlite or parboiled fresh rice hulls (PBH).

The air-filled pore space was not different between substrates containing 20% perlite or PBH. However, the air-filled pore space was higher in PBH-containing root substrates than in equivalent perlite-containing substrates when the amount of PBH or perlite was at least 30%. As the amount of perlite increased, the air-filled pore space increased (Fig. 2), following the model y = 7.94 + 0.08x (R^2 = 0.76). As the amount of PBH increased, the air-filled pore space increased, following the model y = 1.11 + 0.62x (R^2 = 0.95).

Perlite had an air-filled pore space of 54% whereas PBH had an air-filled pore space of 69% (Hanan, 1998). The higher air-filled pore space of PBH could at least partially account for the higher air-filled pore space of PBH-containing substrates overall, and specifically in substrates containing at least 30% PBH. The air-filled pore space of PBH-containing substrates also increased at a higher rate (slope, 0.62) compared with perlite-containing substrates (slope, 0.08). The difference in the rate of change in air-filled pore space may have been partially the result of the higher air-filled pore space of PBH, but also the result of the elongated shape of PBH (in contrast to perlite granules, which are generally spherical), which allowed the individual hulls to cross connect and create more and larger pores in substrates containing high concentrations of PBH.

Water-holding capacity ranged from 59.0% to 68.9% for the perlite-containing substrates and 45.1% to 71.7% for the PBH-containing substrates (Table 1). The 20% PBH-containing substrate had a higher water-holding capacity than the 20% perlite-containing substrate. However, at 30% or more PBH, the PBH-containing root substrates had a lower water-holding capacity than equivalent perlite-containing substrates. As the percentage perlite increased, the water-holding capacity decreased, following the model y = 74 – 0.24x (R^2 = 0.85). As the percentage PBH increased (Fig. 3), the water-holding capacity decreased, following the model y = 84.2 – 0.62x (R^2 = 0.98).

As would have been expected, water-holding capacity was generally inversely related to air-filled pore space. As air-filled pore space increased, the water-filled pores, and thus water-holding capacity, decreased. The properties of PBH—namely, particle size and shape—that resulted in a higher air-filled pore space, and a higher rate of change in air-filled pore space with increasing amounts of PBH also resulted in a lower water-holding capacity and a higher rate of decline (a slope of –0.24 for perlite and –0.64 for PBH) in the water-holding capacity as PBH concentration increased compared with equivalent perlite-containing substrates.

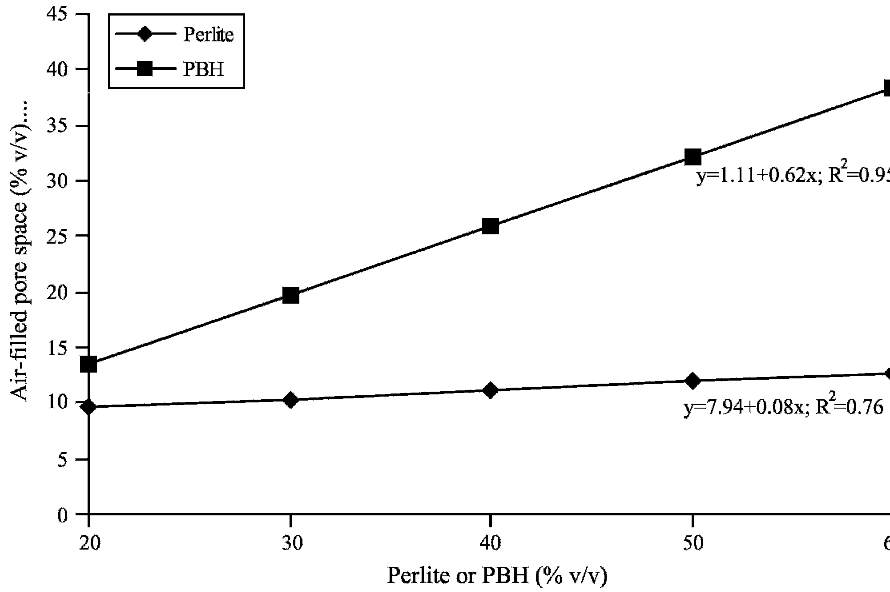

Fig. 2. Air-filled pore space (% by volume) of sphagnum peat-based root substrates containing 20% to 60% perlite or parboiled fresh rice hulls (PBH).

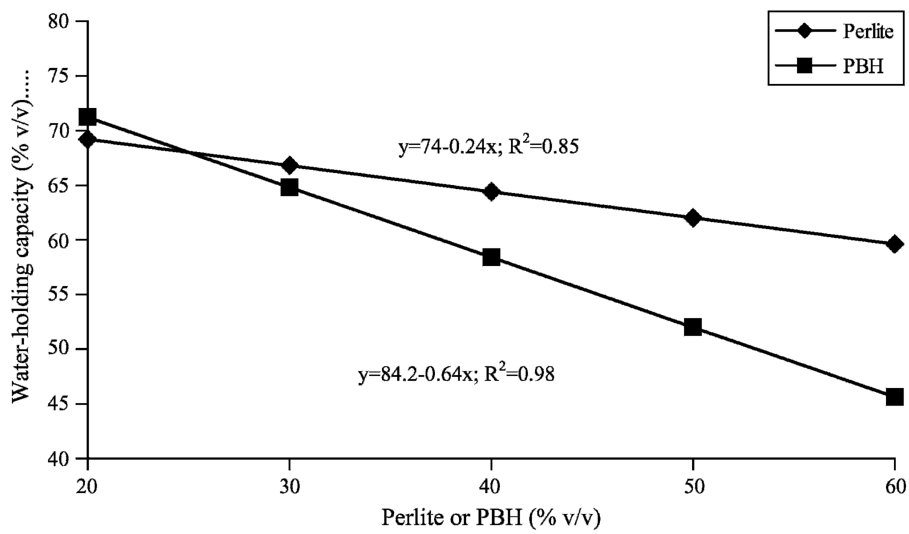

Fig. 3. Water-holding capacity (% by volume) of sphagnum peat-based root substrates containing 20% to 60% perlite or parboiled fresh rice hulls (PBH).

An anomaly in the data for water-holding capacity was that at 20%, PBH had a higher water-holding capacity than the equivalent perlite-containing substrate. This was despite the fact that the 20% PBH substrate had a higher total pore space and a similar air-filled pore space as the 20% perlite substrate. This anomaly could be a data artifact or could be the result of the shape of PBH. In addition to being elongated, PBH have a "canoe" shape that catches water if oriented correctly. At low concentrations of PBH, this might have resulted in additional water-holding capacity of the PBH-containing substrate. However, as the amount of PBH was increased, the cross-linking of PBH that created more and larger pore spaces (and higher air-filled pore spaces) in the substrate would have more than compensated for this phenomenon, and the water-holding capacity would then begin to decline to less than that of the equivalent perlite-containing substrates.

Bulk densities ranged from 0.098 to 0.121 $g\cdot cm^{-3}$ for perlite-containing substrates and 0.097 to 0.112 $g\cdot cm^{-3}$ for PBH-containing substrates (Table 1). Except for substrates containing 40% perlite or PBH, which had similar bulk densities, the bulk densities of perlite-containing substrates were more than the bulk densities of equivalent PBH substrates. For perlite-containing substrates, bulk density decreased (Fig. 4) as the amount of perlite was increased to 40%, and then increased with increasing amounts of perlite, following the model $y = 0.14 - 002x + 0.00004x^2$ ($R^2 = 0.85$). For PBH-containing substrates, bulk density was generally unchanged until the amount of PBH increased to more than 40%, at which point bulk density increased, following the model $y = 0.112 - 001x + 0.00002x^2$ ($R^2 = 0.98$).

Overall, and for all contrasts except for 40%, PBH-containing substrates had a lower bulk density than perlite-containing substrates. Because perlite and PBH had similar bulk densities of 0.10 $g\cdot cm^{-3}$, the differences in bulk density may be a result of how the components packed when blended together, with the elongated shape of the PBH creating more pore space and resisting settling more than perlite. Additionally, horticultural perlite typically contains fine particles that may fill in pores and increase root substrate bulk density. The decrease in bulk density at 40% PBH or perlite may have been the result of how the different substrates settled or packed, or might have been a data artifact as a result of the small values that are measured when determining bulk density.

The differences in bulk densities were not great enough to be of practical significance and were all similar to that of sphagnum peat (0.11 $g\cdot cm^{-3}$) or within the range recommended by Jenkins and Jarrell (1989). Unlike materials such as calcined clay, bulk density of PBH would be acceptable and would not add to shipping costs of the substrates or plants grown in the substrates.

Conclusion

The inclusion of PBH provided for increased and air-filled pore space and drainage in the sphagnum peat-based substrates. Furthermore, increasing the amount of PBH in the substrate resulted in a greater increase in air-filled pore space and a greater decrease in the water-holding capacity than an equivalent amount of perlite. Therefore, PBH served a similar role in the substrate as perlite, but less PBH would be required in a substrate to provide the same air-filled pore space and water-holding capacity as perlite when more than 20% perlite or PBH was used.

Arnold Bik (1983) and Boertje (1984) recommended a minimum of 85% total pore space and at least 45% water-filled pore space. Bunt (1988) recommended an air-filled pore space of at least 10% to 20%. Jenkins and Jarrell (1989) proposed optimal ranges of 60% to 75% for total pore space, 50% to 65% for water-hold capacity, and 10% to 20% for air-filled pore space. All the perlite-containing substrates were within the recommended ranges for these parameters. Only substrates containing up to 30% PBH had physical properties that were within these recommendations. However, in situations when a higher air-filled pore space and lower water-holding capacity (outside production in Florida) are desirable, substrates containing more than 30% PBH would be suitable.

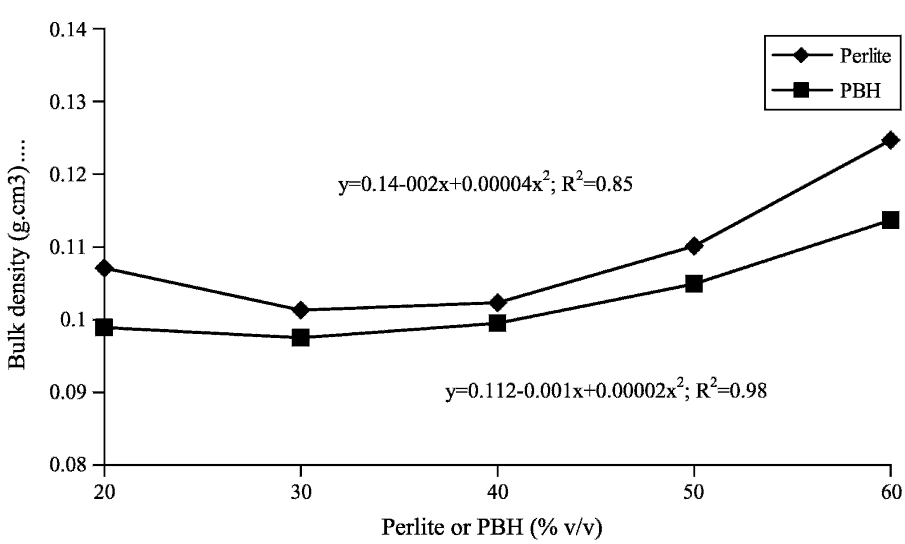

Fig. 4. Bulk density of sphagnum peat-based root substrates containing 20% to 60% perlite or parboiled fresh rice hulls (PBH). 1 $g\cdot cm^{-3}$ = 0.5780 oz/inch^3.

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