Root Substrate pH, Electrical Conductivity, and Macroelement Concentration of Sphagnum Peat-based Substrates Amended with Parboiled Fresh Rice Hulls or Perlite

Mary M. Gachukia[1] and Michael R. Evans[2,3]

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SUMMARY. Substrates were formulated by blending parboiled fresh rice (*Oryza sativa*) hulls (PBH) or perlite with sphagnum peat (peat) to produce root substrates (substrates) that contained 20%, 30%, 40%, 50%, or 60% (by volume) PBH or perlite with the remainder being peat. After 0 (initial mixing), 4, or 8 weeks in a greenhouse environment, samples were taken and pH, electrical conductivity (EC), nitrate (NO_3^-), ammonium (NH_4^+), phosphorus (P), and potassium (K) were determined. As the amount of PBH or perlite in the substrate was increased, the pH increased. After 0 and 8 weeks, the pH of substrates containing up to 30% PBH or perlite had a similar pH. However, the rate of pH increase at these sampling times was higher than that of perlite so that substrates containing 40% or more PBH had a higher pH than equivalent perlite-containing substrates. At the week 4 sampling period, all substrates containing PBH had a higher pH than equivalent perlite-containing substrates. For all sampling times, the difference in pH between equivalent PBH and perlite-containing substrates was not high enough to be of practical significance. For all sampling times, EC increased as the amount of perlite was increased. Depending upon sampling time, the EC decreased or remained unchanged as the amount of PBH was increased. For all sampling times and substrates, EC was within acceptable ranges for unused substrates. Substrates containing PBH had higher NO_3^- levels than equivalent perlite-containing substrates. The NH_4^+ level of the substrates decreased as the amount of PBH or perlite was increased. The levels of NO_3^- and NH_4^+ were within acceptable ranges for unused substrates. Substrate P and K increased as the amount of PBH in the substrate was increased, but the concentration of P and K remained unchanged or decreased as the amount of perlite was increased. None of the differences between equivalent PBH and perlite-containing substrates was high enough to be problematic with respect to crop production and all of the chemical parameters were within acceptable ranges for unused root substrates.

Root substrates (substrates) are commonly used in the production of containerized greenhouse and nursery crops (Bunt 1988; 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). One important physical property of substrates is air-filled pore space (Bunt, 1988). Air-filled pores allow for drainage and gas exchange between the root environment and the outside atmosphere. Various materials have been used to provide for air-filled pore space in substrates, with one of the most common being perlite (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 has been a relatively expensive substrate component. In addition to its cost, in its dry state, perlite produces a siliceous dust that is an eye and lung irritant. Substrate components that are lower in cost, do not have the dust issues associated with perlite, and could provide for air-filled pore space in the substrate would be beneficial to the nursery and greenhouse crop industries.

Some potential alternative components to perlite (i.e., shredded rubber and ground bovine bone) had undesirable chemical properties (Evans, 2004; Evans and Harkess, 1997; Handrek, 1996) such as high pH, high NH_4^+, high electrical conductivity (EC), or phytotoxic levels of one or more mineral nutrients. Other materials evaluated as potential alternatives to perlite were too expensive or had unacceptably high bulk densities (i.e., calcined clay aggregates, gravel) that resulted in unacceptably high shipping costs for most horticultural uses.

Parboiled fresh rice hulls (PBH) are a milling coproduct of the rice industry and comprise ≈20% of the rice grain at harvest (Kamath and Proctor, 1998). PBH are obtained as a result of a steaming process and are therefore sterile and free of viable weed seed when initially produced. 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. Evans and Gachukia (2007) also reported how PBH affected the physical properties of sphagnum peat-based substrates compared with perlite. However, the effects that PBH has on the chemical properties of sphagnum peat-based substrates compared with perlite have not been reported.

The objectives of this study were to determine the effect of increasing concentrations of PBH and perlite on

Department of Horticulture, University of Arkansas, 315 Plant Science Bldg., Fayetteville, AR 72701

[1]Graduate Student.

[2]Associate Professor.

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

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
1	mmho/cm	dS·m^{-1}	1
1	ppm	mg·kg^{-1}	1
1	ppm	mg·L^{-1}	1
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

the pH, EC, NO_3^-, NH_4^+, P, and K of a sphagnum peat-based substrate, to determine if these chemical properties were affected differently by increasing amounts of PBH and perlite, and to determine if these chemical properties were within acceptable ranges for use in substrates.

Materials and methods

PBH were obtained from Riceland Foods (Stuttgart, AR). Perlite and sphagnum peat (peat) were obtained from Sun Gro Horticulture (Bellevue, WA). Perlite and PBH had an initial pH of 7.5 and 6.5 in a deionized water saturated extract, respectively. Peat had an initial pH of 3.5. However, calcitic lime was added to the peat 7 days before formulation of the substrates to adjust the pH to ≈5.0.

Ten substrates were formulated by blending PBH or perlite in a rotary mixer for 1 min at 50 rpm to produce root substrates that contained 20%, 30%, 40%, 50%, or 60% (by volume) PBH or perlite with the remainder being peat. The substrates were moistened to 60% (by weight) during mixing with deionized water. Substrates were then placed into 10-cm-diameter (600 mL) plastic containers without compaction. Containers were transferred to a glass-glazed greenhouse. Air temperatures were maintained between 20 °C and 25 °C under ambient light levels (350–525 $\mu mol \cdot s^{-1} \cdot m^{-2}$ at 1200 HR) and naturally occurring photoperiods from April through September in Fayetteville, AR. The substrates in each container were maintained moist, but without leaching, by applying 60 mL of deionized water to the surface of the substrate by hand on alternate days.

Substrate samples were taken after 0 (after initial mixing), 4, and 8 weeks in the greenhouse environment. These times were selected to determine initial parameters, parameters in the middle of a typical annual bedding plant crop cycle, and parameters near the end of such a greenhouse crop cycle.

Substrate EC, pH, and nutrient status were determined using the saturated media extract method as outlined by the North Central Regional Committee for Soil and Plant Analysis (Warncke, 1988). EC was determined using an EC meter (model 441; Corning, Corning, NY), and the pH was determined using a pH meter (model AB 15; Fisher Scientific, Pittsburgh). NO_3-N concentration was determined using the copperized cadmium reduction procedure (Keeney and Nelson, 1982) and NH_4-N was determined by the nitroprusside-salicylate procedure (Wall, et al., 1975). The concentration of P and K was determined using the filtered extract for simultaneous inductively coupled plasma emission spectrometry (Jones, 1977; Munter and Grande, 1981).

Each container served as a replication. The experimental design was a completely randomized design with nine independent replications per substrate and sampling time. An analysis of variance was conducted to determine if substrate component, component percentage, or sampling time in greenhouse environment affected the chemical properties and whether significant interactions occurred among these variables. For each sampling time, substrate chemical properties were regressed against the percentage of PBH or perlite to determine how the amount of each affected each chemical property tested.

Results and discussion

For all of the parameters measured, component, percentage of the component and sampling time were significant (Table 1). Additionally, for all parameters except phosphorus, all interactions among the variables were significant. When substrates were initially blended (after 0 weeks), substrates containing 20% perlite and 20% PBH had a similar pH of ≈5.0 (Fig. 1A). As the amount of perlite or PBH was increased, the pH of the substrates increased. However, the pH of substrates containing PBH increased at a higher rate than those containing perlite. After 4 weeks in the greenhouse environment, increasing amounts of perlite or PBH resulted in an increasing pH (Fig. 1B). The rate of pH increase was similar for perlite and PBH. For all concentrations of perlite or PBH after 4 weeks, PBH-containing substrate had a higher pH than substrates containing an equivalent amount of perlite. After 8 weeks in the greenhouse environment, the substrate containing 20% perlite had a higher pH than the substrate containing 20% PBH (Fig. 1C). Substrates containing 30% of perlite or PBH had a similar pH. The pH of perlite- and PBH-containing substrates increased as the amount of perlite or PBH increased. However, the pH of substrates containing PBH increased at a higher rate than perlite. This resulted in substrates containing more than 30% PBH having a higher pH than equivalent perlite-containing substrates.

Increasing PBH or perlite resulted in an increase in substrate pH. This may have been a function

Table 1. Main effect and interactions for pH, EC, and macroelement concentration of sphagnum peat-based substrates amended with parboiled fresh rice hulls or perlite.

Chemical property[z]	Component[y]	% Component[x]	Time[w]	Component × % Component	Component × Time	% Component × Time	Component × % Component × Time
pH	***	***	***	*	**	***	*
EC	***	***	***	***	**	***	***
NO_3^-	***	***	***	***	***	***	***
NH_4^+	***	***	***	**	**	***	***
P	***	***	*	***	NS	NS	NS
K	***	***	***	***	***	***	***

[z]Nitrate (NO_3^-), ammonium (NH_4^+) phosphorus (P), and potassium (K).
[y]Components = perlite or parboiled fresh rice hulls.
[x]% Component = percentage of perlite or parboiled fresh rice hulls occurring in the peat-based substrates (20%, 30%, 40% 50%, or 60% by volume).
[w]Time = substrate sampling time (0, 4, and 8 weeks in a greenhouse environment).
[NS,*, **,***]Nonsignificant or significant at $P = 0.05$, 0.01, and 0.001, respectively.

of reducing the overall amount of peat in the substrate, which was the more acidic component of the substrate. However, substrates containing PBH always had a higher pH or the pH increased at a higher rate than substrates containing perlite. This may have been a function of the silica content of PBH, which contained ≈20% silica (Kamath and Proctor, 1998). Silicates act as bases and would therefore have increased the substrate pH. It is important, however, to note that depending upon the sampling time, the increase in pH with increasing amounts of PBH or perlite was only 0.5 units at the maximum. Furthermore, the difference in pH between equivalent PBH- and perlite-containing substrates was only 0.2 units at the maximum. This difference in pH between PBH- and perlite-containing substrates would have no practical significance in commercial production situations.

After 0 weeks, substrates containing 20% perlite or 20% PBH had a similar EC. However, as the amount of perlite was increased, the EC of the substrate increased, while the EC decreased as the amount of PBH was increased (Fig. 2A). After 4 weeks, the substrate containing 20% PBH had a higher EC than the substrate containing 20% perlite (Fig. 2B). However, as the amount of perlite was increased, the EC increased, while as the amount of PBH was increased, the EC decreased. After 8 weeks, at all concentrations of perlite- or

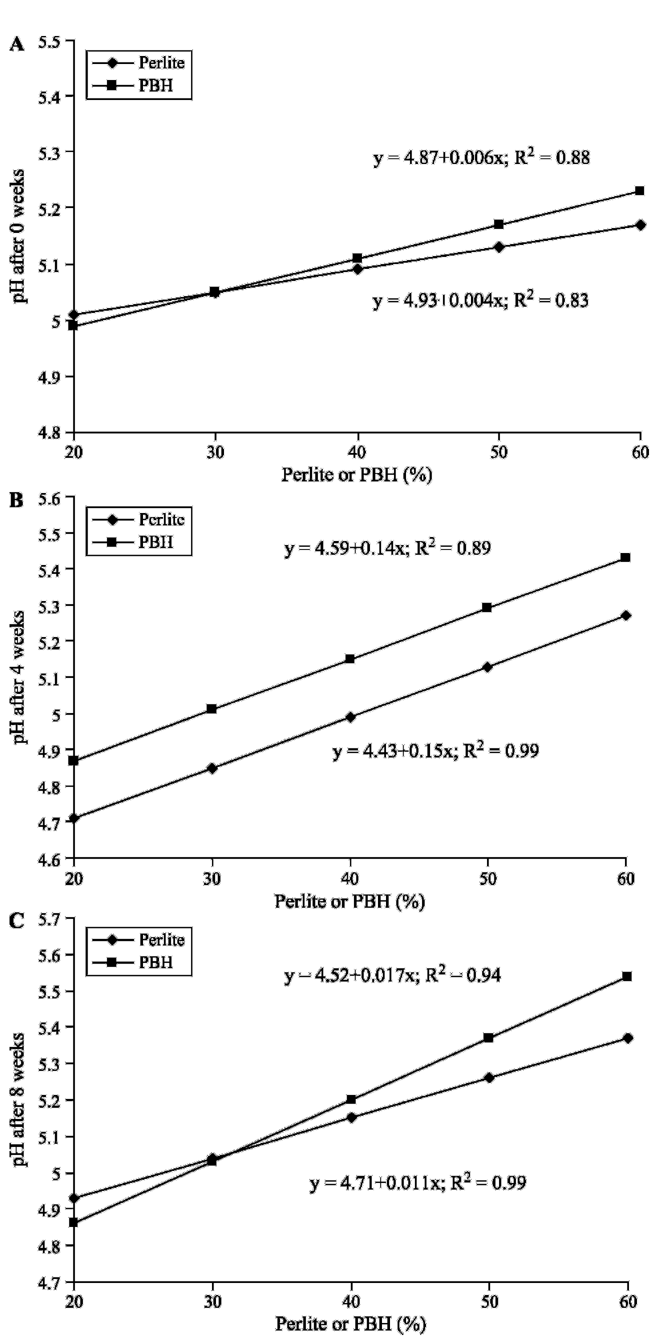

Fig. 1. Substrate pH as affected by parboiled fresh rice hulls (PBH) and perlite concentration after 0, 4, and 8 weeks.

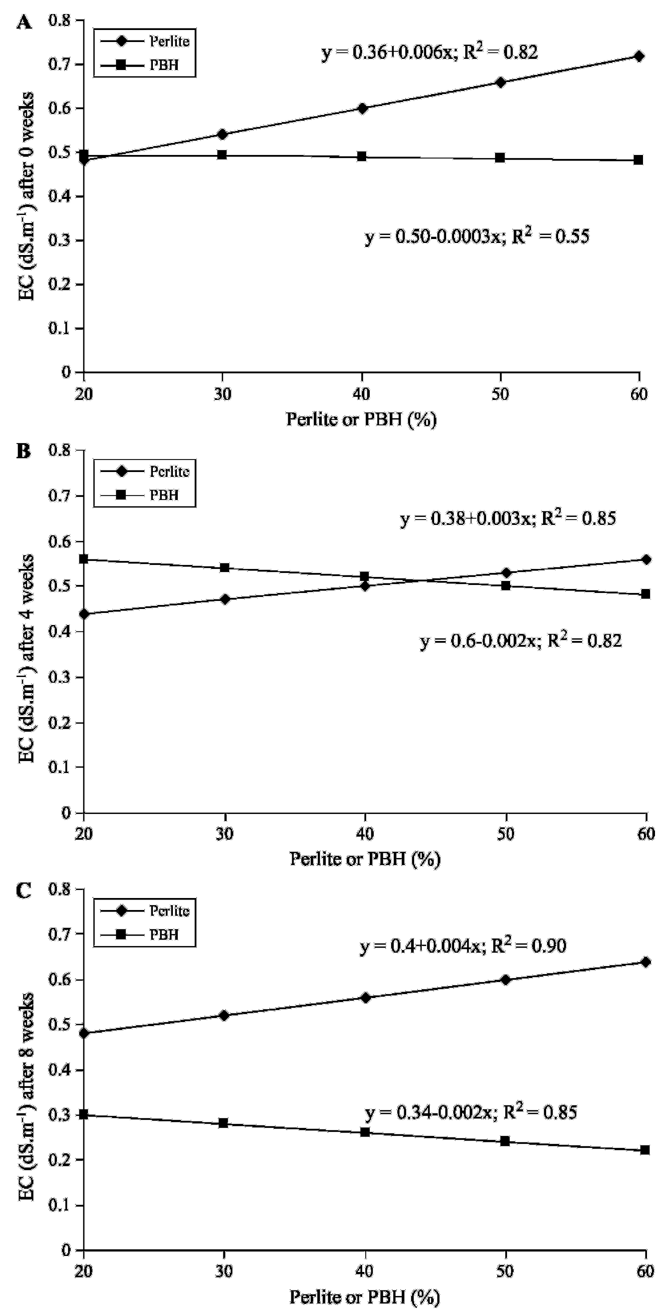

Fig. 2. Substrate electrical conductivity (EC) as affected by parboiled fresh rice hulls (PBH) and perlite concentration after 0, 4, and 8 weeks (1 $dS \cdot m^{-1}$ = 1 mmho/cm).

PBH/perlite-containing substrates had a higher EC than PBH-containing substrates (Fig. 2C). As the amount of perlite was increased, the EC increased, while as the amount of PBH was increased, the EC decreased.

Whereas the perlite was produced from a raw mineral that was heated and expanded, PBH had essentially been washed in hot water during the parboiling process. Therefore, mineral residue of the perlite may have resulted in a higher EC for perlite-containing substrates than for PBH-containing substrates. However, the maximum difference between the EC of an equivalent PBH- and perlite-containing substrate was ≈0.4 $dS \cdot m^{-1}$, and all substrates had EC levels within acceptable ranges for greenhouse crops production.

After 0 weeks, substrates containing 20% perlite or PBH had similar NO_3^- concentrations (Fig. 3A), but as the amount of PBH increased, the NO_3^- concentration increased. The NO_3^- concentration of perlite-containing substrates decreased with increasing amounts of perlite. After 4 and 8 weeks (Fig. 3, B and C), the concentration of PBH did not significantly affect the NO_3^- concentration of the substrate, but as perlite was increased to higher than 30%, the NO_3^- concentration declined.

When substrates were initially blended, substrates containing 20% PBH had a higher NH_4^+ concentration than equivalent perlite-containing substrates (Fig. 4A). As the amount of PBH or perlite was

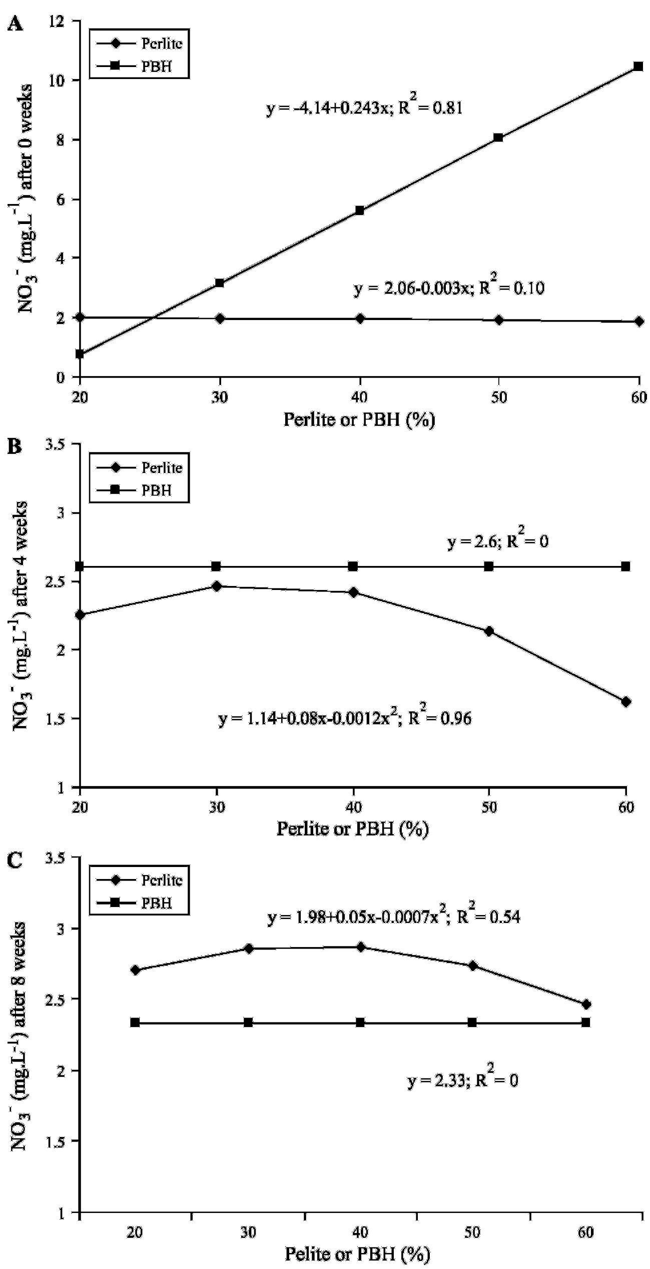

Fig. 3. Substrate nitrate (NO_3^-) concentration as affected by parboiled fresh rice hulls (PBH) and perlite concentration after 0, 4, and 8 weeks (1 $mg \cdot L^{-1}$ = 1 ppm).

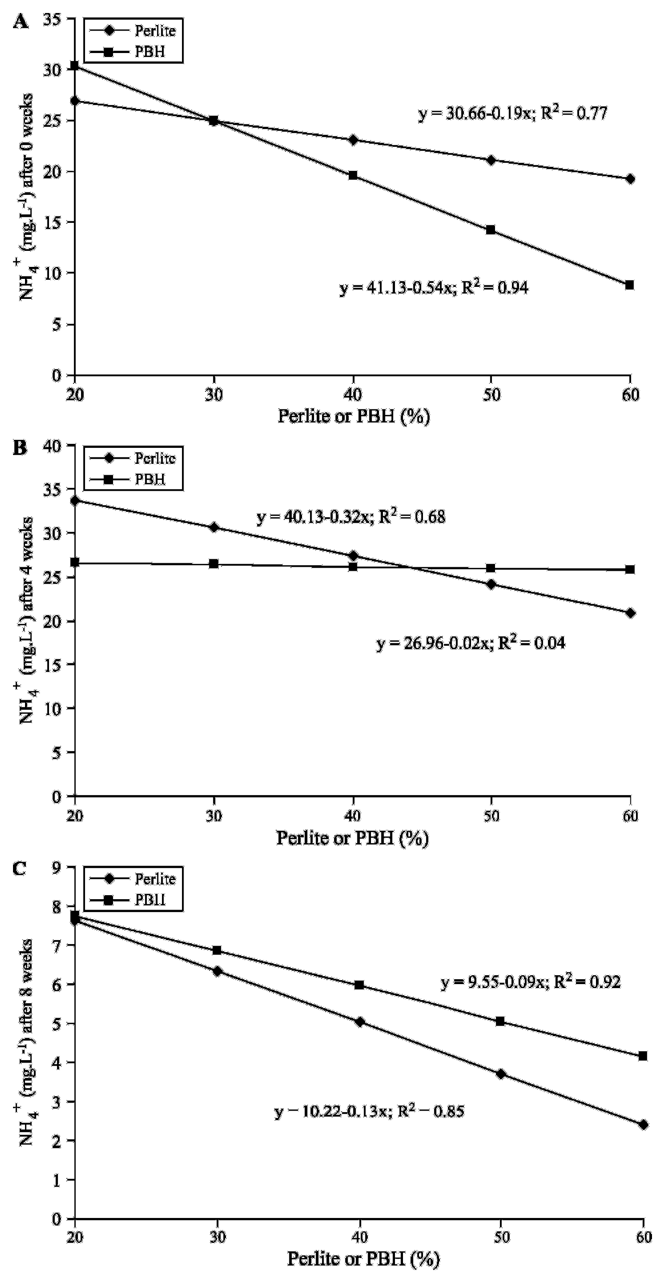

Fig. 4. Substrate ammonium (NH_4^+) concentration as affected by parboiled fresh rice hulls (PBH) and perlite concentration after 0, 4, and 8 weeks (1 $mg \cdot L^{-1}$ = 1 ppm).

increased, the NH_4^+concentration decreased, but at a higher rate for PBH-containing substrates. After 4 weeks in the greenhouse environment, NH_4^+concentration decreased as the amount of perlite or PBH was increased, but at a higher rate in perlite-containing substrates (Fig. 4B). After 8 weeks in the greenhouse environment, NH_4^+concentration was similar for substrates containing 20% perlite or PBH and NH_4^+concentration decreased for perlite- and PBH-containing substrates as the amount of either was increased. At all concentrations above 20%, PBH-containing substrates had higher NH_4^+concentrations than equivalent perlite-containing substrates (Fig. 4C).

According to Cadell (1988), fresh rice hulls contained 3200 mg·kg^{-1} total nitrogen. Rice hulls also contain small amounts of bran and rice grains, both of which contain proteins that would serve as a potential source of nitrogen. After parboiling, decomposition of the bran and rice grains by microorganisms could have resulted in a release of nitrogen that could have then been mineralized. Therefore, PBH could have contributed NO_3^- to the substrate and resulted in the PBH-containing substrates having higher NO_3^- than equivalent perlite-containing substrates. However, NH_4^+ remained constant or decreased with increasing amounts of PBH or perlite. Therefore, PBH and perlite were not the

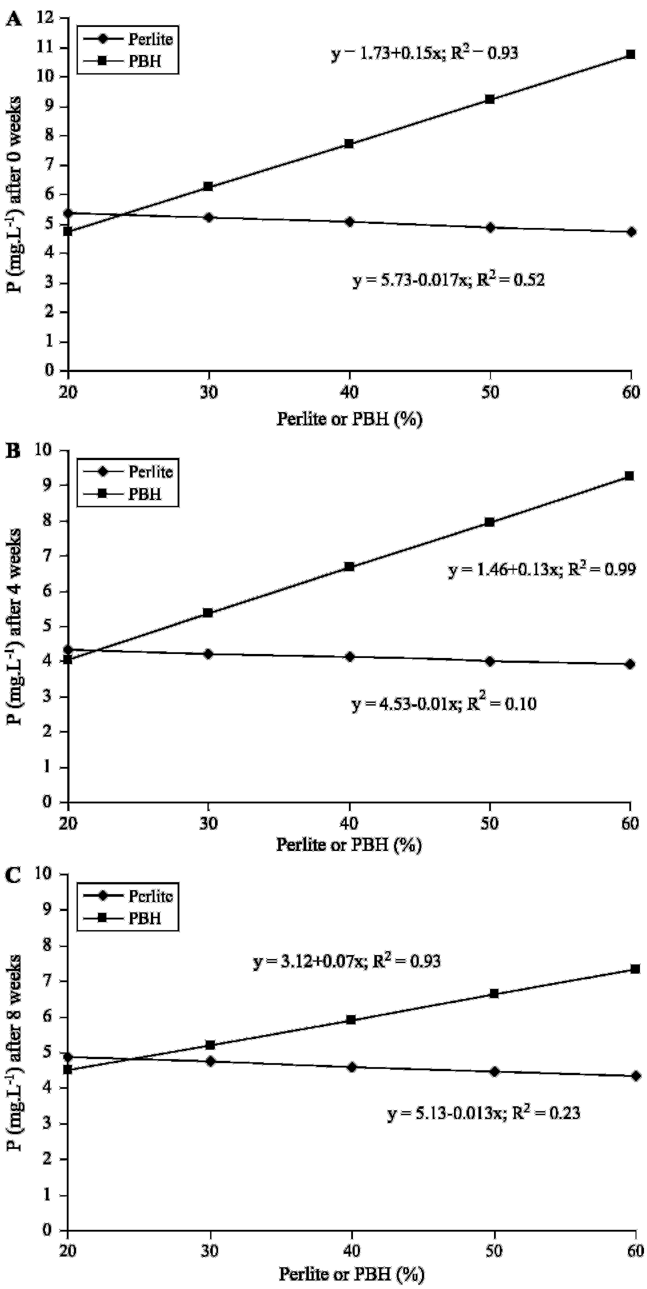

Fig. 5. Substrate phosphorus (P) concentration as affected by parboiled fresh rice hulls (PBH) and perlite concentration after 0, 4, and 8 weeks (1 mg·L^{-1} = 1 ppm).

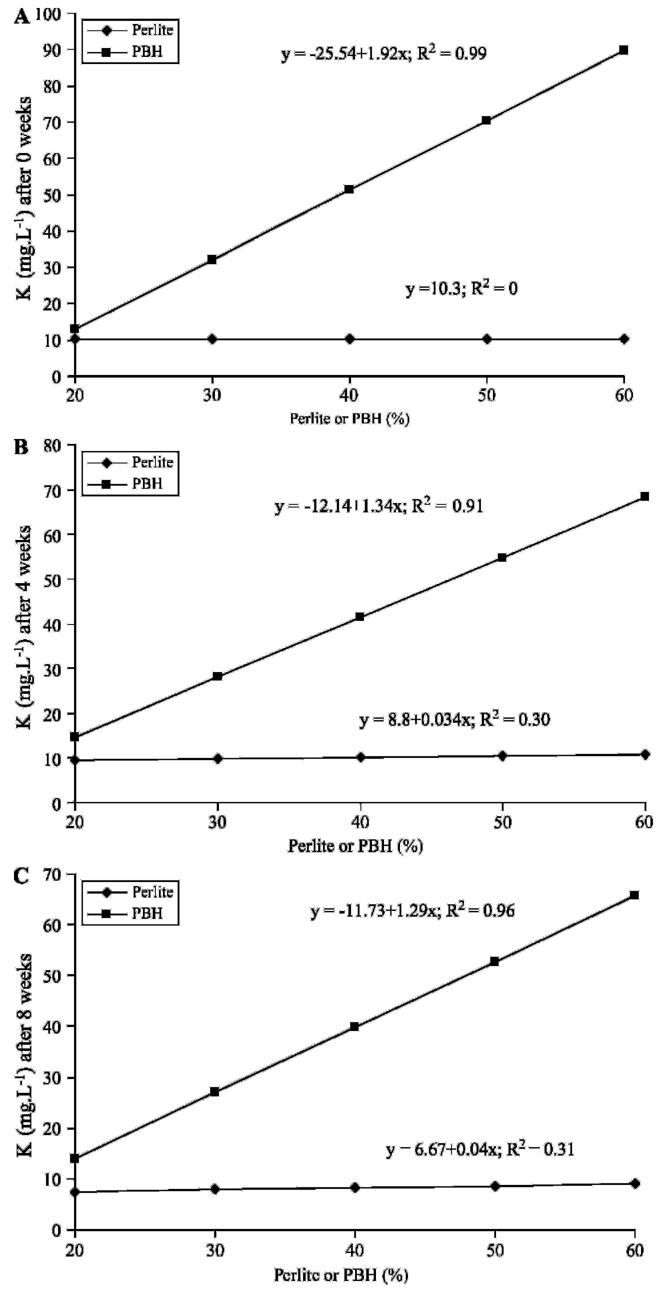

Fig. 6. Substrate potassium (K) concentration as affected by parboiled fresh rice hulls (PBH) and perlite concentration after 0, 4, and 8 weeks (1 mg·L^{-1} = 1 ppm).

source of NH_4^+ in the substrates. As would have been expected, NH_4^+ decreased over time in PBH- and perlite-containing substrates and was within ranges acceptable for most crop production situations.

For all sampling times, substrates containing 20% perlite or PBH had similar P concentrations (Fig. 5, A–C). As the amount of PBH in the substrate was increased, the P concentration increased. However, as the amount of perlite in the substrate was increased, the P concentration decreased.

After 0 weeks, the substrate K was similar for substrates containing 20% perlite or PBH (Fig. 6A). However, as the amount of PBH was increased, the K concentration increased. As the amount of perlite was increased, the K concentration remained unchanged. After 4 and 8 weeks in the greenhouse environment, all substrates containing PBH had a higher concentration of K than equivalent perlite-containing substrates and as the amount of PBH was increased, the K concentration increased at a higher rate than for perlite-containing substrates (Fig. 6, B and C).

Fresh rice hulls were reported to contain 34 $mg \cdot kg^{-1}$ P and 5010 $mg \cdot kg^{-1}$ K (Cadell, 1988), whereas perlite was composed of ≈85% silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3), with only trace concentrations of oxides of iron, titanium, magnesium, calcium, sodium, manganese, and K . The increase in P and K as the amount of PBH was increased in the substrate could be attributed to the P and K released from the PBH incorporated into the substrate. Although PBH-containing substrates generally had higher P and K concentrations than perlite-containing substrate, for all sampling times and concentrations of PBH, the P and K concentrations were within acceptable levels for unused root substrate.

Conclusion

For all amounts of PBH and perlite used and for all time periods sampled, the PBH-containing substrates had similar pH, EC, NO_3^-, NH_4^+, P, and K concentrations as equivalent perlite-containing substrates or were within commonly recommended levels (Bunt, 1988; Nelson, 2003; Peterson et al., 1989). Therefore, the effects of PBH on the pH, EC, NO_3^-, NH_4^+, P, and K concentrations of peat-based root substrates would not present cultural problems or require significant production changes if used in root substrates as an alternative to perlite for providing for drainage and air-filled pore space.

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