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Secondary Macro- and Microelements in Sphagnum Peat-based Substrates Amended with Parboiled Fresh Rice Hulls or Perlite

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ADDITIONAL INDEX WORDS. Root media, substrate chemistry, PBH, manganese

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, 4, or 8 weeks in a greenhouse environment, samples were taken and calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and boron (B) were determined. At all sampling times, substrates containing PBH had higher Ca concentrations than perlite-containing substrates. At all sampling times, Ca concentration decreased as the amount of perlite or PBH was increased, but the Ca concentration decreased at a higher rate in perlite-containing substrates than in PBH-containing substrates. After 0 weeks, perlite-containing substrates had higher Mg concentrations than equivalent PBH-containing substrates, but the opposite was true after 4 weeks. After 8 weeks, perlite- and PBH-containing substrates had similar concentrations of Mg. At all times, Mg concentration decreased as the amount of perlite or PBH was increased. Perlite substrates had higher concentrations of Fe than equivalent PBH substrates, and as the amount of perlite or PBH was increased, the amount of Fe decreased. PBH-containing substrates had higher concentrations of Mn than equivalent perlite-containing substrates, and as the amount of PBH was increased, the amount of Mn increased. Cu concentrations were significantly affected by sampling time, but at all sampling times, PBH-containing substrates had similar or higher Cu concentrations than equivalent perlite-containing substrates. Perlite substrates had higher concentrations of Zn than equivalent PBH substrates, and as the amount of perlite was increased, the amount of Zn increased. S and B were not significantly affected by substrate component or time. Secondary macro- and microelement concentrations of all substrates were within recommended levels for greenhouse crops except for Mn. Mn concentrations were within recommended ranges at up to 50% PBH. In most cases, PBH would be used at levels lower than 50%, but in cases where more than 50% PBH were used in the substrate, proper pH management may be important to prevent excessive Mn availability.

R oot 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 light-weight 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.

Many potential alternative components to perlite (i.e., shredded rubber and ground bovine bone) had undesirable chemical properties. For example, ground bovine bone had too high of a pH as well as a high ammonium (NH_4^+) concentration (Evans, 2004). Shredded rubber tires had high concentrations of Zn that were phytotoxic to many commonly grown greenhouse crops (Evans and Harkess, 1997). Other materials evaluated as potential alternatives to perlite were too expensive or had unacceptably high bulk densities (i.e., calcined clay aggregates and gravel) that resulted in unacceptably high shipping costs for most crops and have thus been limited in their use.

Rice hulls are a milling coproduct of the rice industry. Rice is produced over large areas of Asia. In Europe, most rice is produced in Italy's Po River Valley, and in the United States, it is produced primarily in Arkansas, Texas, Louisiana, Mississippi, and California. With the rice hull comprising ≈20% of the harvested grain by weight (Kamath and Proctor, 1998), rice hulls are an abundant and readily available material throughout much of the world.

Parboiled rice hulls (PBH) are a type of fresh rice hull obtained as a result of a steaming process and are therefore sterile and free of viable weed seeds 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

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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
2.54	inch(es)	cm	0.3937
1	ppm	mg·kg⁻¹	1
1	ppm	mg·L⁻¹	1
(°F − 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

how PBH affected physical properties of sphagnum peat-based substrates compared with perlite, and they reported that the bulk density of perlite and PBH were similar. 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 the secondary macroelement and microelement concentrations 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 greenhouse crop root 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, respectively. Peat had an initial pH of 3.5. However, calcitic limestone was added to the peat 7 d 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 by hand on alternating days to the surface of each substrate.

Substrate samples were taken after 0 (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 greenhouse crop cycle, and parameters near the end of such a greenhouse crop cycle.

Substrate nutrient status was determined using the saturated media extract method as outlined by the North Central Regional Committee for Soil and Plant Analysis (Warncke, 1988). The concentrations of Ca, Mg, S, Fe, Mn, molybdenum (Mo), Cu, Zn, and B were determined using the filtered extract for simultaneous inductively coupled plasma emission spectrometry (Jones, 1977; Munter and Grande, 1981).

The experimental design was a completely randomized design with nine replications per substrate and sampling time. Each container served as a replication. An analysis of variance was conducted to determine if substrate component, component percentage, or time in the 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

Substrate Ca was significantly affected by substrate component, component percentage, and sampling time (Table 1). Only the interaction between component and percentage of component was significant. At all sampling times, PBH-containing substrates had higher Ca concentrations than equivalent perlite-containing substrates (Fig. 1, A–C). Furthermore, at all sampling times, the Ca concentrations of the substrates decreased as the amount of PBH or perlite increased. However, the rate of decrease in Ca concentrations was higher for perlite-containing substrates than for PBH-containing substrates.

The major source of Ca in the substrates was the peat that had been amended with calcitic limestone, therefore increasing the amount of perlite or PBH reduced the amount of peat and thus the concentration of calcium in the substrate. Cadell (1988) reported that rice hulls contained 950 mg·kg^{-1} Ca, whereas perlite contained only trace amounts of calcium (Perlite Institute, 2005). Therefore, the differences in the Ca concentrations between equivalent perlite- and PBH-containing substrates could have been a function of the Ca concentration of the rice hulls.

Table 1. Main effect and interactions for secondary macro- and microelement concentration of sphagnum peat-based substrates amended with parboiled fresh rice hulls or perlite.

Mineral element[z]	Component[y]	Component %[x]	Time[w]	Component × Component %	Component × Time	Component % × Time	Component × Component % × Time
Ca	***	***	*	**	NS	NS	NS
Mg	***	***	***	***	**	NS	*
S	NS	NS	**	NS	NS	NS	NS
Fe	***	***	***	***	***	**	NS
Mn	***	***	***	***	***	***	***
Cu	*	**	***	***	*	***	***
Zn	***	***	***	***	***	***	***

[z]Calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn).
[y]Components refers to perlite or parboiled fresh rice hulls.
[x]Component = percentage of perlite or parboiled fresh rice hulls 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).
[*,**,***]Nonsignificant or significant at $P = 0.05, 0.01, 0.001$, respectively.

(4)

The Ca concentrations for all of the substrates were within acceptable ranges for unused substrates (Bunt, 1988; Nelson, 2003; Peterson et al., 1989).

Substrate Mg was significantly affected by substrate component, component percentage, and sampling time (Table 1). There were significant interactions between substrate component and time, as well as between substrate component, component percentage, and time. After 0 weeks,

perlite-containing substrates had a higher Mg concentration than equivalent PBH-containing substrates (Fig. 2A). After 4 weeks, PBH-containing substrates had a higher Mg concentration than equivalent perlite-containing substrates (Fig. 2B). After 0 and 4 weeks, the Mg concentration decreased as perlite or PBH was increased. After 8 weeks, equivalent perlite- and PBH-containing substrates had similar Mg concentrations, and as perlite or PBH was

increased, the Mg concentration decreased (Fig. 2C).

The primary Mg source appeared to have been the peat because increasing PBH or perlite reduced the Mg concentrations. Perlite and PBH contained Mg (Cadell, 1988; Perlite Institute, 2005), but the difference in Mg levels between week 0 and week 4 may have been due to the rate at which Mg in the perlite or PBH was released into the substrate. For all substrates and sampling times, Mg
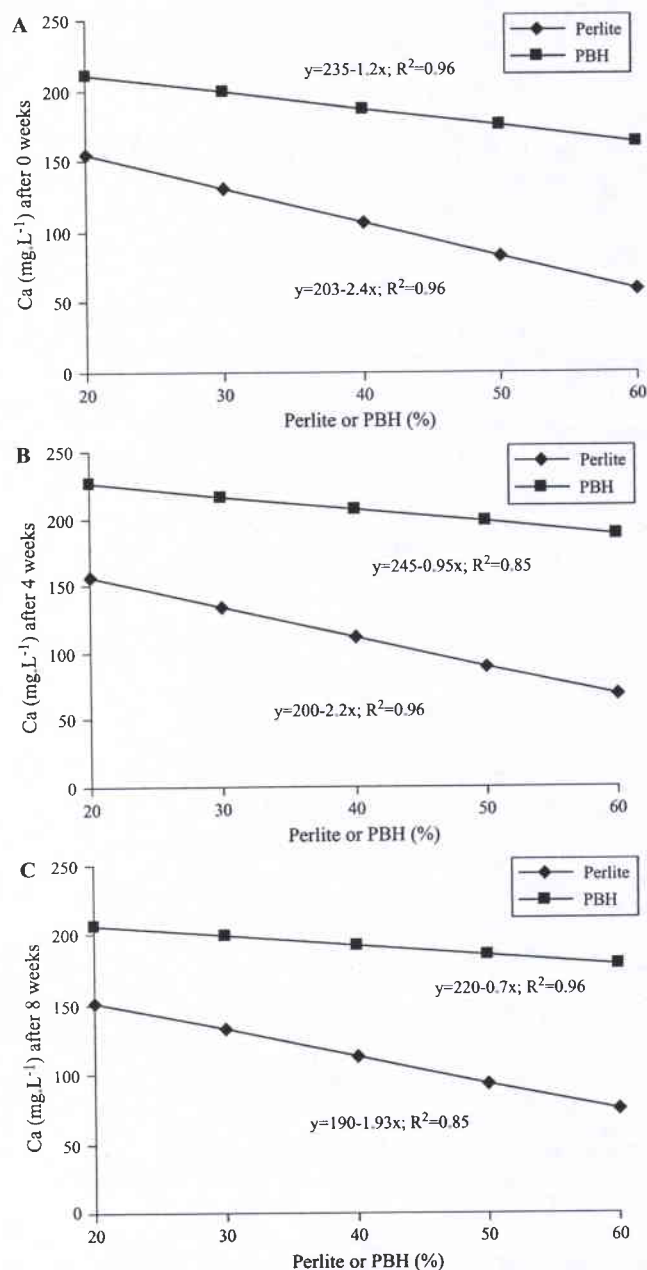

Fig. 1. Substrate calcium (Ca) concentration as affected by perlite and parboiled fresh rice hull (PBH) concentration after 0, 4, and 8 weeks (1 mg·L^{-1} = 1 ppm).
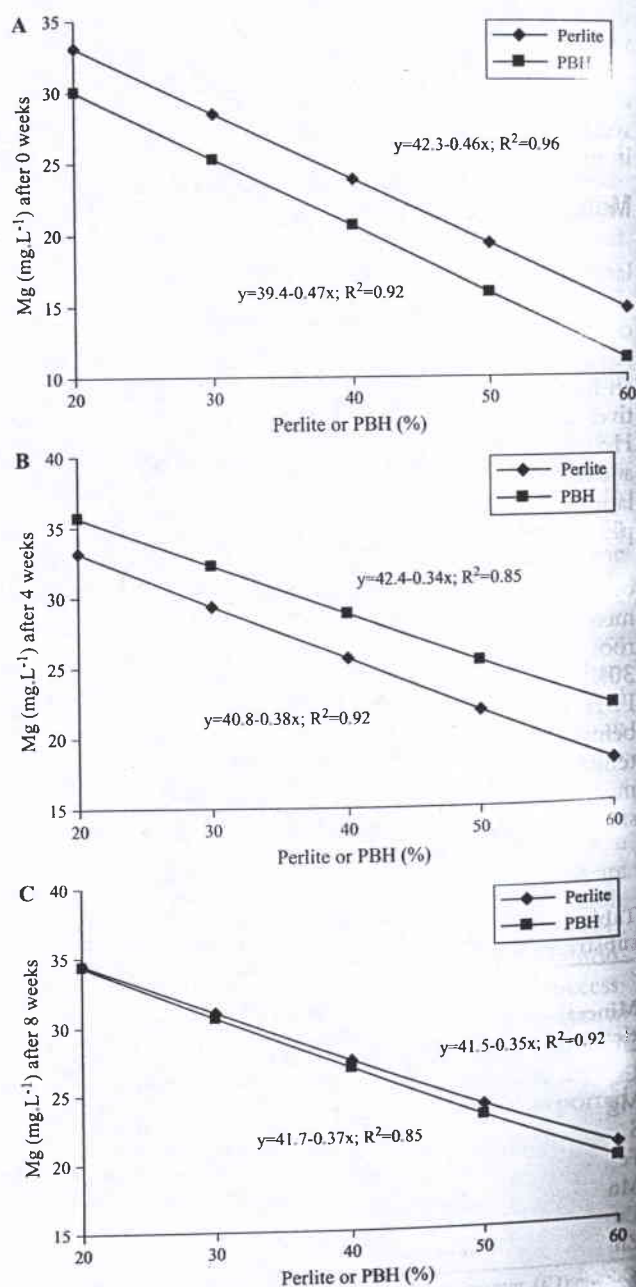

Fig. 2. Substrate magnesium (Mg) concentration as affected by perlite and parboiled fresh rice hull (PBH) concentration after 0, 4, and 8 weeks (1 mg·L^{-1} = 1 ppm).

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levels were within recommended ranges for greenhouse crops (Bunt, 1988; Nelson, 2003; Peterson et al., 1989).

Substrate S was not significantly affected by substrate component or percentage of substrate component. Only time significantly affected substrate S concentration (Table 1). Root substrates had S concentrations of 35, 30, and 28 mg·L^{-1} at weeks 0, 4, and 8, respectively (data not shown). All substrate S concentrations were within the maximum

recommended ranges for greenhouse crops (Bunt, 1988; Nelson, 2003; Peterson et al., 1989).

Substrate Fe was significantly affected by substrate component, component percentage, and sampling time. All two-way interactions among the main effects were significant (Table 1). For all sampling times, substrates containing 20% perlite or 20% PBH had similar substrate Fe concentrations (Fig. 3, A–C). As the amount of perlite or PBH increased,

the Fe concentration decreased. However, the Fe concentration decreased at a higher rate in the PBH-containing substrates so that substrates containing more than 20% perlite had a higher Fe concentration than equivalent PBH-containing substrates.

Perlite is of a mineral origin and contained higher concentrations of Fe than PBH (Cadell, 1988; Perlite Institute, 2005) and thus perlite-containing substrates had higher Fe concentrations than equivalent
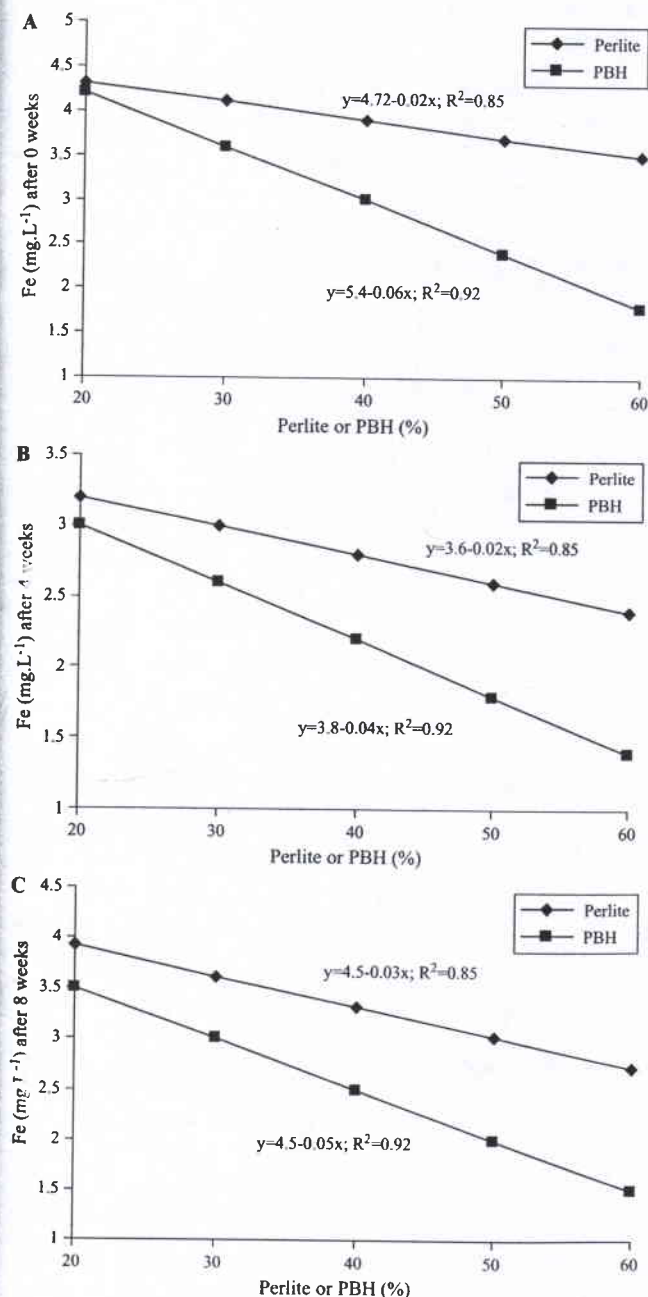

Fig. 3. Substrate iron (Fe) concentration as affected by perlite and parboiled fresh rice hull (PBH) concentration after 0, 4, and 8 weeks.
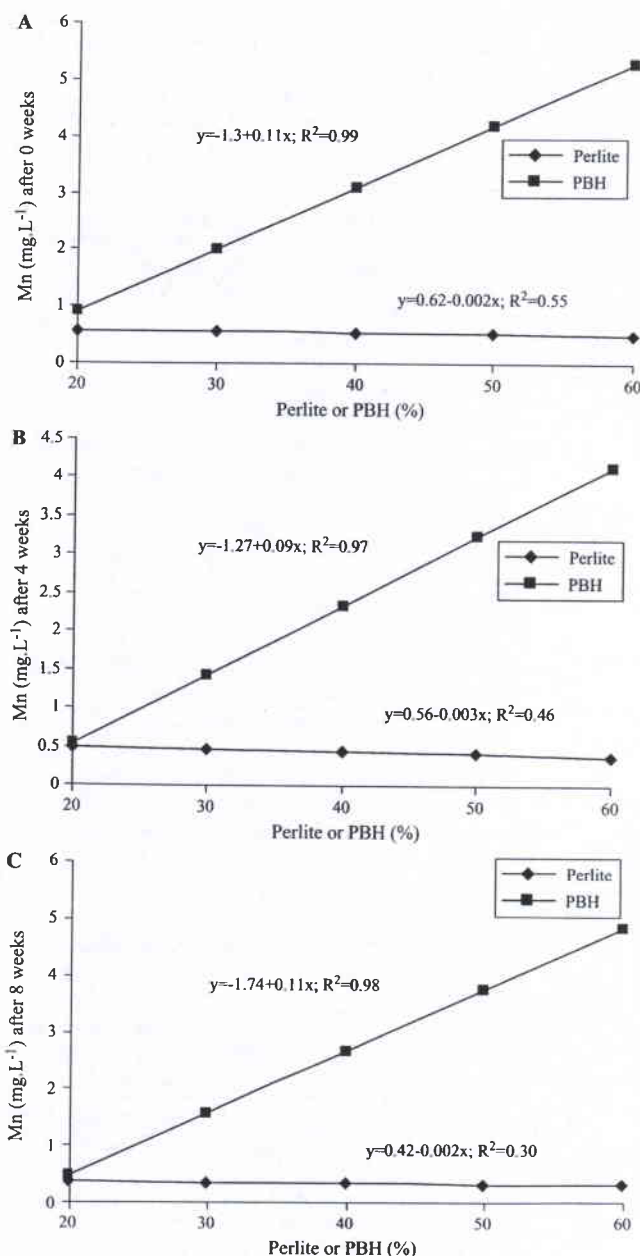

Fig. 4. Substrate manganese (Mn) concentration as affected by perlite and parboiled fresh rice hull (PBH) concentration after 0, 4, and 8 weeks (1 mg·L^{-1} = 1 ppm).

PBH-containing substrates. The Fe concentrations of all perlite- and PBH-containing substrates were within the maximum recommended acceptable ranges (Bunt, 1988; Nelson, 2003; Peterson et al., 1989).

Substrate Mn was significantly affected by substrate component, component percentage, and sampling time. All potential interactions were significant (Table 1). For all sampling times, substrates containing 20% perlite or 20% PBH had similar manganese concentrations (Fig. 4, A–C).

However, as PBH increased, the Mn concentration increased, while as the amount of perlite increased, the Mn concentration decreased.

Rice hulls were reported to contain significant concentrations of Mn (Cadell, 1988). This contributed to PBH-containing substrates having higher Mn concentrations than perlite-containing substrates and to the increasing Mn concentrations with increasing amounts of PBH. Steaming of rice hulls for use in substrates was reported to result in Mn concen-

trations that were above recommended concentrations and potentially phytotoxic (Einert, 1972). However, after 0 weeks, substrates containing up to 40% PBH had Mn concentrations within recommended levels. After 4 and 8 weeks, substrates containing up to 50% PBH had Mn concentrations within acceptable levels (Bunt, 1988; Nelson, 2003; Peterson et al., 1989).

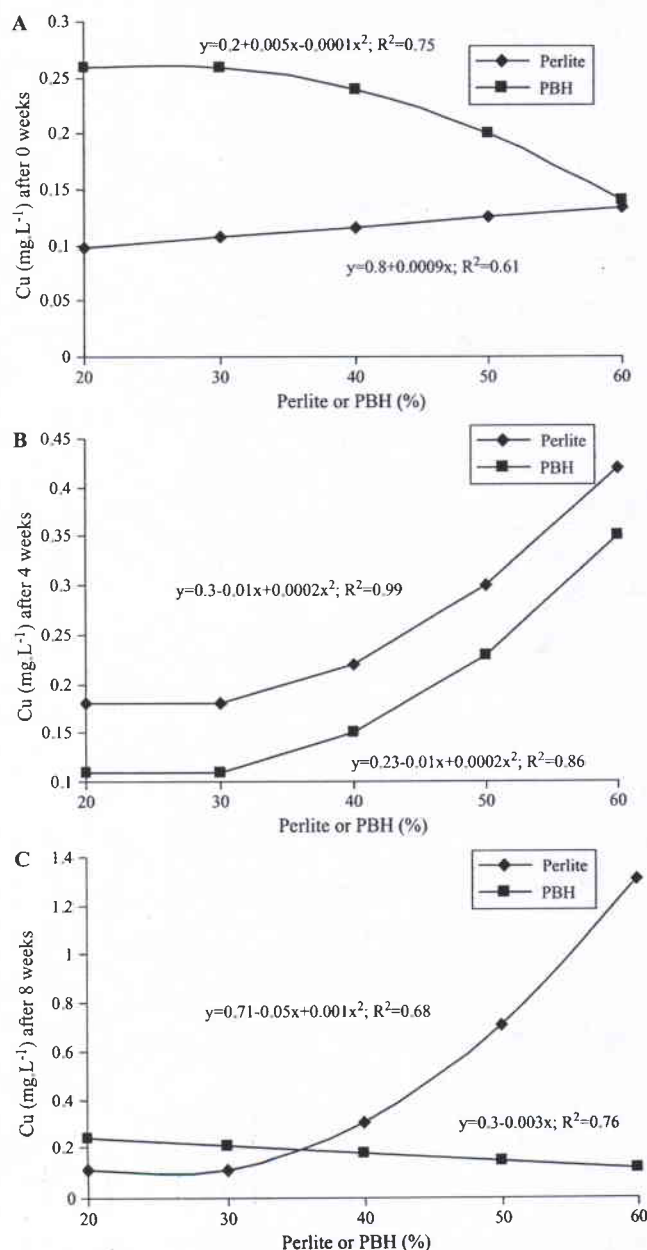Substrate Cu concentration was significantly affected by substrate component, component percentage,

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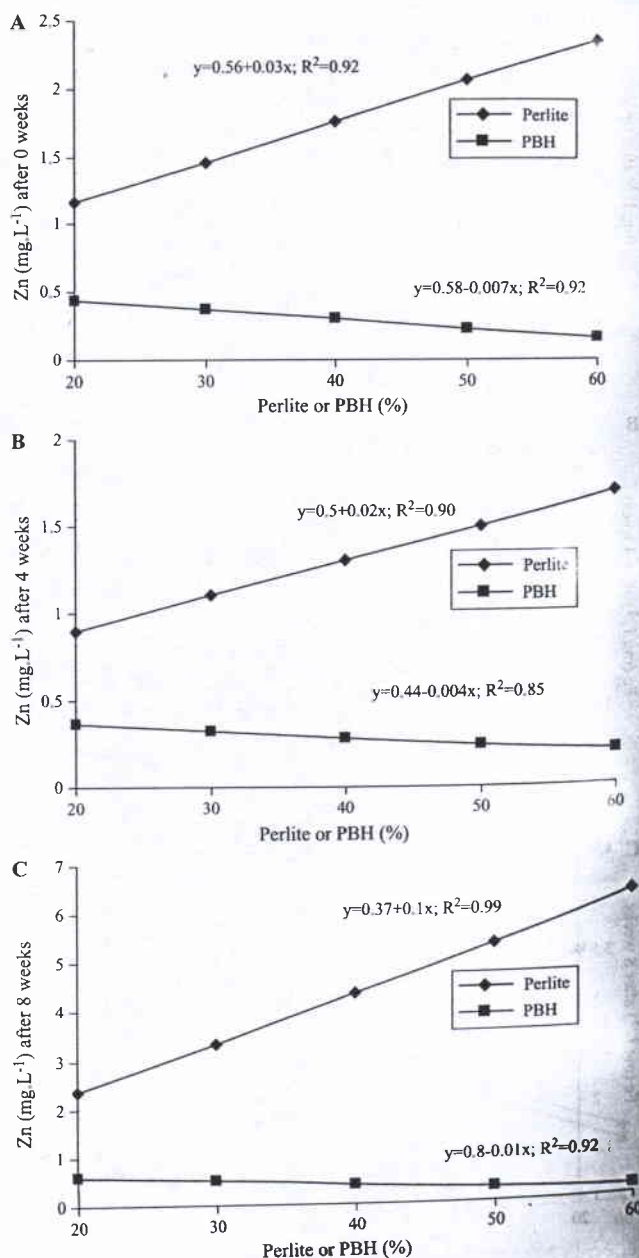

Fig. 6. Substrate zinc (Zn) concentration as affected by perlite and parboiled fresh rice hull (PBH) concentration after 0, 4, and 8 weeks (1 mg·L^{-1} = 1 ppm).

and sampling time. All interactions among the main effects were significant (Table 1). After 0 weeks, Cu concentration was higher in the substrate containing 20% PBH than in the 20% perlite substrate (Fig. 5A). As the amount of PBH was increased, the Cu concentration decreased. As the amount of perlite increased, the Cu concentration increased until the Cu concentration was similar for substrates containing 60% perlite or PBH. After 4 weeks, Cu concentration was higher in all perlite-containing substrates compared with equivalent PBH-containing substrates (Fig. 5B). As perlite or PBH was increased, the Cu concentration increased. After 8 weeks, substrates containing 20% or 30% PBH had a higher Cu concentration than equivalent perlite-containing substrates (Fig. 5C). As the amount of PBH increased, the Cu concentration decreased so that substrates containing 40% or more perlite had higher Cu concentrations than equivalent PBH-containing substrates.

The most dramatic difference in Cu concentrations was the factor of time. These differences are likely due to the amount of Cu supplied by perlite and PBH as well as the rate of release of Cu into the substrate. Some Cu was released from perlite immediately, whereas little Cu was released from the PBH immediately. However, after 4 weeks, Cu was released from perlite and PBH. After 8 weeks, perlite no longer released Cu into the substrate, while PBH continued to release Cu. Therefore, the rate at which Cu was released into the substrate was significantly different between perlite and PBH. The difference in Cu concentrations among the substrates was not high enough to be of practical significance, and the Cu concentration of all substrates was within recommended levels for greenhouse crops (Bunt, 1988; Nelson, 2003; Peterson et al., 1989).

Substrate Zn was significantly affected by substrate components, component percentage, and sampling time. All interactions among the main effects were significant (Table 1). At all sampling times, perlite-containing substrates had higher Zn concentra-

tions than equivalent PBH-containing substrates (Fig. 6, A–C). As the amount of perlite was increased, the Zn substrate concentration increased, while as the amount of PBH was increased, the Zn concentration decreased.

As in the case of Fe, perlite contained significant levels if Zn and this was released into the substrate. The difference in Zn concentrations among the substrates was not high enough to be of practical significance, and the Zn concentration of all substrates was within maximum recommended levels for greenhouse crops (Bunt, 1988; Nelson, 2003; Peterson et al., 1989).

Substrate B and Mo were not significantly affected by substrate component, component percentage, or time (Table 1). Perlite- and PBH-containing substrates had B concentrations of 0.1 mg·L^{-1} and Mo concentrations of 0.01 mg·L^{-1}, respectively, for all component percentages and sampling times (data not shown). The concentrations of B and Mo were within the recommended range for greenhouse crops (Bunt, 1988; Nelson, 2003; Peterson et al., 1989).

Conclusion

With the exception of Mn, all secondary macro- and microelement concentrations of PBH-containing substrates were similar to their respective perlite controls or were within the maximum recommended ranges for greenhouse crops. Mn concentrations were higher in PBH-containing substrates than perlite substrates and were above the recommended concentrations when more than 50% PBH was included in the substrate. Therefore, in situations where crops sensitive to Mn toxicity are to be grown, maintaining optimal pH and limiting PBH content to 50% or lower may be necessary to prevent the occurrence of excessive available Mn in the substrate.

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