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# Efficacy and physical properties of ground, composted rice hulls as a component of soilless substrate for selected bedding plants

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## Abstract

Ground, composted rice hulls were combined as a root substrate component with peat moss and coir at five rice hulls percentages (0, 25, 50, 75, and 100) in a factorial design. Seventy-five percent of the rice hull particles were 0.51 to 1.40 mm and 90% of the particles were 0.51 to 2.00 mm. In physical property evaluations, increasing the percentage of rice hulls in both the peat moss and coir series of substrates increased the dry bulk density and airspace at container capacity; however, as air space increased, container capacity and available water decreased. In the first two of three plant growth experiments, *Impatiens walleriana* Hook. f. 'Super Elfin White' was grown in 288 cell plug trays. In the third experiment, *Verbena* ×*hybrida* Voss. 'Romance Deep Rose' was grown in 48 cell bedding plant flats. Due to problems with high pH in the coir, only the peat moss growth results were reported. Overall, growth was best in 25% rice hulls plus 75% peat moss. Rice hulls increased substrate $Ca^{2+}$ and $Mg^{2+}$ in both the peat moss and coir. Adding rice hulls to the substrate increased $K^+$ in peat and decreased $K^+$ in coir. There was no effect of rice hulls on substrate $NO_3^-$-N, $NH_4^+$-N, and $PO_4$-P in the substrate solution. Ground, composted rice hulls are a potential alternative component of soilless substrate for plugs and bedding plants.

**Key words**: Rice hulls, root substrate, soilless, root media, *Impatiens walleriana, Verbena* ×*hybrida,*

## Introduction

Rice hulls were first investigated as a potential replacement for soil or sand in soil-based substrates (Einert, 1972; 1973), then as a potential replacement for perlite in soilless substrates (Evans and Gachukia, 2004, 2007; Papfotiou *et al.*, 2001). Evans and Gachukia (2007) reported that rice hulls had a greater porosity than perlite. Conversely, Papfotiou *et al.* (2001) found replacement of perlite with rice hulls in a substrate decreased total porosity.

Papfotiou *et al.* (2001) replaced 50 or 100% of the perlite with rice hulls in a 1 peat : 1 perlite (v/v) substrate resulting in similar or slightly reduced growth in several plant species. Marianthi (2006) successfully replaced perlite with fresh rice hulls in a 7 peat moss : 3 perlite (v/v) substrate for the production of *Pinus halepensis* M. seedlings.

Composted rice hulls have a higher dry bulk density and container capacity than fresh rice hulls (Kang *et al.*, 2004). Composting also eliminates plant growth inhibitory chemicals, such as organic acids (Lee *et al.*, 2000). Composted rice hulls have a higher pH, EC, N content, and available P content than fresh rice hulls (Kang *et al.*, 2004). Growth of petunia was better in the root substrate amended with 30 to 60% composted rice hulls than with 0, 15, or 75% composted rice hulls (Song *et al.*, 1996). Laiche and Nash (1990) reported that 50 or 100% substitution of pine bark with composted rice hulls in the root substrate of several woody landscape species provided favourable growth. However, the dolomitic lime amendment had to be reduced or eliminated to compensate for innate $Ca^{2+}$ and $Mg^{2+}$ levels in the rice hulls.

Grinding has also been used to decrease the total porosity and air-filled space and increase the container capacity of rice hulls (Choi *et al.*, 1999). Sambo *et al.* (2008) determined that fresh rice hulls ground to pass through 1 and 2 mm diameter screens were closest to peat moss in physical properties. However, the ground rice hulls had more total and easily available water and a heavier bulk density than peat moss.

In this study, rice hulls were composted to eliminate toxic substances and viable seed, and ground to develop a finer aeration component than whole rice hulls that would be appropriate for plug substrates. The effects of replacing either peat moss or coir with increasing levels of composted, ground rice hulls on substrate physical properties and plant growth were tested.

## Materials and methods

On 23 August, 1 $m^3$ of rice hulls was combined in a Twister 1 Batch Mixer Model 12101 (Bouldin & Lawson, McMinnville, TN) with 2.5, 5, and 10 kg of Gorang commercial compost promoter (Biwang Co., Seoul, South Korea), urea, and wheat bran, respectively. The mixture was then saturated with water and covered with polyethylene film. After 10 d, when the material had an internal temperature of 70-75 °C, it was turned. After 10 more days, the material was turned again. The pile remained in the field under the polyethylene cover until removed as needed for each experiment.

Composted rice hulls moistened to 30% water content by weight were ground using a hammer mill (model 10 BLHM, The C.S.

Bell Co., Tiffin, OH) to pass through a 6.35 mm screen. Three 100 g samples of the ground compost were sieved for 5 min in a Ro-Tap Testing Sieve Shaker Model B (Tyler Industrial Products, Mentor, OH). The sieve fractions of >2.00, 2.00-1.41, 1.40-1.01, 1.00-0.72, 0.71-0.51, 0.50-0.25, and <0.25 mm averaged 2, 15, 36, 28, 11, 6, and 2 %, respectively, by weight of the total samples.

Ten root substrate formulations were prepared for each experiment using the ground, composted rice hulls at 30% moisture by weight and either sphagnum peat moss or coir at 67% moisture. In the peat moss and coir treatment series, rice hulls replaced peat moss or coir at volume percentages of 0, 25, 50, 75, or 100.

**Substrate physical properties**: Columns, 15 cm in height, constructed from 7.7 cm i.d. polyvinylchloride (PVC) pipe were used to determine the physical properties of the ten substrates. Each column was attached to a flat acrylic base plate. A 9.0 mm hole was drilled in the center of each base to provide drainage. A porous, fiberglass mat was placed over the drainage hole of each column. The tare weight of each empty column, including fiberglass mat, was determined. To facilitate filling each column, an extension was made by taping an additional PVC ring 4 cm in height to the top of each column. Each column with extension was filled loosely with substrate and dropped on a laboratory bench from a height of 15 cm three times to compact the substrate. The extension was removed and the substrate remaining above the top of each 15-cm column was cut free with the sawing action of a fine chrome wire. Three replicated columns were filled with each substrate as described.

One complete replication of all ten substrate formulation treatments in this experiment (ten packed columns) was placed in an empty tank at a time. Water was added incrementally to the bottom of the tank over a two hour period until the water level reached the surface of the packed columns. As water entered the base of each column, air within the substrate was displaced upward and expelled from the top of the column. A rubber stopper was weighed and then inserted into the hole in the base of the column. The column of saturated substrate, always maintained in a vertical orientation, was removed from the water and weighed. After subtracting the weight of the stopper and empty column, the net weight of saturated substrate was recorded as weight A. The stopper was removed from the base, the top of the column was loosely covered with plastic tape to prevent evaporation, and gravitational water allowed to drain. The columns drained for 24 h; however, container capacity was reached within 1 h and drainage beyond 1 h was negligible. After 24 h, the column, with its substrate at container capacity, was weighed. The weight of the column was subtracted and the net weight of the substrate at container capacity was recorded as weight B. The substrate was then transferred quantitatively to a ring on the porous plate of a pressure outflow chamber (Klute 1986), rewetted, and a pressure head of -300 cm water (-30 kPa) applied. The water content of the latter sample after it drained to equilibrium in the pressure chamber was taken to be the lower limit of available water. The ring plus substrate was weighed, the weight of the ring was subtracted, and the net weight of substrate at -30kPa was recorded as weight C. The substrate was then quantitatively transferred to an oven, dried at 105 °C for 24 h, and weighed (weight D).

Equation 1: $D_b = D / (Ht \times 7.7 \times 7.7 \times \pi) / 4$

Where, $D_b$ = dry bulk density ($g \cdot cm^{-3}$); D = weight of substrate after oven drying at 105 °C for 24 h (g); Ht = height of column (cm); and $\pi = 3.14$.

Equation 2: $CC = (100 \times D_b) [(B – D) / D]$

Where, CC = container capacity in a 15-cm tall column (% by volume); $D_b$ = bulk density ($g \cdot cm^{-3}$); B = weight of substrate at container capacity (g); and D = weight of substrate after oven drying at 105 °C for 24 h (g).

Equation 3: $LLAW = (100 \times D_b) [(C – D) / D]$

Where, LLAW = lower limit of plant available water (% by volume); $D_b$ = bulk density ($g \cdot cm^{3}$); C = weight of substrate at -30 kPa; and D = weight of substrate after oven drying at 105 °C for 24 h (g).

Equation 4: $AW = (CC – LLAW)$

Where, AW = Available water between CC and -30kPa (% by volume); CC = container capacity (% by volume); and LLAW = lower limit of plant available water (% by volume).

Equation 5: $AS = (100 X D_b) [(A – B) / D]$

Where, AS = Air space at CC (% by volume); $D_b$ = bulk density ($g \cdot cm^{-3}$); A= Weight of saturated substrate (g); B = weight of substrate at CC (g); and D = weight of substrate after oven drying at 105 °C for 24 h (g).

Plant efficacy tests for the ten substrates occurred in three experiments. In these experiments, substrates were irrigated at each irrigation to approximately 20% leaching with tap water. The night/day greenhouse temperatures were set at 21/24 °C.

**Expt. 1 – First plug experiment**: All ten substrates were amended with dolomitic limestone at 7 $g\,L^{-1}$. Seeds of *I. walleriana* 'Super Elfin White' were planted into 288-cell square (2.0 x 2.0 cm x 3.5 cm deep) Landmark (Landmark Plastic Corp., Akron, OH) plug flats cut down to 100 cells on 16 Dec. Fertilizer applications of 20N:4.4P:16.6K at 50 $mg\,L^{-1}$ N at each irrigation began when the cotyledons separated and increased to 100 $mg\,L^{-1}$ N when the first true leaves appeared. A destructive harvest of plants was made on 20 January when plant height and shoot dry weight were recorded.

**Expt. 2 – Second plug experiment**: Substrates were amended with dolomitic limestone at 4.5 $g\,L^{-1}$ in the 100% rice hull treatment and four treatments containing peat moss and 3.5 $g\,L^{-1}$ in the four treatments containing coir to correct for the high pH levels observed in Expt. 1. Seeds of *I. walleriana* 'Super Elfin White' were planted into 288-cell square Landmark plug flats cut down to 100 cells on 1 February. The protocols for fertilizer application were the same as in Expt. 1. A destructive harvest of plants was made on 3 March. Plant height and shoot fresh weight were recorded.

**Expt. 3 – Verbena growth experiment**: Substrates were amended with dolomitic limestone at 4.5 $g\,L^{-1}$ in the 100% rice hull treatment and three treatments containing peat moss and 3.5 $g\,L^{-1}$ in the three treatments containing coir as in Expt. 2. Plug seedlings of *V. ×hybrida* 'Romance Deep Rose' from C. Raker & Sons, Inc. (Litchfield, MI) were transplanted on 31 January into 48-cell (4.4 x 6.7 x 5.7 cm deep) bedding plant flats. Weekly fertilizer applications of 20N:4.4P:16.6K at 200 $mg\,L^{-1}$ N began on 3 February. The date when 75% of the plants in each flat were in flower was recorded. A destructive harvest of plants was made on 19 March. Plant height and shoot fresh weight were recorded.

**Analytical methods**: Substrate solution was extracted at each destructive harvest by squeezing the plug cells. The root substrate extracts were analyzed for pH, EC, $NO_3^-$-N, $NH_4^+$-N, $PO_4^{3-}$-P, $K^+$, $Ca^{2+}$, and $Mg^{2+}$ as follows: A pH/conductivity/TDS/temperature meter (Extech Instruments, Model 695, Waltham, MA) was used for pH and soluble salts (EC) determination. Colorimetric analysis was employed for $NO_3^-$-N (Cataldo *et al.,* 1975), $NH_4^+$-N (Chaney and Marbach, 1962), $PO_4^{3-}$-P concentrations under 10 µg $mL^{-1}$ (Murphy and Riley, 1962), and $PO_4^{3-}$-P concentrations above 10 µg $mL^{-1}$ (Chapman and Pratt, 1961) in a Lambda 3 UV/VIS spectrophotometer (Perkin and Elmer, Norwalk, CT). Atomic absorption spectroscopy was used for $K^+$, $Ca^{2+}$, and $Mg^{2+}$ analyses (AAnalyst 100 atomic absorption spectrometer, Perkin Elmer, Norwalk, CT)

**Experimental design and statistical analysis**: A factorial arrangement of two substrate series (peat moss and coir) and five rice hull rates (0, 25, 50, 75, and 100%) in a randomized complete block design with three blocks (30 experimental units in total) was employed for the physical properties determination and for the three plant experiments. In Expts. 1 and 2, experimental units consisted of one 100-cell flat of plants. In Expt. 3, experimental units consisted of one 48-cell flat of plants. Data were subjected to analysis of variance using SAS 9.1 (Statistical Analysis System, SAS Institute, Cary, NC). Means were separated using a protected LSD. Values for dependent variables with significant analysis of variances were regressed by substrate additives using the PROC GLM procedure to determine the best-fit linear and quadratic models. Terms of the model were based on a comparison of F values at $\alpha$ =0.05.

## Results and discussion

**Physical properties**: Physical property data for the substrates are presented in Table 1. The main effect of rice hull percentage on $D_b$ and AS was significant, but the interactive effects of substrate series by rice hull percentage were not significant. As rice hull proportion increased, $D_b$ and AS increased linearly. This is not a desirable trait for $D_b$ because increased substrate weight results in increased shipping costs for formulators and growers. The increased AS at 25% rice hulls (20.7% by volume) was desirable. Higher AS percentages would pose a problem because it is not needed and comes at the expense of plant available water. The main effect of series was not significant for $D_b$ but was for AS, where the mean AS values were 32.7% for peat and 39.0% for coir. There were interactive effects of substrate series and rice hulls on CC and AW. Both components of water declined as the percentage of rice hulls increased and were lower in the coir series than in the peat moss series. Thus, the slope was more negative in the peat moss series.

Growers desire maximum available water to reduce frequency of watering, particularly in the market channel. Even though 75% of the ground rice hulls in this study were in the 0.51 to1.40 mm particle size range, their main impact on peat moss and coir was an increase in AS at the expense of CC and AW due to the addition of large particles. Unlike finely ground rice hulls, which have physical properties similar to peat moss (Sambo *et al.*, 2008), coarsely ground rice hulls increased aeration in the substrates similar to perlite.

**Growth**: Substrate pH levels in Expt. 1 were significantly affected by substrate series but not by rice hull percentage or the interaction of series by rice hulls. The mean pH levels were 6.7 for peat moss and 7.0 for coir. There was a significant interactive effect of series and rice hull percentage in Expts. 2 and 3 (Table 2). While the pH levels in the peat moss series in each experiment were acceptable, they were too high for the coir series, particularly in the 0 to 50% rice hull treatments in the latter two experiments. Since the high pH levels in the coir series would confound interpretation, only the peat moss series was used for growth evaluation.

Shoot dry weight in Expt.1 was greatest in the 25 and 50% rice hulls treatments while height was highest in the 0, 25, and 50% rice hulls treatments (Table 3). Overall, the 25 and 50% rice hulls rates resulted in maximum Impatiens growth. In Expt. 2, shoot fresh weight was maximized in the 0 and 25% rice hulls treatments

Table 1. Effect of the volume proportion of rice hulls in a peat moss and a coir replacement series of treatments on mean bulk density, container capacity, plant available water and air space in a 15-cm tall column

| Rice hulls | Bulk density | Container capacity (% by volume) | | Plant available water (% by volume) | | Air space |
|---|---|---|---|---|---|---|
| (%) | (g $cm^{-3}$) | Peat | Coir | Peat | Coir | (% by volume) |
| 0 | 0.079 | 76.30 | 67.68 | 56.89 | 46.24 | 7.7 |
| 25 | 0.102 | 68.75 | 58.27 | 48.97 | 39.38 | 20.7 |
| 50 | 0.115 | 54.55 | 46.97 | 38.31 | 31.11 | 40.1 |
| 75 | 0.135 | 40.57 | 36.94 | 28.17 | 23.98 | 50.8 |
| 100 | 0.134 | 24.45 | 24.45 | 15.68 | 15.68 | 59.9 |
| $LSD_{0.05}$[z] | 0.010 | 3.85 | | 3.85 | | 7.6 |
| Linear[y] | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Quadratic | 0.0044 | 0.0126 | 0.3157 | 0.1069 | 0.7135 | 0.1353 |
| a | 0.0847 | 81.4 | 68.4 | 59.2 | 46.6 | 8.97 |
| $b_0x$ | 0.000568 | -0.556 | -0.431 | -0.426 | -0.306 | 0.538 |
| $b_1x^2$ | - | - | - | - | - | - |
| r2 | 0.8 | 0.98 | 0.98 | 0.98 | 0.97 | 0.88 |
| CV | 9 | 5 | 5 | 5 | 7 | 20 |

[z]LSD values for bulk density and air space are for comparing between rice hull contents. LSD values for container capacity and plant available water are for comparing substrate series for a given rice hull content or rice hull contents for a given substrate series.

[y]The equation coefficients for either the linear ($y = a + b_0x$) or quadratic ($y = a + b_0 x + b_1x^2$) regression models are provided for whichever model had the lowest significant Pr>F. The coefficient of determination ($r^2$) and coefficient of variation (CV) were calculated for the best fit model (n = 3). The regression models for bulk density and air space combined data from both substrate series (coir or sphagnum peat moss) since the substrate series x rice hull rate interaction was not significant for these two dependent variables.

Table 2. Effect of rice hull volume proportion in a peat moss and a coir replacement series of treatments on mean pH and electrical conductivity (EC) of substrate solutions of *Impatiens walleriana* 'Super Elfin White' in Expt. 1 and 2 and *Verbena*×*hybrida* 'Romance Deep Rose' in Expt. 3

| Rice | Expt. 2 (pH) | | Expt. 3 (pH) | | Expt. 1 (EC mS·cm$^{-1}$) | | Expt. 3 (EC mS·cm$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|
| hulls(%) | Peat | Coir | Peat | Coir | Peat | Coir | Peat | Coir |
| 0 | 5.4 | 7.2 | 5.3 | 7.3 | 0.23 | 0.42 | 0.30 | 0.85 |
| 25 | 5.8 | 7.2 | 5.9 | 7.3 | 0.32 | 0.40 | 0.29 | 0.67 |
| 50 | 6.3 | 7.0 | 6.6 | 7.3 | 0.39 | 0.39 | 0.29 | 0.40 |
| 75 | 6.5 | 6.3 | 6.7 | 6.9 | 0.38 | 0.31 | 0.37 | 0.31 |
| 100 | 6.5 | 6.5 | 6.9 | 6.9 | 0.37 | 0.37 | 0.50 | 0.50 |
| $LSD_{0.05}$ [z] | 0.2 | | 0.2 | | 0.08 | | 0.13 | |
| Linear [y] | <0.0001 | <0.00001 | <0.0001 | 0.0003 | 0.0150 | 0.0663 | 0.0095 | 0.0016 |
| Quadratic | 0.0003 | 0.8791 | 0.0002 | 0.4167 | 0.0660 | 0.4280 | 0.0501 | 0.0005 |
| a | 5.54 | 7.31 | 5.50 | 7.39 | 0.270 | - | 0.256 | 0.892 |
| $b_0x$ | 0.0114 | -0.00955 | 0.0157 | -0.00535 | 0.00136 | - | 0.00189 | -0.0148 |
| $b_1x^2$ | - | - | - | - | - | - | - | 0.000105 |
| $r^2$ | 0.81 | 0.82 | 0.88 | 0.64 | 0.38 | - | 0.42 | 0.84 |
| CV | 3 | 2 | 4 | 2 | 20 | - | 24 | 17 |

[z] LSD values are for comparing substrate series for a given rice hull content or rice hull contents for a given substrate series.
[y] The equation coefficients for either the linear ($y = a + b_0x$) or quadratic ($y = a + b_0x + b_1x^2$) regression models are provided for whichever model had the lowest significant Pr>F. The coefficient of determination ($r^2$) and coefficient of variation (CV) were calculated for the best fit model (n = 3).

Table 3. Effect of rice hull volume proportion in a peat moss replacement series of treatments on mean shoot dry weight and plant height of *Impatiens walleriana* 'Super Elfin White' in Expt. 1, mean shoot fresh weight and plant height of *Impatiens walleriana* 'Super Elfin White' in Expt. 2, and mean shoot fresh weight, plant height, and days to flowering (DTF) of *Verbena* ×*hybrida* 'Romance Deep Rose' in Expt. 3

| Rice hulls (%) | Expt. 1 Dry wt. (mg) | Expt. 2 Fresh wt. (g) | Expt. 3 Fresh wt. (g) | Expt. 1 Height (cm) | Expt. 2 Height (cm) | Expt. 3 Height (cm) | Expt. 3 DTF (d) |
|---|---|---|---|---|---|---|---|
| 0 | 35 | 0.70 | 3.44 | 5.1 | 4.3 | 6.2 | 48.0 |
| 25 | 39 | 0.70 | 3.82 | 5.1 | 5.1 | 6.9 | 47.0 |
| 50 | 41 | 0.64 | 3.65 | 5.1 | 4.5 | 7.8 | 47.0 |
| 75 | 31 | 0.48 | 3.46 | 3.8 | 3.5 | 7.8 | 48.0 |
| 100 | 28 | 0.38 | 2.66 | 3.6 | 2.6 | 7.1 | 48.3 |
| $LSD_{0.05}$ [z] | 2 | 0.04 | 0.36 | 0.2 | 0.2 | 0.3 | 0.5 |
| Linear [y] | 0.0178 | <0.0001 | 0.0092 | <0.0001 | 0.0003 | 0.0119 | 0.1448 |
| Quadratic | 0.0011 | 0.0006 | <0.0001 | 0.0153 | <0.0001 | <0.0001 | <0.0001 |
| a | 35.3 | 0.754 | 3.45 | 5.44 | 4.45 | 6.08 | 48.5 |
| $b_0x$ | 0.213 | 0.00347 | 0.0193 | -0.0179 | 0.0247 | 0.0531 | -0.0486 |
| $b_1x^2$ | -0.00299 | - | -0.000270 | - | -0.000450 | -0.000423 | 0.000419 |
| $r^2$ | 0.75 | 0.88 | 0.86 | 0.79 | 0.93 | 0.93 | 0.70 |
| CV | 8 | 8 | 5 | 8 | 6 | 2 | 0.77 |

[z] LSD values are for comparing between rice hull contents.
[y] The equation coefficients for either the linear ($y = a + b_0x$) or quadratic ($y = a + b_0x + b_1x^2$) regression models are provided for whichever model had the lowest significant Pr>F. The coefficient of determination ($r^2$) and coefficient of variation (CV) were calculated for the best fit model (n = 3).

while height was highest in the 25% rice hulls treatment. Overall maximum Impatiens growth occurred at 25% rice hulls. In Expt. 3, the shortest number of days to flowering for verbena occurred in the 25 and 50% rice hull treatments (Table 3). Shoot fresh weight was greatest in the 25 and 50% rice hulls treatments and height was maximized in the 50 and 75% treatments. The best rice hulls rate for maximizing growth of verbena was the 50%. However, more compact plants could be produced at 25% rice hulls, where weight was maximized but plants were shorter. Taking into account all three experiments, the best rice hulls rate for plant growth was 25% when blended with peat moss. This was lower than the 30 to 60% composted rice hulls for the best growth of petunia reported by Song *et al.* (1996).

**Available nutrients**: In Expt. 2 only the main effect of series had a significant effect on substrate electrical conductivity (EC). The average EC values for the peat and coir series were 0.51 and 0.58, respectively. The series by rice hull percentage interaction was significant in Expts. 1 and 3 (Table 2). Substrate electrical conductivity (EC) levels were within the acceptable range in all treatments and experiments. Addition of rice hulls to peat moss resulted in increased EC in Expts. 1 and 3, while addition to coir caused a decrease. This indicated that rice hulls were a source of salts, but not as great a source as coir.

There was a significant interactive effect of series by rice hull percentage on substrate $K^+$ concentration in all experiments (Table 4). Available $K^+$ in the root substrate in the three experiments was highest in 100% coir and diminished linearly with increased substitution of coir by rice hulls. Conversely, $K^+$ increased linearly in the peat moss series when peat was substituted by rice hulls in the three experiments. Rice hulls were a source of $K^+$, but a much lower source than coir. Substrate $K^+$ levels did not become excessive in any treatments.

Only the rice hull percentage main effect had a significant effect on substrate $Ca^{2+}$ levels in Expts. 1 and 3 (Table 4). Substrate $Ca^{2+}$ increased with increasing rice hulls in these experiments. There were interactive effects of series by rice hull percentage on substrate $Ca^{2+}$ levels in Expt. 2 and on substrate $Mg^{2+}$ levels in all three experiments. There was a trend for available levels of $Ca^{2+}$ and $Mg^{2+}$ to increase with increasing substitution of coir or peat moss by rice hulls. This is consistent with the report of Laiche and Nash (1990) which indicated that composted rice hulls contributed $Ca^{2+}$, $Mg^{2+}$ and $K^+$ to root substrate. There were no consistent effects of rice hulls on available substrate levels of $PO_4$-P, $NH_4^+$-N, or $NO_3^-$-N in the peat moss and coir series.

Table 4. Effect of rice hull volume proportion in a peat moss and a coir replacement series of treatments on mean $K^+$, $Ca^{2+}$ and $Mg^{2+}$ concentrations of substrate solutions of *Impatiens walleriana* 'Super Elfin White' in Expts. 1 and 2 and *Verbena* × *hybrida* 'Romance Deep Rose' in Expt. 3

| Rice hulls | Expt. 1 $K^+$ mg $L^{-1}$ | | Expt. 2 $K^+$ mg $L^{-1}$ | | Expt. 3 $K^+$ mg $L^{-1}$ | | Expt. 1 $Ca^{2+}$ mg $L^{-1}$ | Expt. 2 $Ca^{2+}$ mg $L^{-1}$ | | Expt. 3 $Ca^{2+}$ mg $L^{-1}$ | Expt. 1 $Mg^{2+}$ mg $L^{-1}$ | | Expt. 2 $Mg^{2+}$ mg $L^{-1}$ | | Expt. 3 $Mg^{2+}$ mg $L^{-1}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (%) | Peat | Coir | Peat | Coir | Peat | Coir | | Peat | Coir | | Peat | Coir | Peat | Coir | Peat | Coir |
| 0 | 21.3 | 72.0 | 33.7 | 102.0 | 9.3 | 151.0 | 10.3 | 12.0 | 4.7 | 11.5 | 8.0 | 7.0 | 12.0 | 4.3 | 15.7 | 6.3 |
| 25 | 31.0 | 66.0 | 41.3 | 100.3 | 16.0 | 117.7 | 11.0 | 11.7 | 6.7 | 11.0 | 11.3 | 7.0 | 11.3 | 6.7 | 10.7 | 7.3 |
| 50 | 44.3 | 58.3 | 37.3 | 68.0 | 16.0 | 73.7 | 14.5 | 15.0 | 11.0 | 9.3 | 12.7 | 9.0 | 14.3 | 10.0 | 11.3 | 6.3 |
| 75 | 38.7 | 42.7 | 40.3 | 58.7 | 31.7 | 41.3 | 15.3 | 17.0 | 18.7 | 12.2 | 12.7 | 8.3 | 14.3 | 15.0 | 12.0 | 9.7 |
| 100 | 45.0 | 45.0 | 47.3 | 47.3 | 25.7 | 25.7 | 20.7 | 23.3 | 23.3 | 16.7 | 10.7 | 10.7 | 14.3 | 14.3 | 11.0 | 11.0 |
| $LSD_{0.05}$[z] | 15.5 | - | 14.6 | - | 22.7 | - | 6.4 | 1.6 | - | 3.9 | 2.8 | - | 1.4 | - | 3.9 | |
| Linear[y] | 0.0095 | 0.0015 | 0.0297 | <0.0001 | 0.0491 | <0.0001 | 0.0003 | <0.0001 | <0.0001 | 0.0309 | 0.1539 | 0.0018 | 0.0019 | <0.0001 | 0.1427 | 0.0044 |
| Quadratic | 0.2451 | 0.7202 | 0.6750 | 0.8807 | 0.7293 | 0.1687 | 0.3654 | <0.0001 | 0.0111 | 0.0125 | 0.0139 | 0.4668 | 0.4991 | 0.1649 | 0.1985 | 0.2264 |
| a | 25.1 | 72.3 | 34.7 | 105 | 10.1 | 147 | 9.37 | 10.2 | 3.00 | 11.9 | 8.02 | 6.67 | 11.7 | 4.40 | - | 5.80 |
| $b_0x$ | 0.220 | -0.309 | 0.105 | -0.604 | 0.193 | -1.31 | 0.100 | 0.112 | 0.197 | -0.120 | 0.164 | 0.0347 | 0.0307 | 0.113 | - | 0.0467 |
| $b_1x^2$ | - | - | - | - | - | - | - | - | - | 0.00166 | -0.00137 | - | - | - | - | - |
| $r^2$ | 0.42 | 0.55 | 0.31 | 0.82 | 0.26 | 0.91 | 0.37 | 0.84 | 0.95 | 0.33 | 0.50 | 0.54 | 0.54 | 0.90 | - | 0.48 |
| CV | 27 | 19 | 15 | 14 | 62 | 19 | 33 | 12 | 13 | 29 | 17 | 14 | 8 | 14 | - | 23 |

[z]LSD values for $Ca^{2+}$ in Expts. 1 and 3 are for comparing between rice hull contents. LSD values for all other dependent variables are for comparing substrate series for a given rice hull content or rice hull contents for a given substrate series.

[y]The equation coefficients for either the linear ($y = a + b_0x$) or quadratic ($y = a + b_0x + b_1x^2$) regression models are provided for whichever model had the lowest significant Pr>F. The coefficient of determination ($r^2$) and coefficient of variation (CV) were calculated for the best fit model (n = 3). The regression models for $Ca^{2+}$ concentration in Expts. 1 and 3 combined data from both substrate series (coir or sphagnum peat moss) since the substrate series x rice hull rate interaction was not significant for these two dependent variables.

Ground, composted rice hulls are a potential alternative component of plug and bedding plant substrates. When ground so that 75% of the particles were 0.51 to 1.40 mm and 90% of the particles were 0.51 to 2.00 mm, composted rice hulls provided AS to the substrate as would be expected from a coarse aggregate such as perlite. The ground rice hulls did not serve as an acceptible replacement for peat moss or coir since CC and AW declined with increasing addition of rice hulls. Rice hulls also contributed $Ca^{2+}$, $Mg^{2+}$, and $K^+$ to root substrate. Overall, the best growth was obtained with 25% rice hulls plus 75% peat moss.

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