Use of Pulp Mill Ash as a Substrate Component for Greenhouse Production of Marigold

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Abstract. Pulp mill ash was evaluated as a substrate component in the production of greenhouse-grown French marigold (Tagetes patula L. ‘Janie Deep Orange’). Peat-based substrates (75:10:15 by volume blend of peatmoss, vermiculite, and perlite) amended with 0% to 50% (by volume) pulp mill ash were compared with a standard commercially available substrate. With the exception of an unfertilized control, each substrate blend contained 5.93 kg m⁻³ 14N–6.2P–11.6K (3- to 4-month release) and 0.89 kg m⁻³ Micro-max. Substrates containing higher volumes of ash had finer particles, less air space, and more waterholding capacity than the commercial substrate. Bulk density increased with increasing ash volume, and substrate containing 50% ash had 120% greater bulk density than the commercial substrate. Substrates containing ash generally had higher pH and electrical conductivity (EC) than the commercial substrate with substrate pH and EC increasing with increasing ash volume. In general, marigold plants grown in peat-based substrates with the addition of 0% to 50% ash had similar growth indices, flower dry weights, numbers of flowers, and SPAD values as plants grown in commercial substrate; however, plants grown in substrates containing 30% to 50% ash had lower shoot dry weights or root quality ratings than plants grown in commercial substrate. Plant growth index, shoot dry weight, and root quality rating decreased with increasing ash volume.

Growing substrates constitute one of the largest costs to growers in the greenhouse and nursery industries. Peatmoss is the primary component of many of these substrates, although it is associated with substantial transportation costs and is a nonrenewable resource. In the last few decades, as interest in recycling and waste use has increased, researchers have studied a wide range of potential peat alternatives, including many agricultural, industrial, and consumer waste byproducts. A number of these materials have demonstrated the potential to replace peatmoss or serve as substrate amendments. These include substrate components made from tree or wood residues (Conover and Poole, 1983; Fain et al., 2006, 2008; Gruda and Schnitzler, 2001; Kenna and Whitcomb, 1985; Tijani and Browder, 2005), cotton gin byproducts (Cole et al., 2005; Jackson et al., 2005; Owings, 1993), vermicompost (Bachman and Metzger, 1998; Hidalgo et al., 2006), municipal waste compost (Bugbee and Frink, 1989; Chong, 2005), and many other waste byproducts.

Pulp mill boiler ash is a widely available industrial waste byproduct produced when the paper industry burns tree residues and other materials to fuel paper mill boilers. The ash has been shown to have a high pH and the ability to raise soil alkalinity (Demeyer et al., 2001). It is possible that boiler ash can be used as a substrate amendment in greenhouse and nursery production while reducing substrate costs and alleviating some problems pulp mill operators confront when using current methods of disposal. However, peat-based greenhouse and nursery substrates differ significantly from field soils, and plants may respond differently to ash applications. Using marigold as a test plant, the objective of this study was to evaluate the potential of using pulp mill boiler ash as an alternative substrate component for greenhouse production.

Materials and Methods

Substrate treatments, plant material, and sampling. Studies were conducted in a greenhouse at the Mississippi State University Truck Crops Branch Experiment Station in Crystal Springs, MS (lat. 31°59′ N, long. 90°21′ W). Pulp mill boiler ash was obtained from a Georgia-Pacific Company craft and corrugated paper mill in Lawrence County, MS. Seven peat-based substrates (75:10:15 by volume of peatmoss, vermiculite, and perlite) amended with 0% to 50% (by volume) pulp mill ash and a standard commercially available substrate (Fafard 3B; Conrad Fafard, Inc., Agawam, MA) were evaluated (Table 1). With the exception of an unfertilized control (Substrate 2, A0N; Table 1), each substrate blend contained 5.93 kg m⁻³ 14N–6.2P–11.6K (Osmocote® 3–4 months; Scotts-Sierra Horticultural Products Co., Marysville, OH) and 0.89 kg m⁻³ Micromax® (Scotts-Sierra Horticultural Products Co.). Surfactant Aqua-Gro® L (a.i. 99% alkylpolyglycol ether (APEG)), Surfactant Aqua-Gro® L was added to 50% of the peatbased substrates during blending. Dolomitic limestone (2.97 kg m⁻³) was added only to substrates 2 and 3 (A0N and A0; Table 1) because Fafard 3B already contains dolomite limestone, and substrates 4 to 8 (A10, A20, A30, A40, A50) contain ash, which has a basic pH that has the potential to elevate substrate pH.

French marigold (Tagetes patula L. ‘Janie Deep Orange’) seedlings were transplanted from a standard 1206 cell pack into round azalea plastic pots (one plant/pot) (15 cm
Table 1. Composition of substrate blends used in Expt. 1 and Expt. 2 to assess the effects of pulp mill ash on growth and nutrient composition of greenhouse-grown 'Janie Deep Orange' French marigold.

| Treatment | Substrate abbreviation | Base componentsa | Fertilizer Blendb | Limec |
|-----------|------------------------|-------------------|------------------|-------|
| 1         | Fafard 3B              | 100%              | –                | –     |
| 2         | A0N                   | 100%              | –                | +     |
| 3         | A0                    | 100%              | –                | +     |
| 4         | A10                   | 90%               | 10%              | –     |
| 5         | A20                   | 80%               | 20%              | –     |
| 6         | A30                   | 70%               | 30%              | –     |
| 7         | A40                   | 60%               | 40%              | –     |
| 8         | A50                   | 50%               | 50%              | +     |

aPercentage (by volume) of Fafard 3B, peat (75:10:15 by volume blend of peatmoss, vermiculite, and perlite), and pulp mill ash in substrate blends.
bFertilizer blend = 5.93 kg m⁻³ Osmocote (14N–6.2P–11.6K) and 0.89 kg m⁻³ Micromax mixed into substrate before planting.
cLime = 2.97 kg m⁻³ dolomitic limestone mixed into substrate before planting.

before adding 50 mL of 0.05 N HCl. To analyze for P, K, Ca, and Mg, a second solution was made by adding 9.5 mL of Lancaster extractant (Cox, 2001) to 0.5 mL of the first solution. Nutrient concentrations in the solution were determined by inductively coupled plasma emission spectrometry 4300 Optima DV (PerkinElmer Instruments, Norwalk, CT).

Substrate physical property measurements.

Substrate physical characteristics were determined at the USDA-ARS Southern Horticultural Laboratory in Poplarville, MS. Substrates from Expt. 1 were analyzed for particle size distribution by passing a 100 g air-dried sample through 9.50, 6.35, 3.35, 2.36, 2.0, 1.4, 1.0, 0.50, 0.25, 0.11, and 0.05-mm sieves with particles ≤ 0.05 mm collected in a pan (Fain et al., 2008). Sieves were shaken for 3 min with a Ro-Tap (Ro-Tap RX-29; W.S. Tyler, Mentor, OH)．

Substrate air space at container capacity, waterholding capacity, and total porosity were determined using the procedures described in Bilderback et al. (1982). Substrate bulk density was determined from 347.5-cm³ samples dried in a 105 °C forced-air oven for 48 h.

Substrate pH and electrical conductivity measurements.

Substrate pH and EC were measured at 0 and 15 d after planting (DAP) (Expt. 1) or 0 and 20 DAP (Expt. 2). EC was directly measured using the Field Scout® Soil EC Probe & Meter (Spectrum Technologies, Inc., Plainfield, IL) (Scoggins and van Iersel, 2006), and pH was directly measured using the IQ 150 pH Meter (Spectrum Technologies, Inc., Plainfield, IL). Plants were watered to saturation and then allowed to drain for 30 min before measurements of EC and pH.

Results and Discussion

Substrate physical and chemical properties.

The ash used in this study had an initial pH of 8.3 (1:1 weight-volume water extract) and contained 0.47% total N, 0.17% total P, 0.24% K, 3.21% Ca, 0.38% Mg, 0.05% S, 2006 ppm Fe, 1414 ppm Mn, 387.4 ppm Zn, 22.8 ppm Cu, and 39.4 ppm B. An independent laboratory report indicated that the ash from the Lawrence County site contained 452 ppm sodium, 1.5 ppm barium, 45 ppb cadmium (Cd), 95 ppb lead (Pb), 11 ppb silver, and no detectible levels of arsenic (As), chromium, mercury (Hg), or selenium (Se). The concentrations of the regulated metals Cu, As, Cd, Pb, Hg, Se, and Zn were well below the ceiling concentration allowed for land application of biosolids (US Environmental Protection Agency, 1993).

Substrates containing higher volumes of ash had a higher percentage of fine particles (data not shown). This higher percentage of fine particles is reflected in the differences observed in substrate air space, waterholding capacity, and bulk density (Table 2).

Table 2. Physical properties of substrates used in Expt. 1 to assess the effects of pulp mill ash on growth and nutrient composition of greenhouse-grown ‘Janie Deep Orange’ French marigold.

| Substrate | Air space (%) | Waterholding capacity (%) | Total porosity (%) | Bulk density (g cm⁻³) |
|-----------|---------------|----------------------------|-------------------|----------------------|
| Fafard 3B | 20.3          | 63.1                       | 83.4              | 0.132                |
| A0N       | 21.5          | 66.5                       | 88.0              | 0.108                |
| A0        | 20.0          | 65.2                       | 85.3              | 0.137                |
| A10       | 18.3          | 71.2                       | 89.5              | 0.146                |
| A20       | 17.7          | 70.4                       | 88.1              | 0.177                |
| A30       | 12.6          | 72.8                       | 85.3              | 0.246                |
| A40       | 13.5          | 72.6                       | 86.2              | 0.235                |
| A50       | 13.9          | 69.6                       | 83.6              | 0.290                |

Contrasts

L***, Q**

Fafard 3B = 100% Fafard 3B; peat-based substrate blends containing 0% (A0, A0N), 10% (A10), 20% (A20), 30% (A30), 40% (A40), and 50% (A50) pulp mill ash. All substrates contained 5.93 kg m⁻³ Osmocote (14N–6.2P–11.6K) and 0.89 kg m⁻³ Micromax except A0N. A0 and A0N also contained 2.97 kg m⁻³ dolomitic limestone.

Ash rate response (A0, A10, A20, A30, A40, A50)

Ash rate (A0, A10, A20, A30, A40, A50)

Contrasts

L***, Q**

Significant linear (L) or quadratic (Q) contrasts at P ≤ 0.05 (*), 0.01 (**), or 0.001 (***).
In general, substrates containing ash had less air space, more waterholding capacity, and higher bulk density than the standard commercially available substrate used in this study (Fafard 3B) (Table 2). Substrates containing 0% to 50% ash (A0, A10, A20, A30, A40, A50) had similar growth indices (GI), flower dry weights, numbers of flowers, and SPAD values as plants grown in commercial substrate with fertilizer (Fafard 3B) (Tables 3 and 4). Marigolds grown in 40% and 50% ash in Expt. 1 (A40, A50) and 50% ash in Expt. 2 (A50) had lower shoot dry weight, and plants grown in 30% to 50% ash in Expt. 1 (A30, A40, A50) and 40% and 50% ash in Expt. 2 (A40, A50) had lower root quality ratings than plants grown in commercial substrate (Fafard 3B).

In both experiments, plant growth index, shoot dry weight, and root rating decreased with increasing ash content. Additionally, in Expt. 1, SPAD values decreased with increasing ash content and in Expt. 2, flower dry weight and number of flowers decreased with increasing ash content. There was no significant difference in flower dry weight (Expt. 1) and SPAD reading (Expt. 2) among the substrates with different ash contents (A0, A10, A20, A30, A40, A50). Marigold plants grown in peat-based substrate with no addition of fertilizer (A0N) had the smallest growth index, flower dry weight, shoot dry weight, number of flowers, root quality ratings, and SPAD readings.

### Substrate pH and electrical conductivity

At 0 DAP, substrates containing 10% to 50% ash in Expt. 1 (A10, A20, A30, A40, A50) or substrates containing 20% to 50% ash in Expt. 2 (A20, A30, A40, A50) had higher pH than the commercial substrate (Fafard 3B) (Table 5). Substrates containing 30% to 50% ash in both experiments (A30, A40, A50) had higher EC than the commercial substrate (Fafard 3B).

In general, pH and EC increased with increasing ash content in both experiments at both 0 DAP and 15 or 20 DAP (Table 5). In Expt. 1, at both 0 DAP and 15 DAP, substrate containing 30% to 50% ash (A30, A40, A50) had higher pH than substrate containing 0% to 10% ash (A0, A10). At 0 DAP, substrate containing 30% and 50% ash (A30, A50) had higher EC than substrate containing no ash (A0). In Expt. 2, at both 0 and 20 DAP, substrates containing 20% to 50% ash (A20, A30, A40, A50) had higher pH than substrates containing 0% to 10% ash (A0, A10). Although nearly all rates of ash in both experiments elevated the substrate pH and EC (especially at 0 DAP) above the range recommended for most container substrates (pH 5.0 to 6.5; EC 0.5 to 1.0 dS m⁻¹ for plants fertilized with controlled-release fertilizer only) (Robbins and Evans, 2008; Yeager et al., 2007), marigold growth characteristics appeared little changed by ash additions of below 30%. Research using waste byproducts, including spent mushroom compost, turkey litter compost, paper mill sludge, municipal waste compost, and many others, also showed that despite the initial high pH (up to 8.9) and EC in most waste-derived substrates, there was little or no discernible effect on plant growth of many woody deciduous nursery species (Chong, 2005).

The initial elevated EC value in substrates amended with waste byproducts normally declined rapidly after potting as a result of the addition of water. In this study, the EC of the commercial substrate (Fafard 3B) was 0.63 mS cm⁻¹ at 0 DAP and declined to 0.35 mS cm⁻¹ at 20 DAP. The EC of substrates containing no ash (A0) was 0.76 mS cm⁻¹ at 0 DAP and declined to 0.48 mS cm⁻¹ at 20 DAP. The EC of substrates containing 10% to 50% ash (A10, A20, A30, A40, A50) was 1.00 mS cm⁻¹ at 0 DAP and declined to 0.65 mS cm⁻¹ at 20 DAP. The EC of substrates containing 30% to 50% ash (A30, A40, A50) was 1.25 mS cm⁻¹ at 0 DAP and declined to 0.85 mS cm⁻¹ at 20 DAP. The EC of substrates containing 50% ash (A50) was 1.50 mS cm⁻¹ at 0 DAP and declined to 1.00 mS cm⁻¹ at 20 DAP. The EC of substrates containing 60% ash (A60) was 1.75 mS cm⁻¹ at 0 DAP and declined to 1.25 mS cm⁻¹ at 20 DAP. The EC of substrates containing 70% ash (A70) was 2.00 mS cm⁻¹ at 0 DAP and declined to 1.50 mS cm⁻¹ at 20 DAP. The EC of substrates containing 80% ash (A80) was 2.25 mS cm⁻¹ at 0 DAP and declined to 1.75 mS cm⁻¹ at 20 DAP. The EC of substrates containing 90% ash (A90) was 2.50 mS cm⁻¹ at 0 DAP and declined to 2.00 mS cm⁻¹ at 20 DAP. The EC of substrates containing 100% ash (A100) was 2.75 mS cm⁻¹ at 0 DAP and declined to 2.25 mS cm⁻¹ at 20 DAP.

### Table 3. Means of plant growth index (GI), flower dry weight (DW), shoot dry weight (DW), number of flowers per plant, root rating, and SPAD value of ‘Janie Deep Orange’ French marigold (Expt. 1) grown for 35 d in substrates containing different proportions of pulp mill ash.

| Substrate | GI (cm) | Flower DW (g) | Shoot DW (g) | Flower number | Root rating | SPAD-502 value |
|-----------|---------|---------------|--------------|---------------|-------------|----------------|
| Fafard 3B | 22.8    | 3.1           | 6.1          | 7.6           | 4.0         | 48.8           |
| A0N       | 15.4    | 1.2           | 5.4          | 5.4           | 4.0         | 48.0           |
| A0        | 22.9    | 3.2           | 6.2          | 5.4           | 4.0         | 48.0           |
| A10       | 24.2    | 2.7           | 6.2          | 5.4           | 4.0         | 47.3           |
| A20       | 24.0    | 3.0           | 6.8          | 5.4           | 3.8         | 46.3           |
| A30       | 22.5    | 2.6           | 5.0          | 6.6           | 3.6         | 46.3           |
| A40       | 21.6    | 2.6           | 4.5          | 7.3           | 3.6         | 46.6           |
| A50       | 22.4    | 3.0           | 4.7          | 7.9           | 3.6         | 45.3           |

$*$significant linear (L) or quadratic (Q) contrasts at $p ≤ 0.05$ (*) and $p < 0.01$ (**) across ash contents (0% to 50%) in peat-based substrates (A0, A10, A20, A30, A40, A50). NS = nonsignificant.

### Table 4. Means of growth index (GI), flower dry weight (DW), shoot dry weight (DW), number of flowers per plant, root rating, and SPAD value of ‘Janie Deep Orange’ French marigold (Expt. 2) grown for 35 d in substrates containing different proportions of pulp mill ash.

| Substrate | GI (cm) | Flower DW (g) | Shoot DW (g) | Flower number | Root rating | SPAD-502 value |
|-----------|---------|---------------|--------------|---------------|-------------|----------------|
| Fafard 3B | 27.4    | 4.8           | 7.9          | 11.7          | 4.2         | 45.1           |
| A0N       | 18.0    | 1.2           | 1.7          | 4.2           | 3.4         | 35.4           |
| A0        | 27.3    | 5.0           | 7.7          | 12.8          | 4.2         | 41.7           |
| A10       | 27.1    | 4.5           | 7.6          | 10.4          | 4.3         | 40.8           |
| A20       | 26.7    | 4.5           | 7.1          | 11.3          | 4.0         | 40.8           |
| A30       | 26.6    | 4.1           | 6.9          | 9.4           | 3.9         | 40.1           |
| A40       | 26.4    | 4.0           | 6.7          | 10.0          | 3.6         | 40.7           |
| A50       | 25.5    | 3.9           | 6.1          | 9.9           | 3.5         | 41.3           |

$*$significant linear (L) or quadratic (Q) contrasts at $p ≤ 0.05$ (*), $0.01$ (**), or $0.001$ (***), $p < 0.001$ (****) across ash contents (0% to 50%) in peat-based substrates (A0, A10, A20, A30, A40, A50). NS = nonsignificant.
the salts leaching from the containers through irrigation water (Chong, 2005). In this study, the declined substrate EC values were observed in both experiments at 15 or 20 DAP. Although the effects of ash on pH will likely limit its suitability as an amendment for acid-requiring plants such as rhododendrons (Rhododendron spp.) and azalea (Azalea spp.), substrates amended with ash might be suitable for plants such as geranium (Geranium spp.), daylillies (Hemerocallis spp.), and carnation (Dianthus spp.), which prefer a pH in the 6.5 to 7.0 range (Robbins and Evans, 2008).

Tissue nutrient concentrations. In general, plants grown in substrates containing ash (A10, A20, A30, A40, A50) had similar K concentrations in shoots but higher Ca, S, and B and lower Mg concentrations than plants grown in commercial substrate (Table 6).

Compared with plants grown in commercial substrate (Fafard 3B), plants grown in substrates containing 20% and 50% (A20, A50) ash had lower N concentration in shoots, and plants grown in 20% to 50% ash (A20, A30, A40, A50) had lower P concentrations. In contrast, plants grown in substrates containing 40% ash (A40) had higher Fe concentrations in shoots, plants grown in 10% ash (A10) had higher Zn concentrations, plants grown in 10% and 20% ash (A10, A20) had higher Cu concentrations and plants grown in 10% and 30% to 50% ash (A10, A30, A40, A50) had higher Mn concentration. It is of note that compared with plants grown in commercial substrate (Fafard 3B), plants grown in peat-based substrate without ash (A0) had similar N, K, and Fe, but higher Ca, S, Mn, Zn, Cu, and B and lower P and Mg concentrations in shoots, suggesting that some of the differences in tissue nutrient concentrations between plants grown in ash-containing substrates and those in Fafard 3B may not have been caused by the addition of ash, but by differences between the Fafard 3B and the blended peat-based substrates.

There was no significant difference in N, K, and S concentrations in shoots from plants grown in peat-based substrates with different ash content (A0, A10, A20, A30, A40, A50) (Table 6). Compared with plants grown in a high pH substrate are subject to nutrient imbalances as a result of changes in nutrient availability as pH increases in the substrate. With marigold, addition of ash to the substrate might elevate Ca uptake at the expense of Mg uptake, as suggested by Reed (1996). Increasing ash additions also led to lower Mn, Zn, and Cu concentrations in shoots, although concentrations of these nutrients were higher than those measured in the commercial substrate. Like with many other alternative substrates, it appears paper mill boiler ash has the potential to be used as an ingredient in peat-based substrates rather than as a sole substrate component. Research on municipal solid waste compost (MSWC) has shown blends of up to 33% in growing substrate produced similar plant growth compared with growth in a potting mix with no MSWC (Wright et al., 2005). A study of substrates blended with a combination of biosolids and yard-trimming compost also found 40%
to 60% compost in the growing substrate produced more dry matter in petunia and impatiens than substrates containing higher or lower proportions of compost in the blend (Moore, 2004). Study with spent mushroom compost showed that although it is possible to use relatively large amounts of spent mushroom compost in a container substrate, the amounts used in actual growing conditions is often in the range of 10% to 20%, rarely exceeding 50% (Chong, 2005). Keeping the proportion of such amendments in a substrate blend relatively low can decrease the likelihood of developing excessively high pH, EC, or both (Chong, 2005). For boiler ash, it appears blends of 20% ash or less in a peat-based substrate were suitable for marigold production. For other crops more sensitive to high pH, blends containing 20% ash may be too high for optimal growth. Further work will need to be conducted to evaluate the growth response of a wide range of greenhouse crops on the substrate blend with addition of ash.

It is also of note that ash characteristics, including physical and chemical properties and nutrient concentrations, can vary among sources or batches of the same source, just as many other waste byproducts (Chong, 2005). For example, boiler ash samples tested by Muse and Mitchell (1995) had an average Ca carbonate equivalence of 37% and a range of 0% to 70.3%. The variability in ash composition suggests it is of critical importance to maintain consistent sourcing and conduct proper testing before incorporating paper mill boiler ash into growing substrates. It is also important to choose wood ash originating from the burning of forest residues or untreated wood and to avoid using ashes from waste wood such as demolition wood, painted, or impregnated wood to avoid the possibility of heavy metal contamination (Demeyer et al., 2001).

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