Paclobutrazol Drench Activity Not Affected in Sphagnum Peat-based Substrates Amended with Pine Wood Chip Aggregates

W. Garrett Owen [1], Brian E. Jackson [2], Brian E. Whipker [3,4], and William C. Fonteno [3]

ADDITIONAL INDEX WORDS. **horticultural substrates, loblolly pine, PGR, plant growth regulator, potting media**

SUMMARY. **Processed pine (*Pinus* sp.) wood has been investigated as a component in horticultural substrates (greenhouse and nursery) for many years. Specifically, pine wood chips (PWC) have been uniquely engineered/processed into a nonfiberous blockular particle size, suitable for use as a substrate aggregate. The purpose of this research was to determine if paclobutrazol drench efficacy is affected by PWC used as a substitute for perlite in a peat-based substrate. Paclobutrazol drench applications of 0, 1, 2, and 4 mg/pot were applied to 'Pacino Gold' sunflower (*Helianthus annuus*); 0.0, 0.25, 0.50, and 1.0 mg/pot to 'Anemone Safari Yellow' marigold (*Tagetes patula*); and 0.0, 0.125, 0.25, and 0.50 mg/pot to 'Variegata' plectranthus (*Plectranthus ciliates*) grown in sphagnum peat-based substrates containing 10%, 20%, or 30% (by volume) perlite or PWC. Efficacy of paclobutrazol drenches for controlling growth of all three species was unaffected by substrate composition. We concluded that substituting PWC for perlite as an aggregate in peat-based substrates should not reduce paclobutrazol drench efficacy, variability in PWC products indicates that efficacy should be tested before large-scale use. The variability results from wood components not being engineered and processed the same across manufacturers, meaning that they are often incapable of improving/influencing the physical and chemical behavior of a substrate similarly.**

Traditionally, greenhouse and nursery operations formulate container substrates primarily from peatmoss (peat), pine bark (PB), perlite, or vermiculite for the production of most all bedding plants and nursery ornamentals (Nelson, 2012). Of these substrate components, peat and PB are used in the greatest quantities. Peat, PB, and perlite can be expensive and prices can fluctuate due to reduced availability and increasing costs associated with harvesting, processing, and long-distance transport. An emphasis on reducing production costs and an increased interest in using local and regional materials has led to the investigation and development of alternative substrates and substrate components for peat, PB, and perlite.

Many substrate components are agricultural, municipal, or waste by-products. Numerous studies have investigated a variety of substitutes for peat, PB, and perlite such as cotton gin waste (Owings, 1993), wood by-products (Chong and Lumis, 2000; Criley and Watanabe, 1974), municipal leaf and sewage sludge (Bugbee et al., 1991; Rosen et al., 1993), rice hulls (Dueitt et al., 1993; Evans and Gachukia, 2004), ground bovine bones (Evans, 2004a), poultry feather fiber (Evans, 2004b), and shredded rubber (Evans and Harkess, 1997). However, inconsistency and insufficient quantities of by-products are challenging for long-term and sustained use as an alternative substrate or substrate component, especially for large production facilities.

The use of plant growth retardants (PGRs) is a common cultural practice of controlling growth in containerized plants in greenhouse production. Plant growth retardants allow growers to control the rate of growth or flowering, increase water uptake efficiency, hold plants longer in production, and produce uniform, compact, and marketable plants (Whipker, 2015). Methods of applying PGRs include foliar sprays, substrate drenches, liner dips or bulb, tuber, and rhizome soaks or dips (Barrett, 2001; Blanchard and Runkle, 2007; Lopez et al., 2010; Whipker and McCall, 2000). However, the most common application methods are foliar sprays, substrate drenches, or a combination of the two (Gent and McAvoy, 2000). Substrate drenches are preferred because of the precision of application, crop uniformity, duration of effectiveness, minimal environmental impact, and the reduction of potential drift from spray applications. However, the efficacy of PGR drenches can be affected by the amount of active ingredient, volume of solution applied, and substrate components (Barrett, 2001; Barrett et al., 2009).

Paclobutrazol provides size control on many floricultural crops (Barrett and Nell, 1989) and is active when applied to the substrate and taken up through the roots (Barrett and Bartuska, 1982; Davis et al., 1988). In comparison with a peat-based substrate, Quarrels and Newman (1994) reported a significant reduction in paclobutrazol control when drenches were applied to poinsettia (*Euphorbia pulcherrima*) plants grown in a PB-based substrate. Similar results of paclobutrazol

Department of Horticultural Science, North Carolina State University, 130 Kilgore Hall, 2721 Founders Drive, Raleigh, NC 27695-7609

Technical assistance of Ingram McCall is gratefully acknowledged.

The cost of publishing this paper was defrayed in part by payment of page charges.

Use of trade names does not imply endorsement of the products named or criticism of similar ones not mentioned.

[1]Former Graduate Research Assistant

[2]Associate Professor

[3]Professor

[4]Corresponding author. E-mail: brian_jackson@ncsu.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
0.7457	horsepower	$kJ \cdot s^{-1}$	1.3410
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.5933	$lb/yard^3$	$kg \cdot m^{-3}$	1.6856
28.3495	oz	g	0.0353
28,350	oz	mg	3.5274×10^{-5}
1	ppm	$mg \cdot L^{-1}$	1
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

activity inhibition were reported by Barrett (1982) for chrysanthemum (*Denranthemum grandiflora*) grown in PB-based substrates. Dasoju et al. (1998) found the activity of paclobutrazol drenches to potted sunflowers in coir- and peat-based substrates to be similar at 2 mg/pot. However, a greater activity was reported for coir-based substrates at 4 mg/pot, Lopez et al. (2010) reported that identical PGR drench applications of ancymidol (Abide; Fine Americas, Walnut Creek, CA), palcobutrazol (Bonzi; Syngenta Crop Protection, Greensboro, NC), and uniconazole (Concise; Fine Americas) to 'Delta Orange Blotch' pansy (*Viola wittrockiana*) and 'Callie Deep Yellow' calibrachoa (*Calibrachoa* ×*hybrida*) grown in a 80% sphagnum peat and 20% perlite- or 20% rice hull-amended (by volume) substrate resulted in similar plant heights and stem length growth patterns.

No information is available regarding the activity of paclobutrazol drenches in peat-based substrates amended with PWC aggregates. Therefore, the objective of this study was to determine if paclobutrazol drench efficacy is affected by PWC used as a substitute for perlite in a peat-based substrate.

Fig. 1. (A) Harvested loblolly pine logs were chipped in a wood chipper resulting in large wood chips [1.0 × 0.2 × 1.0 cm (length × width × height)] before being milled through a 1/4-inch (6.35 mm) hammer mill screen resulting in (B) smaller pine wood chip (PWC) aggregates that are square/blockular in nature and contain little dust or fibers and are similar in size to horticultural grade perlite; 1 cm = 0.3937 inch.

Materials and methods

On 19 Dec. 2011, 8-year-old loblolly pine (*Pinus taeda*) trees were harvested (Chatham County, NC) at ground level, de-limbed, and subsequently stored under shelter for protection from the weather. On 3 Jan. 2012, these logs were chipped (with their bark intact) with an 18-horsepower chipper (model 356447; DR Power Equipment, Vergennes, VT) resulting in large wood chips [1 × 0.2 × 1.0 cm (length × width × height), n = 20 (Fig. 1A)]. Wood chips were then spread out (1-inch deep) on a concrete pad under shelter, turned periodically, and air-dried for 2 d to reduce moisture content, which has been shown in unpublished studies to aid in the processing of wood chips through hammer mills. In this experiment, the moisture content for the fresh wood chips was 43% and 35% after air-drying for 2 d, resulting in 8% moisture loss. Wood chips were then hammer milled through a 1/4-inch screen (Meadows Mills, North Wilkesboro, NC) to produce PWC [0.11 × 0.4 × 0.2 cm (length × width × height), n = 20 (Fig. 1B)]. On 11 Jan., sphagnum peat (Pro-Moss; Premier Tech Horticulture, Quakertown, PA) was taken from a compressed bale, loosened/fluffed, and wetted (by hand) to a moisture content of 50% before being amended with 10%, 20%, or 30% (by volume) perlite (Carolina Perlite Co., Gold Hill, NC) or PWC, to produce a total of six substrate treatments. After formulation of the substrates, initial substrate pH was determined by the 2:1 extract method [2 deionized water and 1 substrate (Argo and Fisher, 2002)] using a pH instrument (HI 9813-6; Hanna Instruments, Woonsocket, RI). Dolomitic limestone was incorporated at a rate of 12 lb/yard^3 and wetting agent (2000 G; Aquatrols, Paulsboro, NJ) was incorporated at a rate of 0.5 lb/yard^3. Substrates were incubated for 4 d in sealed plastic bags to allow pH equilibration before potting. Substrates did not contain a preplant fertilizer.

Experiment 1. On 27 Dec. 2011, 'Pacino Gold' sunflower seeds were double sown into 1203 cell packs [8.0 × 4.0 × 5.5 cm (length × width × height); ITML Horticultural Products, Middlefield, OH] containing Fafard 1P mix (Conrad Fafard, Anderson, SC) in a glasshouse at North Carolina State University (NCSU) in Raleigh. On 3 Jan. 2012, germinated seedlings were pinched at the substrate surface to leave one seedling per cell. On 20 Jan. 2012, sunflowers were transplanted in 6-inch-diameter plastic containers (ITML Horticultural Products) filled with each substrate and watered in with tap water. The seedlings were grown in a polyethylene greenhouse in Raleigh, NC, and grown with 23 °C day/17 °C night air temperature settings (temperatures not monitored during growth trial). All containers had emitters on a ring-drip system placed on the substrate surface and all plants were watered as needed (when the surface began to dry) depending on weather conditions. Equal volumes of irrigation solutions (≈150 mL) were applied to all substrates at each irrigation as a result of the water-holding capacities of all substrates were within 7% of each other (data not shown), according to substrate physical property analysis performed on all substrate blends before potting, using the NCSU Porometer method (Fonteno et al., 1995). Plants were fertilized at each watering with 200 mg·L^{-1} nitrogen (N) injected (TrueAdvantage Dosmatic; Hydro Systems Co., Cincinnati, OH) using 13N–0.9P–10.8K water-soluble fertilizer (Ultrasol Water Soluble Seedling Plus; SQM North America, Atlanta, GA) containing 0.3% ammoniacal (NH_4)-N and 12.7% nitrate (NO_3)-N.

On 4 Feb., 15 d after planting, 4 fl oz of solution containing 0.0, 1.0, 2.0, or 4.0 mg/pot paclobutrazol (Piccolo 10 XC; Fine Americas) per 6-inch pot was applied to each container (nothing was leached/drained from the containers after application). The experiment was a completely randomized design with eight single-plant replications of six substrates × four PGR concentration combinations. On 4 and 24 Feb., growth index {GI [(height + widest width + perpendicular width) ÷ 3]} was determined on all plants. Between 8 and 23 Mar. a final GI of each plant was recorded at the

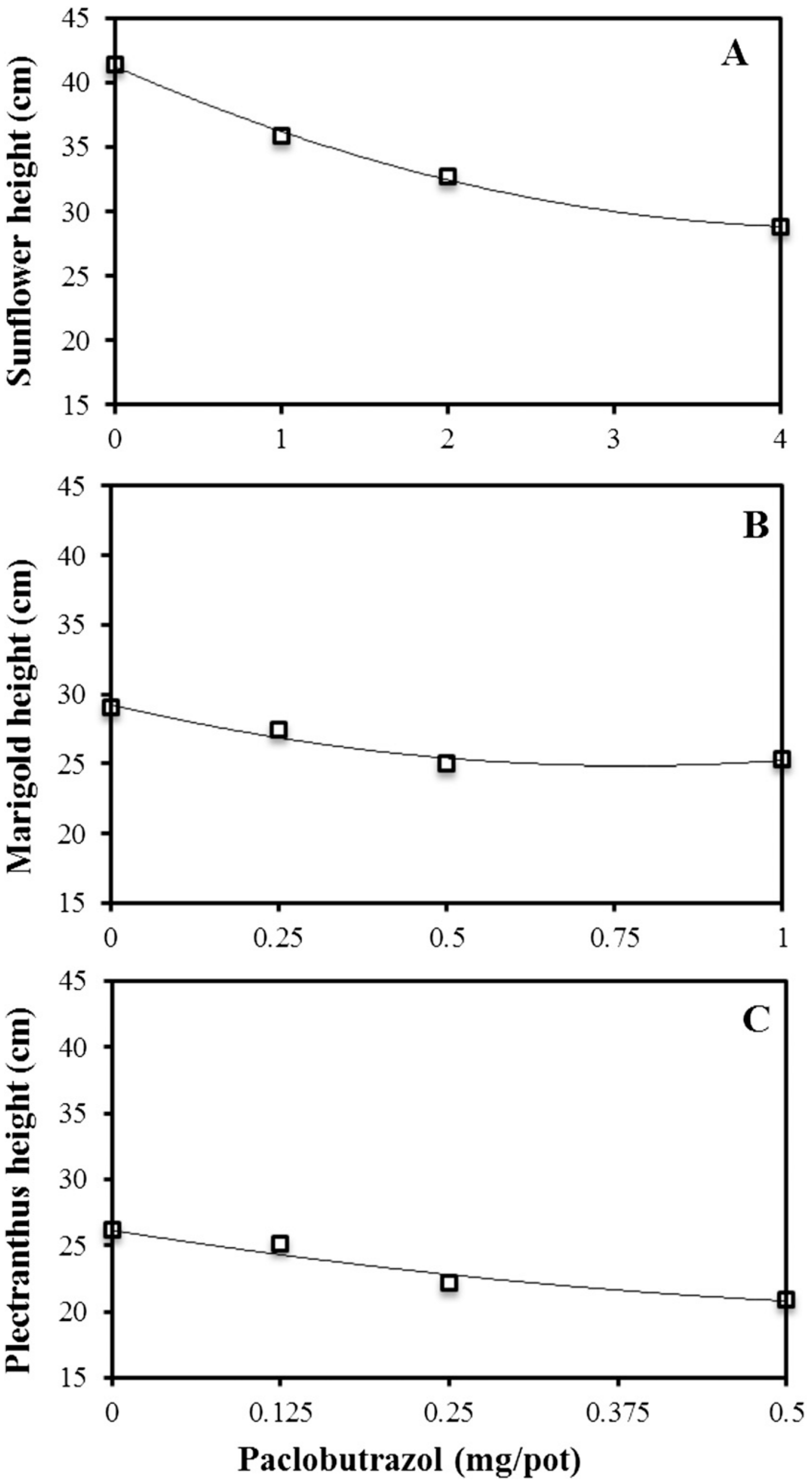

Fig. 2. Plant height of (A) sunflower, (B) marigold, and (C) plectranthus grown in a peat-based substrate amended with either perlite or pine wood chips at 10%, 20%, or 30% ratios (by volume) as influenced by paclobutrazol drench rate. Data were subjected to analysis of variance by the general linear model procedures and regression analysis. Due to lack of substrate effect ($P < 0.05$), data were pooled overall six substrates [sunflower (n = 48), marigold (n = 42), plectranthus (n = 42)]. The adjusted R^2 for sunflower, marigold, and plectranthus were 0.6982, 0.3178, and 0.1846, respectively. ^{NS}, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; L = linear, Q = quadratic. (A) Sunflower: $y = 0.65x^2 - 5.07x + 41.27$ L*, Q***; (B) marigold: $y = 7.35x^2 - 11.40x + 29.26$ L***, Q***; (C) plectranthus: $y = 55.94x^2 - 38.51x + 26.15$ L***, Q**; 1 mg = 3.5274×10^{-5} oz, 1 cm = 0.3937 inch.**

first sign of flower anthesis. At anthesis, the number of days from sowing, total plant height (measured at the substrate surface to the top of the bloom), plant width (measured widest width, turned 90°, and averaged), and inflorescence diameter (measured at the widest diameter, turned 90°, and averaged) were recorded for each plant. Shoots were cut at the substrate surface, dried at 70 °C for 1 week, and weighed.

EXPERIMENT 2. Except where indicated, procedures used in Expt. 2 were as described in Expt. 1. After formulation of the same six substrate ratios, dolomitic limestone was amended at the rate of 10 lb/yard^3. A lower amount of lime was incorporated to achieve the target pH of 5.8 as a result of exceeding the recommended pH range observed in Expt. 1. On 12 July, 5-week-old 'Anemone Safari Yellow' marigold (C. Raker and Sons, Litchfield, MI) plugs were transplanted into 5-inch-diameter plastic containers filled with each substrate. Terminal buds were pinched on 30 July and 8 and 17 Aug. to allow branching of lateral buds. Eighteen days after transplanting, 3 fl oz of solution containing 0.0, 0.25, 0.50, or 1.0 mg/pot paclobutrazol per 5-inch pot was applied to each container. On 11 Sept., a final GI was determined on all plants and shoots were cut at the substrate surface, dried at 70 °C for 1 week, and weighed.

EXPERIMENT 3. Except where indicated, procedures used in Expt. 3 were as described for Expt. 1. After formulation of the same six substrates described for Expt. 1, dolomitic limestone was amended at the rate of 10 lb/yard^3. On 20 July, 4-week-old 'Variegata' plectranthus plugs were transplanted into 6-inch-diameter plastic containers filled with each substrate described for Expt. 1. On 30 July, terminal buds were pinched to two nodes to allow lateral branching. On 14 Aug., 24 d after transplanting, 4 fl oz of solution containing 0.0, 0.125, 0.25, or 0.50 mg/pot paclobutrazol per 6-inch pot was applied to each container. On 13 Sept., a final GI was determined on all plants. Shoots were cut at the substrate surface, dried at 70 °C for 1 week, and weighed. Data were subjected to analysis of variance by the general

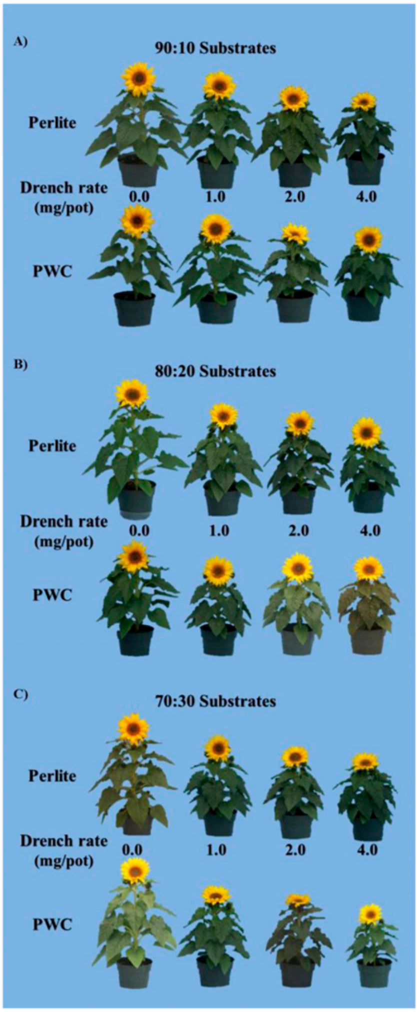

Fig. 3. Visual representation of 9-week-old sunflower plants grown in peat substrates amended with either (A) 10%, (B) 20%, or (C) 30% perlite or pine wood chip (PWC) aggregates (by volume) and treated with four paclobutrazol drench rates; 1 mg = 3.5274 × 10⁻⁵ oz.

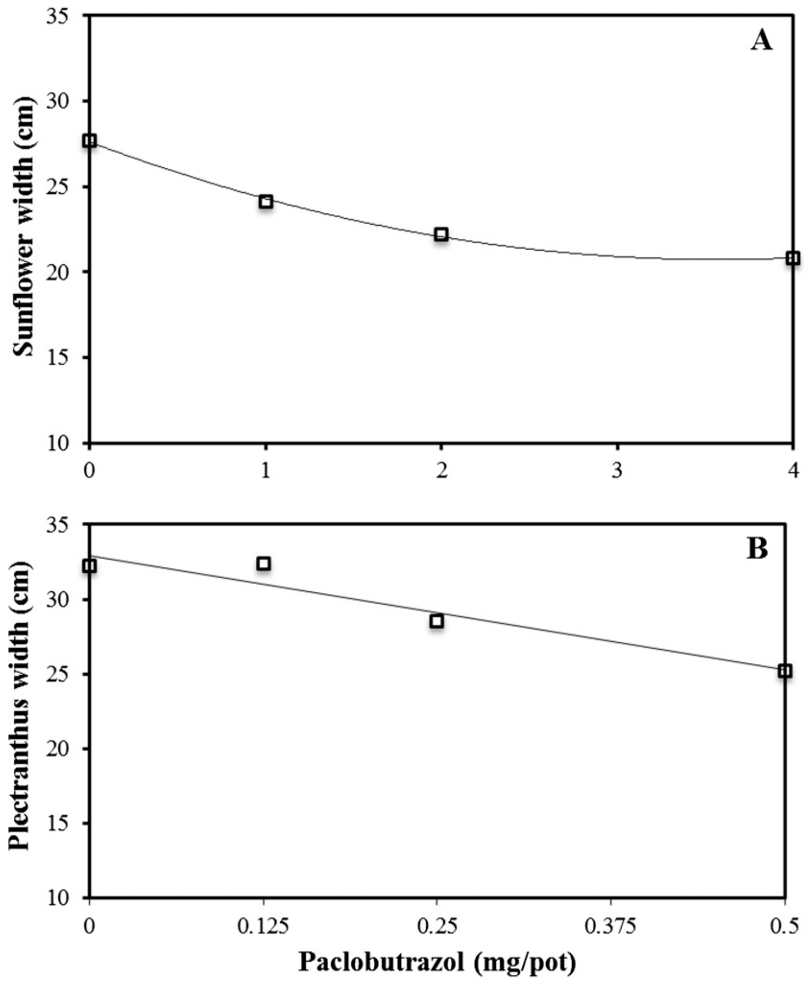

Fig. 4. Plant width of (A) sunflower and (B) plectranthus grown in a peat-based substrate amended with either perlite or pine wood chips at 10%, 20%, or 30% ratios (by volume) as influenced by paclobutrazol drench rate. Data were subjected to analysis of variance by the general linear model procedures and regression analysis. Due to lack of substrate effect ($P < 0.05$), data were pooled overall six substrates [sunflower (n = 48), plectranthus (n = 42)]. The adjusted R^2 for sunflower and plectranthus was 0.5476 and 0.2980, respectively. ^{NS}, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; L = linear, Q = quadratic. (A) Sunflower: $y = 0.55x^2 - 3.88x + 27.61$ L*, Q***; (B) plectranthus: $y = 45.24x^2 - 37.62x + 32.68$ L***, Q*; 1 mg = 3.5274×10^{-5} oz, 1 cm = 0.3937 inch.**

linear model procedures and regression analysis (version 9.4; SAS Institute, Cary, NC). Means were separated by least significant differences at $P \leq 0.05$.

Results

Plant height. Sunflower, marigold, and plectranthus heights were unaffected ($P < 0.05$) by substrate composition; therefore, plant height data for each species were pooled from all substrates before evaluating the effect of paclobutrazol rate on plant height. There was a quadratic relationship between sunflower height and paclobutrazol rate (Fig. 2A). Plant height was 13%, 20%, and 30% shorter than the untreated control for 1, 2, and 4 mg/pot rates, respectively (Fig. 3). A quadratic relationship was also found between marigold height and paclobutrazol rate (Fig. 2B). Plant height was 5%, 15%, and 13% shorter than the untreated control for 0.25, 0.50, and 1.0 mg/pot rates, respectively. No further height control occurred when concentration ≥0.5 mg paclobutrazol. Plectranthus height decreased as paclobutrazol concentration increased (Fig. 2C). Plant height was 3%, 18%, and 23% shorter than untreated control for 0.125, 0.25, and 0.50 mg/pot rates, respectively. Plectranthus height was similar at the untreated control and 0.125 mg/pot and similar at 0.25 and 0.50 mg/pot paclobutrazol.

Plant width. Plant width of sunflower and plectranthus was not influenced ($P < 0.05$) by substrate composition (aggregate type); therefore, plant width data for each species were pooled from all substrates before evaluating the effect of paclobutrazol rate on plant width. Plant width was 13%, 17%, and 24% smaller than the untreated control plants for 1, 2, and 4 mg/pot paclobutrazol, respectively, when applied to both perlite- and PWC-amended substrates (Fig. 4A). Marigold plant width was not influenced

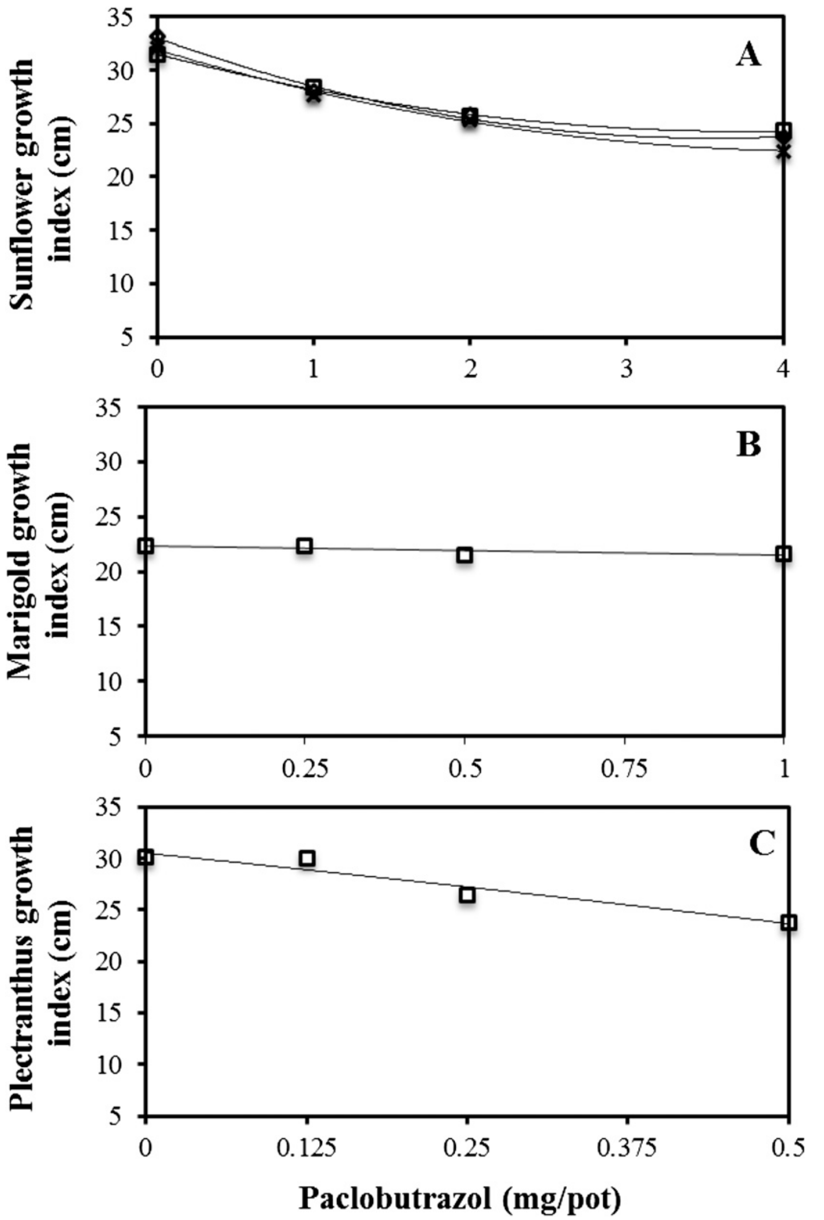

Fig. 5. Plant growth index {GI [(height + widest width + perpendicular width) ÷ 3]} of (A) sunflower grown in a peat-based substrate amended with either perlite or pine wood chips as influenced by aggregate percentage (10% = □, 20% = ×, 30% = ♦ by volume) and paclobutrazol drench rate. Data were subjected to analysis of variance by the general linear model procedures and regression analysis. Data were pooled over aggregate percentage and paclobutrazol drench concentration (n = 16). The adjusted R^2 was 0.6982, 0.7985, and 0.7884, respectively. Plant GI of (B) marigold and (C) plectranthus as influenced by paclobutrazol drenches. Data were pooled over paclobutrazol drench concentration [marigold (n = 14), plectranthus (n = 14)]. The adjusted R^2 for marigold and plectranthus was 0.0326 and 0.3038, respectively. ^{NS}, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; L = linear, Q = quadratic. (A) Sunflower 10%: $y = 0.51x^2 - 3.85x + 31.52$ L*, Q***; 20%: $y = 0.51x^2 - 4.41x + 31.93$ L***, Q***; 30%: $y = 0.73x^2 - 5.52x + 33.02$ L***, Q***; (B) marigold: $y = 0.41x^2 - 1.86 + 78.20$ L**, Q^{NS}; (C) plectranthus: $y = 48.78x^2 - 37.91 + 30.15$ L***, Q**; 1 cm = 0.3937 inch, 1 mg = 3.5274×10^{-5} oz.**

by aggregate type, percentage of aggregate, or paclobutrazol concentrations, respectively, over the course of the experiment (data not shown). The lack of differences may in part be due to the inflorescence removal that was conducted to facilitate plant branching during production. Plectranthus width decreased as paclobutrazol concentration increased. Plants treated with 0.25 and 0.50 mg/pot paclobutrazol were 9% and 20% smaller, respectively, than the untreated control plants (Fig. 4B). Plant width was 11% smaller between 0.25 and 0.50 mg/pot paclobutrazol. Substrate drenches ≥0.25 mg/pot paclobutrazol concentration produced the smallest-diameter plants.

GROWTH INDEX. Sunflower GI was unaffected by aggregate type, but there was a quadratic relationship between the percentage of perlite- or PWC-amended substrates and paclobutrazol concentration; therefore, GI data were pooled and analyzed. Paclobutrazol drenches of 1, 2, and 4 mg/pot applied to plants grown in substrates containing either 10% perlite or PWC, controlled sunflower growth and were 12%, 19%, and 22% less than the untreated control, respectively (Fig. 5A). Paclobutrazol drenches of 1, 2, and 4 mg/pot applied to plants grown in substrates containing either 20% perlite or PWC, controlled plant growth and were 14%, 21%, and 30% less than the untreated control, respectively. Paclobutrazol drench of 1, 2, and 4 mg/pot applied to plants grown in substrates containing either 30% perlite or PWC, controlled plant growth and were 16%, 21%, and 27% less than the untreated control, respectively.

Marigold and plectranthus growth followed similar trends when drenched with paclobutrazol. Marigold plant GI was similar between the untreated control and 0.25 mg/pot and between 0.50 and 1.0 mg/pot paclobutrazol concentrations (Fig. 5B). There was 4% less plant growth for plants treated with 0.50 and 1.0 mg/pot paclobutrazol concentrations; therefore, substrate drenches ≥ 0.50 mg/pot paclobutrazol concentration produced the smallest plants. Plectranthus GI was similar at the untreated control and 0.125 mg/pot paclobutrazol and significantly different at 0.25 and 0.50 mg/pot paclobutrazol concentrations (Fig. 5C). There was 14% and 21% less growth for plectranthus plants treated with 0.25 and 0.50 mg/pot paclobutrazol concentrations, compared with the untreated control and 0.125 mg/pot paclobutrazol.

SHOOT DRY WEIGHT. Sunflower shoot dry weight was not significantly influenced by aggregate type; therefore, shoot dry weight data were

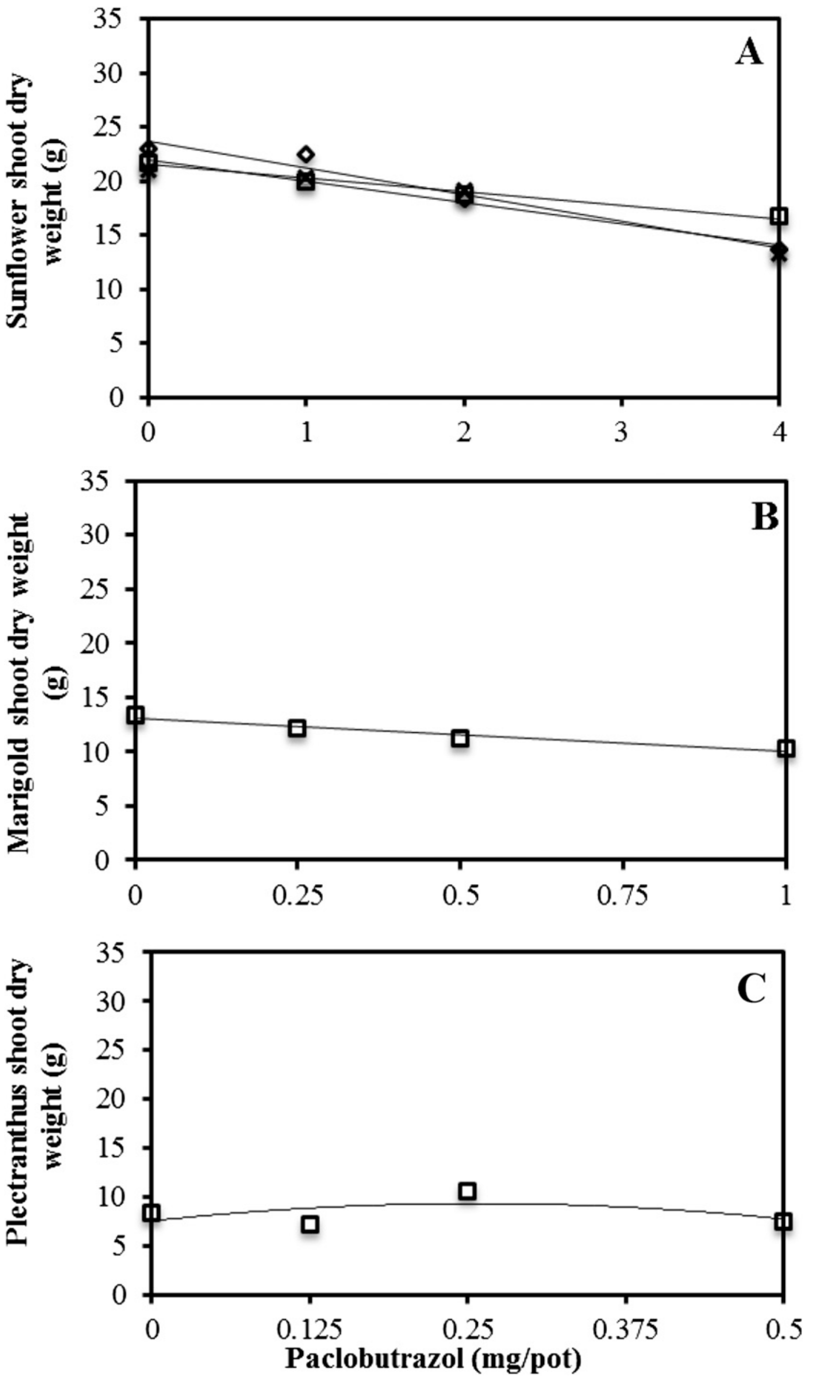

Fig. 6. Shoot dry weight of potted (A) sunflower as influenced by perlite or pine wood chip aggregate percentage (10% = □, 20% = ×, 30% = ♦ by volume) and paclobutrazol drench rate. Data were subjected to analysis of variance by the general linear model procedures and regression analysis. Data were pooled over aggregate percentage and paclobutrazol drench concentration (n = 16). The adjusted R^2 was 0.1853, 0.3950, and 0.4188, respectively. Shoot dry weight (B) marigold and (C) plectranthus as influenced by paclobutrazol drenches. Data were pooled over paclobutrazol drench concentration [marigold (n = 14), plectranthus (n = 14)]. The adjusted R^2 for marigold and plectranthus was 0.1952 and 0.1196, respectively. ^{NS}, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; L = linear, Q = quadratic. (A) Sunflower 10%: $y = 1.72x - 21.60$ L*, Q^{NS}; 20%: $y = 1.80x - 21.90$ L***, Q^{NS}; 30%: $y = 2.50x + 23.73$ L***, Q^{NS}; (B) marigold: $y = 3.03x - 13.11$ L***, Q^{NS}; (C) plectranthus: $y = 57.99x^2 - 28.97x + 7.53$ L***, Q***; 1 mg = 3.5274×10^{-5} oz, 1 g = 0.0353 oz.**

pooled and analyzed by the aggregate percentage and paclobutrazol concentration. There was a significant linear relationship between percentage of perlite- and PWC-amended substrates and paclobutrazol concentrations. Shoot dry weights were similar between the untreated control and 1 mg/pot paclobutrazol concentrations and lower at 2 and 4 mg/pot paclobutrazol concentrations. Shoot dry weight of plants grown in 10% perlite- and PWC-amended substrates were 7%, 12%, and 21% smaller than the untreated control for 1, 2, and 4 mg/pot paclobutrazol, respectively (Fig. 6A). Shoot dry weight of plants grown in 20% perlite- and PWC-amended substrates were 8%, 13%, and 38% smaller than untreated control for 1, 2, and 4 mg/pot paclobutrazol, respectively. Shoot dry weight of plants grown in 30% perlite- and PWC-amended substrates were 1%, 25%, and 40% smaller than untreated control for 1, 2, and 4 mg/pot paclobutrazol, respectively. Similar to GI, shoot dry weight was less in substrates amended with 10% perlite or PWC.

Marigold and plectranthus shoot dry weights were not influenced by aggregate type or percentage; therefore, shoot dry weight data were pooled and analyzed by paclobutrazol concentration. For marigold shoot dry weights, there was a linear relationship among all paclobutrazol concentrations. Shoot dry weights were 11%, 15%, and 21% less than the untreated control for 0.25, 0.50, and 1.0 mg/pot paclobutrazol, respectively (Fig. 6B). Differences occurred in marigold shoot dry weights among all paclobutrazol concentrations. Dry weights of plectranthus were similar among the 0.0, 0.125, and 0.50 mg/pot paclobutrazol treatments, respectively (Fig. 6C). However, shoot dry weights were 32% larger between the untreated control and 0.25 mg/pot paclobutrazol drench application occurred.

The results of the shoot dry weight data were inconclusive. For potted sunflower, there was more control as the percentage of aggregates (perlite and PWC) increased at the highest paclobutrazol drench concentration. Marigold followed the expected trend of less dry weight accumulation as the paclobutrazol drench concentration rate increased.

Plectranthus plants followed the opposite trend in dry weight accumulation with a slightly higher dry weight for the 0.125 mg/pot.

DAYS TO ANTHESIS. Days to anthesis of 'Pacino Gold' sunflower were not influenced by aggregate type and percentage; therefore, data were pooled and analyzed by paclobutrazol rate. The mean number of days to anthesis was 78 d for the untreated control and was 80, 80, and 79 d for the 1, 2, and 4 mg/pot paclobutrazol concentrations, respectively. Results were similar to those reported earlier by Dasoju and Whipker (1997) with a mean of 75 d to flowering for 'Pacino' sunflower. Although there were differences between days to anthesis and paclobutrazol concentration, the difference of 2 d would not seem commercially important.

Discussion

This research demonstrates that PWC can be used from 10% to 30% (by volume) in greenhouse substrates as a perlite replacement without affecting paclobutrazol activity. Similar drench concentration of paclobutrazol applied to 10%, 20%, and 30% perlite- and PWC-amended substrates controlled plant height, and shoot GI of sunflower, marigold, and plectranthus. Trends with respect to shoot dry weights of sunflower and marigold also followed the similar trends of greater control as paclobutrazol concentration increased. Days to anthesis for sunflower plants were influenced by increased paclobutrazol concentrations; however, the difference in days of the untreated control and drenched plants would not be commercially significant.

Similar container capacities of each substrate amended with all rates of perlite or PWC (data not shown) suggest similar paclobutrazol drench solutions were available for plant uptake rather than leached from the containers/substrates. Substrate solution pH range and electrical conductivity levels were within the recommended range. This provides additional support that sunflower, marigold, and plectranthus can be grown successfully in peat-based substrates amended with PWC.

The evaluation of 30% wood chips in comparison with perlite in a peat-based substrate is considered to be the upper end of commercial/practical aggregate usage for most greenhouse crops. It is unknown whether PWC percentages > 30% would result in decreased paclobutrazol activity. Million et al. (1998a) reported that increased percentages of composted PB (up to 60%) decreased the efficacy of PGRs, but it is thought that at higher percentages (>30%), other factors (porosity, nutrient immobilization, etc.) would likely decrease plant growth independent of PGR activity. Numerous other studies have also reported reduced PGR drench efficacy when organic materials including aged PB are used as substrate components (Barrett, 1982; Bonaminio and Larson, 1978; Million et al., 1998b; Newman and Tant, 1995; Tschabold et al., 1975). Adsorption or binding of PGR molecules onto nonpolar, hydrophobic surfaces of PB has been suggested as a reason for reduced activity (Barrett 1982; Burchill et al., 1981). The chemistry and physical nature of fresh pine wood particles are also likely much different from that of PB (or any other organic or inorganic substrate component), which is also a likely explanation for why paclobutrazol efficacy changes in the presence of different organic components in horticultural substrates.

Commercially, PWC should be usable in greenhouse substrates as a perlite substitute (<30%) without concern of reduced paclobutrazol efficacy. Additionally, PWC are likely cheaper than perlite (based on current wood availability and pricing), while using a sustainable, local material of the southeastern United States. Aggregates of PWC are blockular (cubed-shaped), consistent in size, and mix well with peat. Therefore, mixing substrates and filling pots and flats with PWC-amended substrates should work well without the dust problems associated with perlite. When replacing perlite with PWC, there are no recommended changes in production practices and growers should expect similar plant PGR response and crop quality.

Pine wood chips are engineered and processed to specific sizes and shapes to be functional as aggregates in a container substrate. Not all wood components are designed, or capable of improving/influencing the physical behavior of a substrate the same. There are various methods and processes for making wood substrate components with some being more fibrous than others which would likely change the resulting properties (chemical, physical, and biological) when amended with peat in a substrate. Based on the known variability of many wood components being developed, commercialized, marketed, and sold today, it is highly suggested that any and all substrate wood components not be considered the same, and be tested/trialed before large-scale use.

Literature cited

Argo, W.R. and P.R. Fisher. 2002. Understanding pH management for container-grown crops. Meister Publ., Willoughby, OH.

Barrett, J.E. 1982. Chrysanthemum height control by ancymidol, PP333, and EL500 dependent on medium composition. HortScience 17:896–897.

Barrett, J.E. 2001. Mechanisms of action, p. 32–41. In: M.L. Gaston, P.S. Konjoian, L.A. Kunkle, and M.F. Wilt (eds.). Tips on regulating growth of floriculture crops. OFA Serv., Columbus, OH.

Barrett, J.E. and C.A. Burtuska. 1982. Effects on stem elongation dependent on site of application. HortScience 17:737–738.

Barrett, J.E. and T.A. Nell. 1989. Comparison of paclobutrazol and uniconazole on floriculture crops. Acta Hort. 251:275–280.

Barrett, J.E., J. Boldt, and C.A. Bartuska. 2009. Factors affect activity of PGR substrate applications. Greenhouse Product News 19(7):38–44.

Blanchard, M.G. and E.S. Runkle. 2007. Dipping bedding plant liners in paclobutrazol or uniconazole inhibits subsequent stem extension. HortTechnology 17:178–182.

Bonaminio, V.P. and R.A. Larson. 1978. Influence of potting media, temperature, and concentration of ancymidol on growth of *Chrysanthemum morifolium* 'Ramat'. J. Amer. Soc. Hort. Sci. 103:752–756.

Bugbee, G.J., C.R. Frink, and D. Migneault. 1991. Growth of perennials and leaching of heavy metals in media amended with a municipal leaf sewage sludge and street sand compost. J. Environ. Hort. 9:47–50.

Burchill, S., M.H.B. Hayes, and D.J. Greenland. 1981. Adsorption, p. 221–400. In: D.J. Greenland and M.H.B. Hayes (eds.).

The chemistry of soil process. Wiley, New York, NY.

Chong, C. and G.P. Lumis. 2000. Mixtures of paper mill sludge, wood chips, bark, and peat in substrates for pot-in-pot shade tree production. Plant Sci. 80:669–675.

Criley, R.A. and R.T. Watanabe. 1974. Response of chrysanthemum in four soilless media. HortScience 9:385–386.

Dasoju, S. and B.E. Whipker. 1997. Efficacy of paclobutrazol drenches on growth of potted sunflowers grown in 16.5-cm pots. HortScience 32:438 (abstr.).

Dasoju, S., M.R. Evans, and B.E. Whipker. 1998. Paclobutrazol drench activity in coir- and peat-based root substrates. HortTechnology 8:595–598.

Davis, T.D., F.L. Steffans, and N. Sankhla. 1988. Triazole plant growth regulators. Hort. Rev. 10:63–105.

Dueitt, S., J. Howell, and S.E. Newman. 1993. Rice hulls as a vermiculite substitute in peat-based media for growing greenhouse bedding plants. Proc. Southern Nursery Assn. Res. Conf. 38:62–63.

Evans, M.R. 2004a. Ground bovine as a perlite alternative in horticultural substrates. HortTechnology 14:171–175.

Evans, M.R. 2004b. Processed poultry feather fiber as an alternative to peat in greenhouse crops substrates. HortTechnology 14:176–179.

Evans, M.R. and M. Gachukia. 2004. Fresh parboiled rice hulls serve as an alternative to perlite in greenhouse crop substrates. HortScience 39:232–235.

Evans, M.R. and R.L. Harkess. 1997. Growth of *Pelargonium* x*hortorum* and *Eurphorbia pulcherrima* in rubber-containing substrates. HortScience 32:874–877.

Fonteno, W.C., C.T. Harden, and J.P. Brewster. 1995. Procedures for determining physical properties of horticultural substrates using the NC State University porometer. North Carolina State Univ., Hort. Substrates Lab., Raleigh, NC.

Gent, M.P. and R.J. McAvoy. 2000. Plant growth retardants in ornamental horticulture, p. 89–146. In: A.S. Basara (ed.). Plant growth regulators in agriculture and horticulture: Their role and commercial uses. Food Products Press, Binghamton, NY.

Lopez, R.G., C.J. Currey, D.M. Camberato, and A.P. Torres. 2010. Plant growth retardant drench efficacy is not affected by substrate containing parboiled rice hulls. HortTechnology 20:863–866.

Million, J.B., J.E. Barrett, T.A. Nell, and D.G. Clark. 1998a. Influence of media components on efficacy of paclobutrazol in inhibiting growth of broccoli and petunia. HortScience 33:852–852.

Million, J.B., J.E. Barrett, T.A. Nell, and D.G. Clark. 1998b. Influence of pine bark on the efficacy of different growth retardants applied as a drench. HortScience 33:1030–1031.

Nelson, P.V. 2012. Greenhouse operation and management. 7th ed. Prentice Hall, Upper Saddle River, NJ.

Newman, S.E. and J.S. Tant. 1995. Rootzone medium influences growth of poinsettia treated with paclobutrazol-impregnated spikes and drenches. HortScience 30:1403–1405.

Owings, A.D. 1993. Cotton gin trash as a medium component in production of 'Golden Bedder' coleus. Proc. Southern Nursery Assn. Res. Conf. 38:65–66.

Quarrels, J.R. and S.E. Newman. 1994. Pine bark levels and particle size influence the activity of paclobutrazol and uniconazole on 'Freedom' and 'Gutbier V-14 Glory' poinsettias. HortScience 29:737 (abstr.).

Rosen, C.J., T.R. Halbach, and B.T. Swanson. 1993. Horticultural uses of municipal solid waste composts. HortTechnology 3:167–173.

Tschabold, E.E., W.C. Meredith, L.R. Gruse, and E.V. Krumkalns. 1975. Ancymidol performance as altered by potting media composition. J. Amer. Soc. Hort. Sci. 100:142–144.

Whipker, B.E. and I. McCall. 2000. Response of potted sunflower cultivars to daminozide foliar sprays and paclobutrazol drenches. HortTechnology 10:209–211.

Whipker, B.E. 2015. Plant growth regulator guide. GrowerTalks Mag., Ball Publ., West Chicago, IL.