6. Henny, R.J. 1985. BA induces lateral branching of *Peperomia obtusifolia*. HortScience 1:115–116.

7. Holland, A.S., G.J. Keever, J.R. Kessler, and F. Dane. Single cyclanilide applications promote branching of woody ornamentals. J. Environ. Hort. 25:139–144.

8. Holland, A.S., G.J. Keever, J.R. Kessler, Jr., and F. Dane. 2007. Multiple cyclanilide applications promote branching of woody ornamentals. J. Environ. Hort. 25:191–196.

9. Keever, G.J. 1994. BA-induced offset formation in hosta. J. Environ. Hort. 12:36–39.

10. Keever, G.J. and W.J. Foster. 1990. Chemically induced branching of woody landscape plants. J. Environ. Hort. 8:78–82.

11. Mok, D.S. and M.C. Mok. 1994. Cytokinins: Chemistry, Activity, and Function. CRC Press, Boca Raton, FL.

12. Morris, G.C. and C.A. Harrington. 2007. Apical dominance and apical control in multiple flushing of temperate woody species. Can. J. Forest Res. 37:74–83.

13. Pedersen, M.K., J.D. Burton, and H.D. Coble. 2006. Effect of cyclanilide, ethephon, auxin transport inhibitors and temperature on whole plant defoliation. Crop Sci. 46:1666–1672.

14. USDA, National Agricultural Statistics Service. 2009. 2009 Census of Horticultural Specialties. Accessed February 9, 2011. http://www.agcensus.usda.gov.

15. Vander Woude, S. 2002. Early pruning equals more dollars. NM Pro 18(6):57–58.

16. Williamson, Z., G.J. Keever, J.R. Kessler, and J.W. Olive. 2009. Drench application of cyclanilide promotes shoot development in containerized woody landscape species during nursery production. J. Environ. Hort. 27:217–222.

Use of Ground Miscanthus Straw in Container Nursery Substrates[1]

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Abstract

Pine bark (PB) is the primary component in nursery substrates in the United States. Availability of pine bark is decreasing and price is increasing. The objective of this research was to determine if miscanthus straw (MS) can replace all or part of the pine bark fraction in nursery container substrates. Five substrates were created that contained 15% sphagnum peatmoss, 5% municipal solid waste compost, and the remaining 80% consisted of one of the five following PB:MS ratios: 0:80, 20:60, 40:40, 60:20, and 80:0. Luna Red hibiscus (*Hibiscus moscheutos*) were grown in each substrate and evaluated for eight weeks in a greenhouse. Ground MS increased air space and decreased container capacity and bulk density as its concentration in the substrate increased. Additions of MS did not affect hibiscus chlorophyll content, and had negligible effects on hibiscus foliar nutrient levels. Increasing levels of MS caused a decrease in plant shoot dry weight, although growth reduction was most pronounced with 80% MS. Ground MS has potential to be a suitable substrate for nursery growers, however, some changes to management practices will be necessary.

Index words: container substrate, pine bark, miscanthus, nursery crops.

Significance to the Nursery Industry

Pine bark is the primary component of substrates used in outdoor container production. External market forces have caused availability of pine bark to decrease, while costs have increased. The objective was to determine if ground miscanthus (*Miscanthus ×giganteus*) straw (MS) could be used to replace all or part of the pine bark fraction in container substrates. We found that MS made a suitable substrate for production of 'Luna Red' hibiscus over an 8 week period, so long as at least 20% of the substrate volume remained PB. Considering substrates with 20 to 60% MS, pH were moderate and plants were of high quality, comparable foliar color, and similar size compared plants growing in substrates with no MS. Amendment with sphagnum peat moss and compost are necessary for moderation of MS physical properties and substrate pH.

Introduction

Nursery-grown trees, shrubs, and some herbaceous perennials are traditionally produced outdoors in containers filled with a soilless substrate composed of 60 to 80% (v/v) pine bark, 10 to 20% sphagnum peatmoss, 0 to 10% compost, 0 to 10% sand, and sometimes smaller proportions of other materials. Over the past five years, availability of pine bark has decreased and cost has increased. Pine bark is primarily generated by paper and lumber mills in the southern United States. Decrease in demand for forest products, coupled with increased use of pine bark as a fuel source at paper and lumber mills, has caused a decline in pine bark inventories available for horticultural use. Pine bark is also being diverted to biomass or bioenergy uses. Increasing demand for wood-based ethanol over the next 20 years will result in even greater competition for pine bark and other woody biomasses (3). Development of alternatives to pine bark for use in container nursery production is important for stability in the U.S. nursery industry.

One of several possible alternatives to pine bark is the use of agronomic biomass materials. Most nursery producing regions in the United States also produce agronomic crops on large acreage. Altland and Krause (2) have shown that agronomical-grown switchgrass could be used as an alternative to pine bark for production of roses. Giant miscanthus (*Miscanthus ×giganteus*) is a sterile, rhizome-propagated grass that is currently being grown for its biofuel potential. Giant miscanthus has been shown to produce greater biomass per acre than switchgrass, which should reduce the cost per ton of biomass produced. Kresten Jensen et al. (7) reported that English ivy (*Hedera helix* L.) grew well in composted miscanthus (*Miscanthus ogiformis*) substrates, although dry matter accumulation was greater in peat-based substrates. Dresboll and Thorup-Kristensen (4) assessed the suitability of miscanthus clippings for use as a container substrate by measuring various physical properties of this material and other composted crop residues. Their (4) research did not include plant evaluations and their findings were generally inconclusive; however, they did document differences between wheat straw, hemp straw, and miscanthus straw with respect to water holding capacity and moisture characteristic curves. The objective of this research was to determine if all or part of pine bark (PB) could be replaced by ground miscanthus straw (MS) in container substrates for short-production cycle crop.

Materials and Methods

Miscanthus straw was obtained from the University of Illinois Energy Biosciences Institute (Urbana, IL). The straw was baled in early Spring 2009 and stored in a barn until needed. Ground MS was generated by passing baled miscanthus through a hammermill (NO. 30 with blower discharge, The C.S. Bell Co., Tiffin, OH) equipped with a 0.48 cm (0.188 in) screen. Ground pine bark (PB) was obtained from a commercial source (Fafard). Particle size distribution was determined by passing approximately 100 cm^3 oven dried [72C (162F)] MS and PB through 19.0, 12.5, 6.30, 4.0, 2.8, 2.0,1.4, 1.0, 0.71, 0.50, 0.35, 0.25, 0.18, and 0.11 mm (0.75, 0.5, and 0.25 in, and nos. 5, 7, 10, 14, 18, 25, 35, 45, 60, 80, and 140) soil sieves (Table 1). Particles ≤ 0.11 mm (no. 140 screen) were collected in a pan. Sieves and pan were shaken for 3 min with a RX-29/30 Ro-Tap® test sieve shaker (278 oscillations·min^{-1}, 150 taps·min^{-1}) (W.S. Tyler, Mentor, OH). Initial moisture content of PB and MS was determined as the mass of water to substrate (Table 1).

Table 1. Particle size distribution of pine (*Pinus taeda*) bark and hammermilled miscanthus (*Miscanthus ×giganteum*) straw used in container substrates.

Sieve size	Pine bark	Miscanthus	Significance
(mm)		%	
6.3	11.7	0.0	***
4.0	15.9	0.1	***
2.8	12.8	1.5	***
2.0	9.4	7.0	***
1.4	9.8	22.2	***
1.0	7.7	18.3	***
0.7	7.5	13.8	***
0.5	7.3	12.0	***
0.4	5.7	8.5	***
0.3	5.0	5.2	
0.2	2.9	2.9	
0.1	2.6	3.3	
<0.1	1.6	5.1	*
Moisture content	55.0%	8.0%	***

*, **, *** denote significant differences between pine bark and miscanthus straw at each sieve size where $P < 0.05$, 0.01, and 0.001.

Pine bark and MS were used to create five substrate blends. All substrates contained 15% sphagnum peatmoss and 5% municipal solid waste compost (Technagro, Kurtz Bros., Akron, OH) with the remaining 80% consisting of one of the five following PB:MS ratios: 0:80, 20:60, 40:40, 60:20, and 80:0. All substrates were amended with 0.9 kg·m^{-3} (1.5 lb·yd^{-3}) Micromax (The Scotts Co., Marysville, OH) micronutrients and 1.2 kg·m^{-3} (2 lb·yd^{-3}) gypsum ($CaSO_4$). Substrates were used to fill 2.9 liter (trade gallon) plastic containers and potted with Luna Red hibiscus (*Hibiscus moscheutos* L. 'Luna Red') that were approximately 7 cm (2.8 in) tall and 9 cm (3.5 in) wide at planting. A controlled release fertilizer (Osmocote 18-6-12 Classic, The Scotts Co.) was applied at 20 g (0.7 oz) per container, and dibbled immediately beneath the hibiscus liners prior to transplanting. Plants were potted November 16, 2009, and placed in a glass greenhouse supplemented with sodium vapor lights providing 13 h of lighting from 6:00 am to 7:00 pm. Thermostat heat and cool points were set at 21 and 27C (70 and 81F), respectively. There were eight single plant replications per treatment arranged in completely randomized design.

Substrate physical properties were determined for each substrate mix prior to transplanting. Substrates were packed in aluminum (Al) cores [7.6 cm (3 in) tall by 7.6 cm (3 in) i.d.] according to methods described by Fonteno and Bilderback (6). There were three replications for each substrate. Aluminum cores were attached to North Carolina State University Porometers™ (Horticultural Substrates Laboratory, North Carolina State University, Raleigh, NC) for determination of air space (AS). Cores were weighed, oven dried for four days at 72C (162F), and weighed again to determine container capacity (CC). Total porosity (TP) was calculated as the sum of AS and CC. Bulk density (D_b) was determined using oven dried [72C (162F)] substrate in Al cores. Substrate pH was measured using the pour-through procedure at 1, 2, 4, 6, and 8 weeks after transplanting (WAT). Foliar chlorophyll content was measured with a SPAD 502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ) 1, 2, 4, 6, and 8 WAT, by averaging five readings per plant. Foliar samples were harvested (9) at the conclusion of the experiment by first rinsing with deionized water then drying at 72C (162F) for 3 d. Samples were ground in a Tecator Cyclotec mill (Tecator AB, Hogenas, Sweden) through a 0.5 mm (0.02 in) screen. Foliar N was determined with a Vario Max CN analyzer (Elementar Americas, Mt. Laurel, NJ). Other macronutrients and micronutrients were determined with a Thermo Iris Intrepid ICP-OES (Thermo Fisher Scientific, Waltham, MA). Growth was determined at the conclusion of the experiment by measuring shoot dry weight (SDW) and rating the root system on a scale from 0 to 10 where 0 = no roots present on the substrate container interface and 10 represents complete root coverage of the substrate-container interface.

The experiment was repeated beginning January 21, 2010. Pine bark and MS were obtained from the same source as the first experiment. Substrate physical properties and the

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Table 2. Physical properties of substrates comprised of 15% sphagnum peat moss, 5% municipal solid waste compost, and the remaining 80% comprised of varying ratios of pine (*Pinus taeda*) bark and miscanthus (*Miscanthus xgiganteum*) straw.

		Experiment 1^z				Experiment 2			
Pine bark	Miscanthus straw	AS	CC	TP	D_b	AS	CC	TP	D_b
		(%)			($g\cdot cm^{-3}$)	(%)			($g\cdot cm^{-3}$)
0	80	46	44	90	0.09	39	48	88	0.09
20	60	37	53	90	0.10	33	52	85	0.10
40	40	38	48	86	0.14	31	57	88	0.13
60	20	30	53	84	0.17	26	56	82	0.16
80	0	26	55	81	0.19	24	57	81	0.18
LSD^y		6	6	3	0.01	7	8	5	0.00
Trend^x		L***	L***	L***	L***	L***	L**	L***	L***Q*

^{z}AS, CC, TP, and D_b refer to air space, container capacity, total porosity, and bulk density, respectively.

^{y}LSD refers to Fisher's least significant difference value where $\alpha = 0.05$.

^{x}Trend refers to the linear (L) or quadratic (Q) rate response to changing pine bark and miscanthus straw ratios.

*, **, *** denote significant regression response where $P < 0.05$, 0.01, and 0.001, respectively.

eight-week growth experiment with hibiscus were repeated similar to the previous trial. Hibiscus liners in this second trial were larger at the time of transplanting, approximately 18 cm tall and 20 cm wide.

Data from both experiments were subjected to analysis of variance (ANOVA), and repeated measures ANOVA where data were measured more than once over time. Regression analysis, via orthogonal contrast statements, was used to determine if there were significant linear or quadratic rate responses in each measured parameter to PB:MS ratios. Fisher's least significant difference is presented for each parameter in order to make treatment comparisons. All data were analyzed with SAS 9.1 (SAS Institute Inc., Cary, NC).

Results and Discussion

Pine bark and MS had different particle size distributions (Table 1). Drzal et al. (5) and Puustjarvi and Robertson (12) separated soilless substrates into three classes; course [> 2.0 mm (0.08 in)], medium [0.5 to 2.0 mm (0.02 to 0.08 in)], and fine [< 0.5 mm (0.02 in)]. By this convention, PB used in these trials had more coarse particles, fewer medium particles, and a similar quantity of fine particles compared to MS [with the exception of particles sized 0.4 and < 0.1 mm (0.015 and < 0.004 in)]. Miscanthus straw used in these experiments had lower moisture content than PB. Initial moisture content for MS observed in these studies would be typical of baled straw materials.

Air space decreased and CC increased linearly with increasing levels of PB (Table 2). Yeager et al. (14) suggest that substrates with 10 to 30% AS and 45 to 65% CC are ideal. According to these standards, substrates with 40% or more MS had higher than ideal AS in both experiments. However, research by Ownley et al. (11) showed that substrates with higher AS (25 to 36%) reduced the incidence of Phytophthora root rot (*Phytophthora cinnamomi* Rands.). All substrates with the exception of 80% MS in Experiment 1 had sufficient CC according to standards by Yeager et al. (14). Bulk density increased linearly with increasing levels of PB, owing to the higher D_b of pure PB [~0.18 $g\cdot cm^{-3}$ (11.2 $lb\cdot ft^{-3}$)] compared to pure MS [~ 0.07 $g\cdot cm^{-3}$ (4.4 $lb\cdot ft^{-3}$)]. Substrates composed of 80% PB had twice the D_b of those with 80% MS.

Substrate pH increased over time for all treatments (Table 3). For both studies, repeated measures analysis showed a significant effect of time (P = 0.0001) on substrate pH, but not an interaction between time and treatment. This indicates the change in pH over time was similar among treatments. Substrate pH decreased linearly with increasing PB fraction at 1, 4, and 8 WAT in both experiments. Throughout both experiments, there was less than 1 pH unit difference between 0 and 80% PB. While the effect of increasing PB resulted in a significant linear pH response, the overall change in pH was not horticulturally significant. Previous research has shown that amendment with sphagnum peat moss and municipal solid waste compost lowers and buffers pH of grass-based substrates (2). Although specific pH ranges have been established for some woody and herbaceous crops (10, 13), the range of substrate pH observed in these experiments would be suitable for most crops.

Foliar SPAD chlorophyll readings were not affected by PB:MS treatment in either experiment (data not shown). SPAD chlorophyll readings averaged 28.2 across treatments at 1 WAT, and increased to 35 by 8 WAT, but were similar among treatments within each date.

Foliar nutrient content was affected by PB:MS ratio (Table 4). All foliar nutrients were in greater concentration for Experiment 1 compared to Experiment 2, with the exception of Mg and Fe. Plants were larger at the beginning and end of Experiment 2 (Table 3), thus it's possible that similar fertilizer rates applied to both experiments were diluted in larger plants of Experiment 2. While no specific recommendations for foliar nutrition of *H. moscheutos* could be found, McGinnis et al. (8) reported the following nutrient concentrations [calculated as the ratio of nutrient mass (mg) to leaf dry weight (g)] for *H. moscheutos* growing in a well-fertilized pine bark substrate: 1.9% N, 0.12% P, 2.5% K, 1.6% Ca, 0.58% Mg, 0.18% S, 36 $\mu g\cdot g^{-1}$ (36 ppm) B, 221 $\mu g\cdot g^{-1}$ (221 ppm) Fe, $\mu g\cdot g^{-1}$ (403 ppm) Mn, 9.5 $\mu g\cdot g^{-1}$ (9.5 ppm) Cu, and $\mu g\cdot g^{-1}$ (128 ppm) Zn. Relative to hibiscus in the referenced study (8), all nutrients in our study were similar or higher in concentration, with the exception of Fe. Foliar N did not respond to PB:MS ratio in either experiment, and was greater than twice the concentration reported by McGinnis et al. (8) when averaged across treatments. All other nutrients responded linearly or quadratically to PB:MS ratio, although absolute differences in treatments were relatively minor and caused no observable symptoms of nutrient deficiency or toxicity.

Table 3. Substrate pH of containers filled with substrates comprised of 10% sphagnum peat moss, 10% municipal solid waste compost, and the remaining 80% one of four combinations of pine bark and miscanthus straw (MS).

Experiment	Pine bark	Miscanthus straw	1 WAT^z	4 WAT	8 WAT	Shoot dry weight (g)	Root rating
1	0	80	5.6	6.2	6.2	8.6	4.7
	20	60	5.3	5.9	6.0	11.2	5.9
	40	40	5.1	5.7	5.8	11.7	6.3
	60	20	5.3	5.9	5.7	12.7	6.1
	80	0	5.1	5.6	5.4	12.0	6.6
	Trend^y		L***Q***	L***Q*	L***	L***Q*	L***
	LSD^x		0.1	0.2	0.3	2.0	0.8
2	0	80	6.1	6.7	6.6	15.1	5.3
	20	60	5.8	6.5	6.4	17.3	6.0
	40	40	5.5	6.1	5.5	16.9	6.3
	60	20	5.3	5.9	5.8	18.5	6.4
	80	0	5.3	6.1	5.9	20.4	6.4
	Trend		L***Q***	L***Q***	L***Q***	L***	L**
	LSD		0.1	0.1	0.2	2.1	0.7

^{z}WAT refers to weeks after transplanting.

^{y}Trend refers to the linear (L) or quadratic (Q) rate response to changing pine bark and miscanthus straw ratios.

^{x}LSD refers to Fisher's least significant difference value where $\alpha = 0.05$.

*, **, *** denote significant regression response where $P < 0.05$, 0.01, and 0.001, respectively.

Shoot dry weight of hibiscus increased with increasing PB percentage in both experiments (Table 3). Despite the significant rate response, plants grown in 80% PB were similar in size to plants grown in 20 to 60% PB in Experiment 1, and those grown in 60% PB in Experiment 2 (according to LSD values; Table 3). Root ratings increased linearly with increasing PB percentage in both experiments. However,

Table 4. Foliar nutrient levels of hibiscus growing in substrates comprised of 15% sphagnum peat moss, 5% municipal solid waste compost, and 80% of various combinations of pine bark and hammermilled miscanthus straw.

Experiment	Pine bark	Miscanthus straw	N	P	K	Ca	Mg	S	B	Fe	Mn	Cu	Zn
	(%)	(%)	%						$mg\cdot kg^{-1}$				
1	0	80	5.2	0.72	3.8	2.5	0.76	0.87	55.2	125.1	1180	15.8	246.9
	20	60	5.1	0.56	3.2	2.5	0.78	0.84	62.6	124.5	1381	13.6	266.2
	40	40	5.0	0.54	3.3	2.3	0.73	0.76	65.1	120.0	1380	13.3	226.2
	60	20	5.1	0.55	3.3	2.4	0.71	0.80	66.7	126.1	1214	13.4	241.3
	80	0	5.1	0.53	3.2	2.6	0.68	0.75	63.1	142.7	1212	12.6	215.2
	Trend^z		NS	L***Q*	L***Q**	Q**	L***	L**	L**Q**	L*Q*	Q*	L***	L***
	LSD^y		NS	0.10	0.2	0.2	0.04	0.07	5.7	14.0	170	1.4	21.0
2	0	80	3.7	0.44	2.3	1.6	0.76	0.33	37.1	145,8	526	9.7	131.3
	20	60	3.8	0.41	2.4	1.6	0.72	0.37	38.0	114.5	561	8.0	173.0
	40	40	4.0	0.40	2.2	1.6	0.73	0.36	42.1	114.2	653	7.9	178.7
	60	20	3.8	0.36	2.2	1.6	0.77	0.36	43.9	120.7	592	6.0	180.8
	80	0	3.9	0.34	2.1	1.8	0.77	0.41	54.0	126.1	973	8.2	212.5
	Trend		NS	L***	L**	L**	NS	L**	L***Q*	NS	L***Q**	L***Q***	L***
	LSD		NS	0.05	0.16	0.14	0.05	0.04	4.9	23.5	137	1.0	25.9

^{z}Trend refers to the linear (L) or quadratic (Q) rate response to changing pine bark and miscanthus straw ratios.

^{y}LSD refers to Fisher's least significant difference value where $\alpha = 0.05$.

*, **, *** denote significant regression response where $P < 0.05$, 0.01, and 0.001, respectively.

according to LSD values, all plants with 20 to 80% PB had similar ratings.

Miscanthus straw, as processed in these experiments, had more fine particles than PB. The finer particles and drier nature of MS can make the mixing process more difficult. Miscanthus straw, in general, is dusty and prone to blowing with even light winds. Storage and wetting of MS will have to be addressed further if this material is adopted by the nursery industry. Despite finer particle size distribution of MS, it has lower CC than PB. Amendment with sphagnum peat moss and compost increases CC to acceptable levels in this and other grass straw-based substrates (1), however, growers should be prepared to adjust irrigation regimes if all or a portion of their PB is replaced by MS. Since bulk density of substrates decreases with increasing portion of MS, substrates composed of MS will be lighter and thus reduce the costs of transport. However, containers filled with lighter substrates are also more prone to falling over with high winds.

Substrate pH was affected by PB:MS ratio, but the greatest difference within any date was less than 1 pH unit. A common practice in U.S. nursery production is to incorporate dolomitic limestone at rates from 1.2 to 4.7 $kg \cdot m^{-3}$ (2 to 8 $lb \cdot yd^{-3}$). This not only raises substrate pH, but also provides a source of Ca and Mg in the substrate. These experiments did not incorporate dolomitic limestone, partly because of the foreknowledge that MS substrates have inherently high pH. Gypsum was incorporated at a low rate in these studies to provide a source of Ca without raising substrate pH. Irrigation water can also provide a source of Ca and Mg. Lack of dolomitic limestone, but additions of gypsum, compost, and nutrients resulting from other substrate materials and irrigation water resulted in sufficient Ca and Mg levels in plant foliage as measured in these studies.

Foliar SPAD chlorophyll levels were similar across treatments. Foliar nutrient levels were affected by treatments, but absolute differences of most nutrients were minor across treatment. This suggests that nutrient uptake of the plants was largely unaffected by substrate types used in this study. Of greatest concern with grass straw-based substrates is N immobilization. With fertilizer rates and application methods used in this study, N immobilization was not observed. Preliminary studies by the author have shown that dibbling controlled release fertilizers results in greater plant growth and less N immobilization compared to traditional methods of topdressing or incorporating controlled release fertilizers in substrates (data unpublished). We believe placing the entire allotment of controlled release fertilizer beneath the young plant concentrates the fertilizer in a single location where it is available for plant uptake. In contrast, incorporating the controlled release fertilizer distributes it uniformly throughout the substrate making it less available to the non-established root system of the young plant and more prone to N-immobilization.

While there were significant rate responses in shoot dry weight and root ratings in both experiments, only plants growing in 80% MS (0% PB) were reduced in size to the point that they might be considered commercially less desirable compared to those growing in the industry standard of 80% PB.

In summary, MS processed as described in these experiments made a suitable substrate for production of hibiscus over an 8 week period, so long as at least 20% of the substrate volume was PB. Considering substrates with 20 to 60% MS, pH were moderate and plants were of high quality, comparable foliar color, and similar size compared plants growing in substrates composed of the industry standard 80% PB (0% MS). Based on results of these experiments, along with others (1, 2), amendment with sphagnum peat moss and compost are necessary for moderation of MS physical properties and substrate pH. We also believe these results are predicated on dibbling a controlled release fertilizer to reduce or eliminate N-immobilization. Future work will focus on suppressiveness or conduciveness to root pathogens and long-term physical stability in container systems.

Literature Cited

1. Altland, J.E. 2010. Use of processed biofuel crops for nursery substrates. J. Environ. Hort. 28:129–134.

2. Altland, J.E. and C. Krause. 2010. Modification of switchgrass substrate pH using compost, peatmoss, and elemental sulfur. HortTechnology 20:950–956.

3. Day, M. 2009. Mulch producers tune into biofuel boom. Soil Mulch Producers News 3(1):1, 3, 16.

4. Dresboll, D.B. and K. Thorup-Kristensen. 2005. Structural differences in wheat (*Triticum aestivum*), hemp (*Cannabis sativa*) and Miscanthus (*Miscanthus ogiformis*) affect the quality and stability of plant based compost. Scientia Hort. 107:81–89.

5. Drzal, M.S., W.C. Fonteno, and D.K. Cassel. 1999. Pore fraction analysis: A new tool for substrate testing. Acta Hort. 481:43–54.

6. Fonteno, W.C. and T.E. Bilderback. 1993. Impact of hydrogel on physical properties of coarse-structured horticultural substrates. J. Amer. Soc. Hort. Sci.118:217–222.

7. Kresten Jensen, H.E., M. Leth, and J.J. Lonsmann Iversen. 2001. Growth of *Hedera helix* L. container plants in compost substrates made with *Miscanthus ogiformis* Honda straw and various N-sources. Comp. Sci Util. 9:206–214.

8. McGinnis, M.S., S.L. Warren, and T.E. Bilderback. 2009. Replacing conventional nursery crop nutrient inputs with vermicompost for container production of *Hibiscus moscheutos* L. 'Luna Blush'. Hortscience 44:1698–1703.

9. Mills, H.A. and J.B. Jones. 1996. Plant Analysis Handbook II. MicroMacro Publishing. Athens, GA.

10. Nash, V.E., A.J. Laiche, Jr., and F.P. Rasberry. 1983. Effects of amending container growing media with dolomitic limestone on the growth of *Photinia* 'Fraseri'. Commun. Soil Sci. Plant Anal. 14:497–506.

11. Ownley, B.H., D.M. Benson, and T.E. Bilderback. 1990. Physical Properties of container media and relation to severity of Phytophthora root rot of rhododendron. J. Amer. Soc. Hort. Sci. 115:564–570.

12. Puustjarvi V. and R.A. Robertson. 1975. Physical and chemical properties. p 23–38. *In*: D.W. Robinson and J.G.D. Lamb (eds.). Peat in Horticulture. Academic Press, London.

13. Wright, A.N., A.X. Niemiera, J.R. Harris, and R.D. Wright. 1999. Micronutrient fertilization of woody seedlings essential regardless of pine bark pH. J. Environ. Hort. 17:69–72.

14. Yeager, T.H., C.H. Gilliam, T.E. Bilderback, D.C. Fare, A.X. Niemiera, and K.M. Tilt. 2007. Best management practices: Guide for producing nursery crops. Southern Nursery Assoc., Atlanta, GA.