Research Reports

Change in Physical Properties of Pine Bark and Switchgrass Substrates Over Time[1]

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— **Abstract** —

Alternatives to pine bark for nursery crop substrates have been proposed, including the use of straw materials such as switchgrass. While straw substrates can be developed with suitable physical properties measured immediately after mixing, little is known about how the physical properties of straw-based substrates change over time. The objective of this research was to measure the change in air space (AS), container capacity (CC), total porosity (TP), and bulk density (D_b) over time of a switchgrass-based substrate compared to a pine bark substrate. Switchgrass and pine bark substrates were packed into 15 cm (6 in) tall aluminum cores and placed in a production greenhouse with or without a single hibiscus plant. Physical properties of the substrates were measured at the beginning of the experiment and 9 to 10 weeks later when the plants were nearly too large for their containers. Air space decreased over time, primarily as a function of root growth and shrinkage. Container capacity increased slightly across all treatments over time. Bulk density changed very little over time. The switchgrass substrate was more prone to shrinkage than the pine bark substrate, although vigorous hibiscus root growth reduced shrinkage in switchgrass substrates.

Index words: air space, container capacity, bulk density, porosity, substrate amendments.

Significance to the Nursery Industry

Regionally sourced alternatives to pine bark have been explored, including use of straw materials such as switchgrass. Switchgrass substrates can be engineered to have optimum physical and chemical properties at the time of potting.

Changes in chemical properties of switchgrass substrates over time have been studied; however, little is known about how physical properties change over time. Pine bark is considered to be ideally stable over the production period of most containerized plants. The objective of this research was to document the change in physical properties of switchgrass compared to pine bark substrates. Air space decreased in all substrates, but decreases were greater with switchgrass. Shrinkage was also greater in switchgrass substrates. Vigorous root growth may act as a biological scaffolding to support substrates and reduce shrinkage, especially in substrates that are otherwise prone to shrinkage. Our data show that while switchgrass substrates can initially have ideal physical properties, there will be greater shrinkage in the absence of vigorous root growth and thus may not be suitable for production of slow-rooting crops.

Introduction

Soilless substrates change physically and chemically over time. Substrate decomposition, settling, or a combination of the two can cause shrinkage in substrates. Shrinkage or reduction in substrate volume results in a change in physical properties that could affect air space (AS) and container capacity (CC). Aendekerk (1) showed the relative decomposition and shrinkage of several peat sources as a function of substrate pH and sub-irrigation level. While pH and sub-irrigation level both influenced AS, pH as a function of peat source was more influential than irrigation factors. Allaire-Leung et al. (2) showed that with a peat based substrate, AS decreased and easily available water increased over a 14 month period, with a net effect of no change in total porosity (TP). Changes in chemical properties such as pH, EC, or nutrient levels can often be managed, although not necessarily easily, by fertilization or change in irrigation quantity or quality. However, changes in physical properties are difficult or impossible to correct once the crop has begun to grow. Changes in irrigation management can counteract changes in AS or CC. However, shrinkage of the substrate cannot be fixed other than to replant into another container with added substrate.

Recent efforts have attempted to develop new greenhouse and nursery substrates from diverse materials such as pine (*Pinus* spp.) wood (7, 8, 15), cedar (*Juniperus* spp.) chips (14), miscanthus (*Miscanthus* ×*giganteus*) straw (6), bamboo (*Phyllostachys* spp.) (data unpublished), and switchgrass (*Panicum virgatum*) straw (3, 4). Straw-based substrates are being developed for upper Midwest nursery producers who have limited access to forest biomass materials. Straw-based substrates can be amended such that initial physical properties are similar to typical pine bark substrates; however, little is known about how these substrates change physically over time. The objective of this research was to measure the change in AS, CC, TP, and bulk density (D_b) over time of a switchgrass-based substrate compared to a pine bark substrate.

Materials and Methods

A 19 × 19 cm (7.5 × 7.5 in) square of 20 mesh fiberglass insect screen (Phifer Wire Products, Inc. Tuscaloosa, AL) was used to cover the bottom of aluminum cylinders (sampling cores) 15.2 cm (6 in) tall with 7.6 cm (3 in) inside diameter using a 1.3 cm (0.5 in) wide rubber band (size 84). Aluminum cores were extended for packing by adding an additional 3.8 cm (1.5 in) tall × 7.6 cm (3 in) inside diameter core on top to ensure uniform D_b throughout the sampling core. Cores were packed with each soilless substrate by dropping the core from a height of 6 cm (2.4 in) five times to imitate common industry packing procedures. Treatment design was a 2 × 2 factorial with two substrate types and either presence or absence of a plant. One of the substrates was a pine bark (PB) substrate composed of 80% pine bark, 15% sphagnum peatmoss, and 5% municipal solid waste (MSW) compost (Technagro, Kurtz Bros., Akron, OH) (v/v). The use of these ratios for PB, peat, and MSW are typical of container nursery producers in Ohio. The second substrate was composed of 60% switchgrass (SG) straw, 20% pine bark, 15% sphagnum peatmoss, and 5% municipal solid waste compost. The replacement of 60% of the PB with SG in this substrate is due to the authors' observation of successful SG-based growing

substrates in previous research (4). Cores that were randomly assigned to receive a plant were packed with a single plug of hibiscus (*Hibiscus moscheutos* L. 'Luna Red') from a 144 cell pack. Plugs were gravity planted as the column was packed to ensure substrate was not affected by planting. Cores with plants and no plants were randomized together on a bench in a glass greenhouse with night and day temperatures set at 21 and 27C (70 and 80F), respectively. There were six replications per treatment combination arranged in a completely randomized design.

The first 3 d following potting, cores were overhead irrigated in two sets of 11 min [approximately 1.2 cm·d⁻¹ (0.5 in per day)]. Thereafter, containers were fertigated at the same irrigation rate with 20N-8.7P-16.6K-0.05Mg fertilizer (JR Peters, Inc., Allentown, PA). Fertilizer was injected at a constant rate of 100 mg·liter⁻¹ (100 ppm) nitrogen (N) with a DI16 Dosatron injector (Dosatron International, Clearwater, FL) and a calibrated injection rate of 1:100.

The experiment was initiated February 17, 2011, and terminated May 3, 2011. At the conclusion of the experiment, aluminum cores were attached to NCSU Porometers™ for determination of physical properties using methods described by Fonteno and Bilderback (9). Cores were saturated and drained to determine AS. Cores were oven dried for four days at 68C (154F) to determine CC. Total porosity was calculated as the sum of AS and CC. Bulk density was calculated as g·cm⁻³ on a dry basis. Shrinkage was determined by measuring the distance between the top of the container and the substrate surface. The shrinkage value was determined by the mean of four measurements around the circumference of the container. At the beginning of the experiment when cores were packed, two additional cores of each substrate combination were packed (without plants) using the same procedures described above so that physical properties could be determined at the initiation of the experiment.

The experiment was repeated using the same procedures described above. Cores were packed and planted May 11, 2011, and terminated July 12, 2011.

Data were analyzed with analysis of variance (ANOVA) to determine influence of main effects on individual parameters. Means separation using Fisher's protected least significant difference test was used to compare means of initial physical properties.

Results and Discussion

Initial measured properties. Analysis of variance indicated different results for each measured parameter in Expts. 1 and 2, thus each experiment was analyzed and presented separately. At the start of Expt. 1, SG substrates had higher AS, similar CC, higher TP and lower D_b than PB substrates (Table 1). Air space was higher and CC lower than recommended (16) for both substrates (10 to 30% for AS and 45 to 65% for CC). This was likely due to their measurement in 15 cm (6 in) tall porometer cores, compared to measurement in standard 7.5 cm (3 in) tall cores for which recommendations are based. As the height of a column increases, AS will increase and CC will decrease for any given substrate (13). Initial properties of substrates in Expt. 2 followed a similar trend to Expt. 1 with a few exceptions. Air space in SG substrates was greater than those in PB, but the magnitude of the difference in Expt. 2 was greater. Container capacity was greater in PB substrates than SG substrates. Initial higher AS and lower CC in SG substrates compared to PB substrates

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Table 1. Initial physical properties of pine bark and switchgrass substrates measured in 15.2 cm tall porometers.

	Experiment 1				Experiment 2			
Substrate	AS[z]	CC	TP	D_b	AS[z]	CC	TP	D_b
	(%)			$g \cdot cm^{-3}$	(%)			$g \cdot cm^{-3}$
Pine bark	35.1	43.8	78.9	0.16	32.4	48.5	80.9	0.16
Switchgrass	43.6	41.1	84.6	0.11	45.9	41.8	87.7	0.10
LSD$_{0.05}$[y]	1.9	NS	2.2	0.00	3.6	2.9	1.8	0.00

[z]AS, CC, TP, and D_b refer to air space, container capacity, total porosity, and bulk density, respectively.

[y]Least significant difference according to Fisher's test. NS represents no significant difference.

is typical (3). Like Expt. 1, TP was greater in SG substrates compared to PB substrates, due primarily to greater AS in SG substrates. Bulk density for SG and PB substrates were consistent within substrates across Expts. 1 and 2.

By the conclusion of Expt. 1, AS was affected by the presence of a plant and substrate type, but not their interaction (Table 2). Air space was higher in cores with no plant (38.8 vs 36.6%), but substrate type was still of greater influence with SG cores having higher AS than PB (41.3 vs 34.1%). Change in AS over time (ΔAS) was affected by plant presence. Air space in cores with plants decreased 2.7% compared to those without plants decreasing only 0.6%. In Expt. 2, AS and ΔAS were affected by an interaction between substrate type and plant presence (Table 3). Absent a plant, AS was similar in cores with PB or SG. In the presence of a plant, AS of SG cores was far greater than that of PB cores (39.7 vs 23.0%). Air space decreased for all cores in Expt. 2. Change in AS was similar for PB and SG cores with plants, however, ΔAS was more negative for SG cores than PB cores without plants (–14.0 vs –3.1%).

Neither CC nor ΔCC were affected by substrate or plant presence in Expt. 1 (Table 2). Change in CC was similar across treatments and positive. Container capacity was affected by plant presence and substrate type in Expt. 2, but not their interaction (Table 3). Averaging across presence or absence of plants, CC was greater in PB cores compared to SG cores (51.3 vs 45.5%). Conversely, averaging across substrate types, CC was greater in cores without compared to

those with plants (49.8 vs 47.1%). Change in CC was positive for all treatments, and greater in cores with no plants compared to those without. Although there were no significant differences in CC or ΔCC in Expt. 1, the rank order of main effect means were similar to Expt. 2.

Total porosity is determined as the sum of AS and CC, thus reflects the net effect of the two parameters. Total porosity in Expt. 1 was affected by the interaction of substrate type and plant presence (Table 2). Total porosity of SG substrates was greater than PB substrates, however, the difference between PB and SG substrates was greater in the presence of a plant compared to cores without a plant. Change in TP was also affected by the interaction of substrate type and plant presence. Change in TP was positive for both substrates in the absence of a plant while ΔTP was negative or near zero for both substrates in the presence of a plant. This is likely due to the more negative ΔAS in both substrates in the presence of a plant. In Expt. 2, TP was affected by an interaction between substrate type and plant presence. Similar to Expt. 1, differences in TP between PB and SG substrates were greater with plants compared to without plants. Change in TP of cores with PB and no plant was only 0.2% as negative ΔAS was offset by positive ΔCC of similar absolute value. All other treatments resulted in negative ΔTP due to greater decreases in ΔAS relative to their increase in ΔCC.

Bulk density and $ΔD_b$ responded similarly in Expts. 1 and 2. Both parameters were affected by substrate type and plant presence, but not their interaction. Despite significant

Table 2. Physical properties of pine bark (PB) and switchgrass (SG) substrates after exposure to production environment with or without Luna Red hibiscus (*Hibiscus moscheutos* L.) growing within the container (Expt. 1).

Scenario	Substrate	AS[z]	ΔAS	CC	ΔCC	TP	ΔTP	D_b	$ΔD_b$	Shrinkage	Shoot mass	Root mass
		(%)						$g \cdot cm^{-3}$		mm	g	g
No plant	PB	35.9	0.8	47.2	3.4	83.1	4.2	0.16	0.00	1.3	—	—
	SG	41.6	–1.9	45.4	4.4	87.1	2.4	0.09	–0.02	4.5	—	—
With plant	PB	32.2	–2.8	45.1	1.3	76.4	–2.5	0.17	0.01	0.5	7.84	1.66
	SG	40.9	–2.6	44.4	3.4	85.3	0.7	0.10	–0.01	3.5	4.52	0.70
LSD$_{0.05}$[y]		2.5	2.5	NS	NS	3.1	3.1	0.00	0.00	1.65	NS	NS
Plant presence		*	*	NS	NS	***	***	***	***	NS	—	—
Substrate		***	NS	NS	NS	***	NS	***	***	***	NS	NS
Interaction		NS	NS	NS	NS	*	*	NS	NS	NS	—	—

[z]AS, CC, TP, and Db refer to air space, container capacity, total porosity, and bulk density, respectively. The symbol Δ refers to change in the respective parameter from the initial measurement made at the beginning of the study until 76 days later when the experiment was harvested.

[y]Least significant difference according to Fisher's test. NS represents no significant difference.

*, **, *** represent significant effects when $P \leq 0.05$, 0.01, and 0.001, respectively.

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Table 3. Physical properties of pine bark (PB) and switchgrass (SG) substrates after exposure to production environment with or without Luna Red hibiscus (*Hibiscus moscheutos* L.) growing within the container (Expt. 2).

Scenario	Substrate	AS[z]	ΔAS	CC	ΔCC	TP	ΔTP	D_b	$ΔD_b$	Shrinkage	Shoot mass	Root mass
				(%)				g·cm^{-3}		mm	g	g
No plant	PB	29.3	−3.1	51.8	3.3	81.1	0.2	0.16	0.00	4.9	—	—
	SG	31.9	−14.0	47.8	6.0	79.7	−8.0	0.09	−0.01	16.7	—	—
With plant	PB	23.0	−9.4	50.8	2.3	73.9	−7.0	0.17	0.01	−0.9	15.64	5.42
	SG	39.7	−6.2	43.3	1.5	83.0	−4.6	0.10	0.00	1.5	13.92	6.45
LSD$_{0.05}$[y]		4.2	4.2	2.6	2.6	4.2	4.2	0.00	0.00	1.36	NS	NS
Plant presence		NS	NS	**	**	NS	NS	***	***	***		
Substrate		***	*	***	NS	*	NS	***	***	***		
Interaction		***	***	NS	NS	**	**	NS	NS	***		

[z]AS, CC, TP, and Db refer to air space, container capacity, total porosity, and bulk density, respectively. The symbol Δ refers to change in the respective parameter from the initial measurement made at the beginning of the study until 62 days later when the experiment was harvested.

[y]Least significant difference according to Fisher's test. NS represents no significant difference.

*, **, *** represent significant effects when P ≤ 0.05, 0.01, and 0.001, respectively.

differences in these parameters, D_b changed very little from the beginning of the experiment. Bulk density has shown to be very stable over long periods of time in other substrates (5).

In Expt. 1, substrate shrinkage was affected by substrate type. Pine bark substrates shrank less than SG cores (0.85 vs 3.98 mm, respectively). Cores were 152 mm tall, thus SG and PB cores shrank approximately 0.6 and 2.6% of the core height, respectively. Shrinkage was more pronounced in Expt. 2 (Table 3). Shrinkage was affected by an interaction between substrate type and plant presence. Switchgrass and PB cores without plants had greater shrinkage than those with plants. Among cores with or without plants, SG substrates had more shrinkage than PB substrates. Among cores with plants, PB substrates rose (negative shrinkage) while SG substrates exhibited relatively minor shrinkage (approximately 1% of core height). Greater shrinkage in Expt. 2 compared to Expt. 1 could have been caused by conditions more conducive to microbial activity in the substrate. Expt. 2 was conducted later in the growing season which had longer day lengths, higher temperatures (despite cooling), and required more evaporative cooling in the greenhouse and thus higher humidity.

Hibiscus shoot and root mass in SG substrates was 42 and 58% smaller than PB substrates (*P* = 0.0599 and 0.0568, respectively) in Expt. 1. Shoot mass and root mass were similar between substrate types in Expt. 2 (Table 3). Hibiscus were several times larger in Expt. 2 compared to Expt. 1. This could have been due to conditions more conducive to plant growth in Expt. 2, as described previously.

Changes in AS are likely related to a combination of root colonization and shrinkage. Air space in these experiments was measured by recording the volume of water draining from each core after complete saturation. This volume represents the fraction of void spaces (pore spaces not occupied by roots) that freely drain after saturation. As roots explore the core volume and displace some of the pore spaces, AS is expected to decrease over time. Shrinkage can also cause AS to decline. Substrate shrinkage along the vertical axis occurs as substrate particles reorient and compress into a smaller volume. Because D_b changed very little in all substrates across both experiments, there was presumably little

change in mass. Thus compression of the substrate along the vertical axis must have been at the expense of losing AS. For example, in Expt. 2 among cores with no plants, we would expect 3.2 and 11.0% reduction in AS considering the loss of volume from shrinkage. Assuming hibiscus roots are approximately 85% water (10) and the density of water is 1.0 g·cm^{-3}, loss of AS due to root growth would have been 4.4 and 5.3% for PB and SG substrates, respectively. Add to that no change in shrinkage for PB substrates and 1% loss of volume for SG substrates, one would expect 4.4 and 6.3% loss of AS in PB and SG substrate, respectively, for cores with plants. These values are reasonably well reflected in actual loss of AS over time.

Container capacity was measured as the volume of water lost from a core that was saturated and drained and then oven dried. Thus CC would include water in the substrate retained in the macro void space after gravity draining, and in our experiments, water within roots. This causes a slight problem in interpretation, as CC does not necessarily reflect the amount of water available to plants, as it also includes water already within plant roots. All cores in both experiments had positive ΔCC, with all cores having similar ΔCC in Expt. 1 and higher ΔCC in cores with plants than those without plants in Expt. 2 (4.6 vs 1.9%). However, when accounting for water trapped in root masses, ΔCC is negative for cores with plants after factoring out water that would be trapped in roots. Increases in CC, in the absence of plants is likely due to the aforementioned decomposition of organic matter and related changes in pore size.

The objective of this research was to measure the change in AS, CC, TP, and D_b over time in SG substrates, and compare these to changes in PB. Pine bark substrates are perceived to be stable over long production periods (1 to 2 years), and thus suitable for production of container-grown trees and shrubs that require one or more years to mature. In fact, it has been shown with traditional substrates composed of either PB or sphagnum peat moss, that PB is more resistant to decomposition and shrinkage than the peat moss fractions. Nash and Laiche (11) reported 10% shrinkage of a pine bark:sand substrate (4:1 by vol) compared to 33% shrinkage of a pine bark:peat moss (1:1 by vol) substrate. In their study, shrinkage increased as the percent of peat moss

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in the substrate increased. Likewise, Nelson et al. (12) showed that shrinkage in peat-based substrates was incrementally reduced as coir incrementally replaced peat in the substrate. Altland et al. (5) similarly showed virtually no shrinkage in Douglas fir (*Pseudotsuga menziesii*) bark substrates. Data in the experiments described here show that PB substrates are more resistant to shrinkage than SG substrates. Even in Expt. 2 where shrinkage in cores without plants was severe, PB substrates only shrunk 4.9 mm (~ 3% of container height) while SG substrates shrunk 16.7 mm. Switchgrass substrates may not be suitable for plants that lack vigorous root growth. In Expt. 2 where root growth in SG substrates was more vigorous, shrinkage was only 1.5 mm (~ 1% of container height) although shrinkage was still greater in SG than PB.

In conclusion, SG substrates are more prone to shrinkage than PB substrates. Shrinkage should be expected to be greater in conditions favorable to microbial activity in substrates, or in conditions in which root growth is slow. Shrinkage in SG substrates results in decreased AS. Despite relatively high decreased AS in SG substrates, AS at the end of these experiments was still higher than recommended levels and thus should be conducive to plant root growth. When growing plants with vigorous root systems, SG substrates may be a viable alternative to PB substrates; however, more research is needed before this and other straw-based alternatives can be recommended for commercial use.

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