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Use of Switchgrass as a Nursery Container Substrate

James E. Altland[1,3] and Charles Krause[2]

USDA-ARS, Application Technology Research Unit, Ohio Agricultural Research and Development Center, 208 Ag. Eng. Building, 1680 Madison Avenue, Wooster, OH 44691

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Abstract. Loblolly pine (*Pinus taeda* L.) bark is the primary component of nursery container substrates in the eastern United States. Shortages in pine bark prompted investigation of alternative substrates. The objective of this research was to determine if ground switchgrass (*Panicum virgatum* L.) could be used for short production-cycle woody crops. Two experiments were conducted using 'Paprika' rose (*Rosa* L. 'Chew-MayTime') potted in 15-cm tall and wide containers. In Expt. 1, substrates were composed of coarse-milled switchgrass (processed in a hammermill with 1.25- and 2.5-cm screens) amended with 0%, 30%, or 50% peatmoss and fertilized with 100, 250, or 400 mg·L⁻¹ nitrogen (N) from ammonium nitrate. In Expt. 2, substrates were composed of coarse-milled (similar to Expt. 1) or fine-milled switchgrass (processed through a single 0.48-cm screen), amended with 0% or 30% peatmoss, and fertilized with the same N rates as in Expt. 1. Summarizing across both experiments, coarse switchgrass alone had high air space and low container capacity. Fine switchgrass had physical properties more consistent with what is considered normal for nursery container substrates. Switchgrass pH was generally high and poorly buffered against change. Fine switchgrass had higher pH than coarse switchgrass. Tissue analysis of rose grown in switchgrass substrate for 7 to 9 weeks revealed low to moderate levels of calcium and iron, but all other nutrients were within acceptable ranges. Despite varying substrate physical properties and pH levels, all roses at the conclusion of the experiment were of high quality. Switchgrass processed to an appropriate particle size and amended with typical nursery materials should provide a suitable substrate for short production-cycle woody crops.

Containerized nursery and greenhouse crops are grown almost exclusively in soilless substrates. Substrates for outdoor nursery crops are primarily composed of softwood bark amended to some extent with peatmoss, sand, pumice, perlite, compost, and/or various other minor materials. Softwood barks used by the nursery industry are regional and dependent on local forest inventories with most nurseries on the East Coast, Midwest, and southern United States using loblolly pine (*Pinus taeda* L.) bark (PB) and the West Coast using douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] bark. A decrease in forest products output, coupled with increased use of bark as a fuel at paper and lumber mills, has caused a decline in PB inventories available for horticultural use. Increasing demand for wood-based ethanol over the next 20 years will cause even greater

competition for PB and other woody biomasses (Day, 2009).

Scientists have explored replacements for PB in nursery containers. Researchers at Auburn University are exploring the use of a product called clean chip residual for nursery crops (Boyer et al., 2009). Researchers in Mississippi and Alabama are exploring the concept of using a *WholeTree*™ product, which involves harvesting whole trees, grinding them to an appropriate particle size, and using this as a bark substitute (Fain et al., 2008). Researchers in Virginia have used a similar approach in exploring the possibility of wood fiber sawdust for production of containerized nursery crops (Jackson et al., 2006; Wright and Browder, 2005; Wright et al., 2008). To summarize all this research, use of pine wood materials, as opposed to bark only, provides a suitable environment for plant growth with respect to substrate physical and chemical properties. This approach is proving successful in the southeastern United States where pine plantations, paper mills, and lumber mills are primarily located. This approach would be difficult to adopt in the northeastern and midwestern United States where there is less forestry activity and fewer softwood forest plantations (Lu et al., 2006).

Switchgrass (*Panicum virgatum* L.) is a native grass grown throughout the United States for its biofuel potential. Because it can

be grown in upper Midwest states that have abundant farmland, and because it offers high biomass yields, it has potential for replacing pine bark as the primary potting component in nursery containers. Others have attempted to grow container plants in substrates comprised of grass clippings. Kresten Jensen et al. (2001) 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 (2005) 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 (Dresboll and Thorup-Kristensen, 2005) research did not include plant evaluations and their findings were generally inconclusive; however, they did document differences among wheat straw, hemp straw, and miscanthus straw with respect to water-holding capacity and moisture characteristic curves. Our objective was to document the suitability of locally grown switchgrass as the primary component in container nursery substrates with a short production-cycle woody crop.

Materials and Methods

Expt. 1. Baled switchgrass was obtained from a farm in Crawford County, PA. Switchgrass was grown and allowed to dry in the field before baling in early spring. Bales were processed in a tub grinder that included a hammermill with 1.25- and 2.5-cm screens (H-1100 Haybuster II; Duratech Ind., Jamestown, ND). Hereafter, switchgrass ground with this machine is referred to as coarse switchgrass. Particle size distribution (Table 1) was determined by passing ≈100 cm³ oven-dried coarse switchgrass (60 °C) 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 soil sieves. Particles 0.11 mm or less 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, 150 taps/min; W.S. Tyler, Mentor, OH).

Treatment design was a 3 × 3 factorial with three substrates and three nitrogen (N) fertilizer rates. The three substrates included coarse switchgrass amended with 0%, 30%, or 50% sphagnum peatmoss (v/v). All substrates were amended with 0.9 kg·m⁻³ Micromax (The Scotts Co., Marysville, OH) micronutrients and 1.2 kg·m⁻³ gypsum. Containers (15 cm i.d.) were filled with substrate and planted with Oso Easy™ Paprika roses (*Rosa* 'ChewMayTime') that were ≈10 cm tall and 15 cm wide at the time of planting. Plants were potted 28 Oct. 2008 and placed in a glass greenhouse supplemented with sodium vapor lights providing 13 h of lighting from 0600 HR to 1900 HR. Thermostat heat and cool points were set at 18 and 24 °C, respectively. Fertilizer treatments were initiated on 30 Oct. 2008 and is designated as the

experiment starting date. Plants were ferti-
gated with 100, 250, or 400 mg·L⁻¹ N from
ammonium nitrate (NH_4NO_3) and 90 mg·L⁻¹
phosphorous (P) and 225 mg·L⁻¹ potassium
(K) from dibasic potassium phosphate
(K_2HPO_4). Plants were fertigated 4 d each
week (Monday, Tuesday, Thursday, and Fri-
day) and watered with tap water the remain-
ing days. Fertigation and irrigation volume
were adjusted to maintain ≈30% leaching
fraction.

Substrate physical properties were deter-
mined before the experiment by packing in
347-cm³ aluminum cores (7.6 cm tall × 7.6
cm i.d.) according to methods described by
Fonteno and Bilderback (1993). There were
three replications for each substrate. Alumi-
num 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 4 d at 72 °C, 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 deter-
mined using oven-dried (72 °C) substrate in
the same 347-cm³ cores. Substrate pH was
measured using the pourthrough procedure
at 2, 4, 6, and 9 weeks after treatment

Table 1. Switchgrass (*Panicum virgatum*) particle
size distribution for coarse switchgrass
processed through a hammermill equipped
with 1.25- and 2.54-cm screens and fine
switchgrass processed through a smaller
hammermill with a single 0.47-cm screen
(n = 3).

Screen size (mm)	Expt. 1 Coarse (%)	Expt. 2 Coarse (%)	Expt. 2 Fine (%)
Pan	0.7	0.3	0.8
0.106	1.0	0.6	1.2
0.18	1.4	0.9	1.8
0.25	3.2	2.0	4.4
0.35	5.8	3.9	6.6
0.5	10.6	8.8	10.5
0.71	12.9	10.8	11.6
1.0	16.4	17.2	15.2
1.4	25.4	25.9	19.1
2.0	14.6	17.4	9.7
2.8	5.8	8.8	7.7
4.0	1.6	2.7	8.3
6.3	0.4	0.8	3.1
12.5	0.0	0.0	0.0

initiation (WAT). Foliar samples were har-
vested (Mills and Jones, 1996) by first rinsing
with deionized water and then drying at 72 °C
for 3 d. Samples were ground in a Tecator
Cyclotec mill (Tecator AB, Hogenas, Swe-
den) through a 0.5-mm screen. Foliar N was
determined with a Vario Max CN analyzer
(Elementar Americas, Mt. Laurel, NJ). Other
macronutrients and micronutrients were de-
termined with a Thermo Iris Intrepid ICP-
OES (Thermo Fisher Scientific, Waltham,
MA). Shoot dry weight (SDW) and root dry
weight (RDW) were determined at the con-
clusion of the study (9 WAT) by harvesting
roots and shoots separately, rinsing them free
of substrate, and oven drying them at 72 °C
for 3 d.

Expt. 2. Coarse switchgrass described in
Expt. 1 was used again. In addition, a fine
switchgrass material was generated by pass-
ing dried and baled switchgrass (same source
material as Expt. 1) through a smaller ham-
mermill (No. 30 with blower discharge; The
C. S. Bell Co., Tiffin, OH) equipped with
a single 0.48-cm screen. Particle size distri-
bution for each material was determined as in
Expt. 1 (Table 1).

Treatment design was a 2 × 2 × 3 factorial
with two switchgrass grades (fine and
coarse), two peat amendment rates (0% and
30%), and three N rates, the same as those
used in Expt. 1. Substrates were amended and
irrigated similar as those in Expt. 1. The same
rose cultivar and containers were used, and
greenhouse conditions with respect to light
and temperature were the same. Plants were
potted 30 Jan. 2009. Substrate physical prop-
erties were determined as described in Expt.
1. Substrate pH was measured using the
pourthrough procedure at 2, 4, and 7 WAT.
Foliar nutrition, RDW, and SDW were de-
termined at the conclusion of the experiment,
7 WAT.

In both experiments, there were six single
plant replications per treatment combination
arranged in a completely randomized design.
Data were subjected to analysis of variance
(ANOVA) and repeated measures ANOVA
where data were measured more than once
over time. Linear or quadratic trends over
N rate were determined with orthogonal
contrasts. Least significant difference (LSD)
values for each parameter were calculated
with Fisher's LSD test.

Results and Discussion

Physical properties. Physical properties
of the three substrates differed with respect to
AS and CC are shown in Table 2. Air space
decreased from 53% to 36% with increasing
peatmoss volume. Ideal AS levels are thought
to be 10% to 30% (Yeager et al., 2007). By
this standard, coarse switchgrass alone has
extremely high AS, whereas that amended
with 50% peatmoss is close to the ideal range.
The ideal range for CC is thought to be 45%
to 65% (Yeager et al., 2007); thus, the sub-
strate containing only switchgrass would
have less than ideal CC, whereas the other
two substrates are within acceptable ranges.
Although the substrate containing 70%
switchgrass has significantly lower TP than
the other two substrates, a difference of 2% is
inconsequential. Bulk density of the substrate
containing 100% switchgrass was lower than
with the other two substrates, but a difference
of just 0.003 g·cm⁻³ is likely inconsequential.

In Expt. 2, physical property values of
coarse switchgrass substrate were similar to
those found in Expt. 1 when amended with
0% or 30% peatmoss. In Expt. 2, AS, CC, TP,
and D_b were affected by interactions between
switchgrass grade and peatmoss amendment
(Table 2). Peatmoss amendment decreased
AS and increased CC in coarse switchgrass
but had no effect on fine switchgrass. Re-
gardless of peatmoss amendment, fine
switchgrass had less AS and greater CC than
coarse switchgrass. Bulk density of fine
switchgrass was greater than coarse switch-
grass, likely as a result of the finer particles
that compress more efficiently in a given unit
volume. Compared with the aforementioned
recommended ranges for physical properties,
fine switchgrass with or without peatmoss
had closer to ideal physical properties than
coarse switchgrass.

Substrate pH. In Expt. 1, repeated mea-
sures analysis indicated that pH was affected
by an interaction among date, substrate type,
and N rate ($P = 0.0001$). At 2 WAT, pH in
substrates containing 100% switchgrass
responded quadratically to increasing N rate,
although differences among N rate treatments
were minor and averaged 6.4 (Table 3).
Amending substrates with 30% or 50% peat-
moss reduced pH to 4.1 and 3.9, respectively,
averaged across N rate. Substrates amended

Table 2. Physical properties of switchgrass (SG) (*Panicum virgatum*) substrates amended with 0%, 30%, or 50% peatmoss.[z]

Switchgrass grade	Peat (%)	Expt. 1 Air Space (%)	Container capacity (%)	Total porosity (%)	Bulk density (g·cm⁻³)	Expt. 2 Air space (%)	Container capacity (%)	Total porosity (%)	Bulk density (g·cm⁻³)
Coarse	0	53 a[y]	36 c	89 a	0.068 b	55 a	29 c	84 b	0.066 c
	30	41 b	45 b	87 b	0.071 a	47 b	42 b	90 a	0.073 b
	50	36 c	53 a	89 a	0.072 a				
Fine	0					37 c	53 a	90 a	0.092 a
	30					37 c	52 a	90 a	0.089 a
Main effects				*Significance*					
SG type						0.0001	0.0001	0.0015	0.0001
Peat rate						0.0692	0.0019	0.0055	0.0335
Interaction						0.0382	0.0009	0.0028	0.0008

[z]Switchgrass used was classified as either coarse (processed through 1.25- to 2.5-cm screens) or fine (processed through a 0.47-cm screen) (n = 6).
[y]Means with different letters, within a column, are significantly different according to Fisher's protected least significant difference test.

with 30% peatmoss also responded quadratically to increasing N rate, whereas those amended with 50% peatmoss did not. By 9 WAT, substrates containing either 0% or 30% peatmoss were again affected by N rate with pH decreasing linearly with increasing N rate. Similar to results at 2 WAT, substrates containing only 50% switchgrass were unaffected by N rate. Averaging across N rate, pH for substrates containing 0%, 30%, or 50% peatmoss were 5.9, 4.6, and 3.9, respectively, and each differed significantly from the others (contrast analyses, $P \leq 0.01$ across all comparisons). Argo and Biernbaum (1996) reported that a water-soluble fertilizer containing 50% NH_4^+-N reduced pH over time. The water-soluble fertilizer used in this experiment contained 50% NH_4^+-N and had a similar effect on pH. The depression in pH was N rate-responsive in the two substrates containing primarily switchgrass. Previous unpublished research by the author has shown that switchgrass is poorly buffered against changes in pH from other amendments or fertilizers.

In Expt. 2, substrate pH was affected by switchgrass grade, peat amendment, and N rate (Table 4). At 2 and 4 WAT, pH increased and then decreased with increasing N rate in substrates amended with 30% peat, but did not respond to N rate in nonamended switchgrass. By 9 WAT, all substrates responded either linearly or quadratically to increasing N rate. Averaging across peatmoss amendments and N rates, pH was higher in fine switchgrass than coarse switchgrass ($P = 0.0001$). This observation is consistent with findings in other research with switchgrass by the authors (J.E. Altland, unpublished data) in that pH increases as the particle size of switchgrass is reduced. Similar to Expt. 1, peatmoss amendment reduced substrate pH.

Foliar nutrient content. Peatmoss amendment rate and N rate interacted for all foliar elements analyzed (Table 5). There is no information on nutrient sufficiency ranges for landscape shrub roses; however, inferences can be made from sufficiency ranges developed for cut-flower hybrid tea roses (Mills and Jones, 1996). All nutrients with the exception of calcium and iron were within sufficiency ranges (1% to 2% and 56 to 200 mg·kg^{-1}, respectively) suggested for the nine cultivars listed by Mills and Jones (1996). Foliar N increased with increasing N rate with all three substrate types. Roses grown in substrates containing 30% peatmoss had higher foliar N than roses in substrates with 0% peatmoss and numerically greater (although not statistically greater) foliar N than substrates with 50% peatmoss. If switchgrass were immobilizing N within the substrate such that less N was available for uptake, one would expect foliar N to increase with increasing peat amendment rate. However, increasing peat volume from 30% to 50% did not increase foliar N and, in fact, caused a decrease when 250 mg·L^{-1} N was applied. Differences in foliar N are thus likely the result of differences in available water among the three substrates tested. A similar trend

was observed with foliar P and K where increasing N rate tended to cause an increase in foliar levels with substrates containing 30% peatmoss resulting in higher foliar P and K than other substrates. Calcium, boron, iron, and silicon all tended to decrease with increasing N rate and increasing peat amendment rate, suggesting higher available

Table 3. Effect of peatmoss amendment and nitrogen (N) rate on pH of switchgrass (*Panicum virgatum*) substrates over time and root and shoot dry weight of roses (*Rosa* 'ChewMay Time') growing in those substrates (n = 6).

Peat (%)	N rate (mg·L^{-1})	Substate pH[z]				Shoot dry wt (g)	Root dry wt (g)
		2 WAP	4 WAP	6 WAP	9 WAP		
0	100	6.56	6.46	6.39	6.30	4.1	2.2
	250	6.25	6.63	6.66	5.97	5.4	1.7
	400	6.49	6.12	5.97	5.63	5.1	1.6
		Q***	L***Q***	L**Q***	L***	NS	NS
30	100	4.42	4.65	4.76	5.00	5.6	1.9
	250	3.96	4.58	4.69	4.74	6.6	1.8
	400	4.00	3.88	4.17	3.82	5.3	1.4
		L***Q***	L***Q***	L***	L***	NS	NS
50	100	3.92	4.36	4.32	4.14	4.5	1.7
	250	3.98	3.82	3.86	3.79	4.7	1.2
	400	3.92	3.86	3.87	3.76	4.9	1.3
		NS	L***Q***	L*Q*	NS	NS	NS
LSD$_{0.05}$		0.11	0.19	0.27	0.42	1.8	0.7

Main effects			*Significance*				
Peat (P)		0.0001	0.0001	0.0001	0.0001	0.0735	0.1048
N rate (N)		0.0001	0.0001	0.0001	0.0001	0.2437	0.0383
P*N		0.0001	0.0001	0.0001	0.0001	0.6856	0.8005

[z]Substate pH was determined with the pourthrough method.
L, Q, and NS represent linear, quadratic, or nonsignificant rate response with respect to N rate.
*, **, and *** represent significant effects with P values less than or equal to 0.05, 0.01, or 0.001, respectively.
LSD values are the least significant difference as determined by Fisher's least significant difference test.
WAP = weeks after planting.

Table 4. Effect of coarse of fine switchgrass (*Panicum virgatum*) substrate amended with 0% or 30% peatmoss and fertilized with three nitrogen (N) rates on substrate pH and rose (*Rosa* 'ChewMayTime') root and shoot growth grown in those substrates (n = 6).

Switchgrass grade[y]	Peat (%)	N rate (mg·L^{-1})	Substate pH[z]			Root dry wt (g)	Shoot dry wt (g)
			2 WAP	4 WAP	7 WAP		
Coarse	0	100	6.64	6.86	6.69	2.7	5.0
		250	6.72	6.70	6.59	2.5	7.9
		400	6.50	6.81	5.98	2.0	9.0
			NS	NS	L***Q*	L***	L***Q*
	30	100	4.58	4.80	5.09	1.8	3.9
		250	4.75	5.44	5.21	1.5	7.4
		400	4.22	4.74	4.83	1.8	9.0
			Q**	Q***	Q*	NS	L***
Fine	0	100	6.89	6.95	6.83	1.9	3.2
		250	6.84	6.99	6.75	1.5	6.4
		400	6.81	6.91	6.47	1.3	9.1
			NS	NS	L**	L**	L***
	30	100	5.28	5.68	5.94	2.0	4.1
		250	5.49	5.90	5.63	1.4	8.3
		400	5.33	5.42	5.19	1.3	8.2
			Q*	Q***	L***	L***	L***Q***
LSD			0.26	0.16	0.24	0.4	1.3

Main effects					*Significance*		
Switchgrass		0.0001	0.0001	0.0001	0.0001	0.1299	
Peat (P)		0.0001	0.0001	0.0001	0.0001	0.6463	
S*P		0.0001	0.0001	0.006	0.0001	0.0593	
N rate (N)		0.0027	0.0001	0.0001	0.0001	0.0001	
S*N		0.0802	0.3863	0.2254	0.3456	0.5122	
P*N		0.2212	0.0001	0.9509	0.1181	0.2938	
S*P*N		0.3988	0.0012	0.0032	0.0744	0.0077	

[z]Substrate pH was determined with the pourthrough method.
[y]Coarse switchgrass was processed through a hammermill with 1.25- and 2.54-cm screens, whereas fine switchgrass was processed through a hammermill with a single 0.48-cm screen.
L, Q, and NS represent linear, quadratic, or nonsignifican rate response with respect to N rate.
*, **, and *** represent significant effects with P values less than or equal to 0.05, 0.01, or 0.001, respectively.
LSD values are the least significant difference as determined by Fisher's least significant difference test.
WAP = weeks after planting.

Table 5. Foliar nutrient content of rose (*Rosa* 'ChewMayTime') grown in switchgrass (*Panicum virgatum*) and peatmoss substrates fertilized with one of three nitrogen (N) rates.[z]

Switchgrass grade	Peat (%)	N rate (mg·L⁻¹)	N	Phosphorus	Potassium	Calcium	Magnesium	Sulfur	Boron	Iron	Manganese	Copper	Zinc	Silicon
						(%)					(mg·kg⁻¹)			
Expt. 1														
Coarse	0	100	2.82	0.43	1.8	1.4	0.41	0.20	77.0	83.4	372.0	6.2	33.2	195.6
		250	3.84	0.65	2.3	1.1	0.36	0.34	51.4	67.9	294.2	10.2	45.6	156.0
		400	4.01	0.71	2.1	1.1	0.38	0.36	66.2	81.5	401.1	9.6	42.7	149.1
	30	100	3.64	0.61	2.2	1.1	0.37	0.33	60.4	73.9	616.0	9.6	42.4	146.5
		250	4.14	0.81	2.3	1.0	0.40	0.34	63.5	70.4	675.1	10.8	49.5	136.1
		400	4.43	0.87	2.6	0.8	0.36	0.34	58.6	58.7	487.7	8.2	37.2	131.1
	50	100	3.46	0.60	2.2	1.0	0.36	0.33	61.5	95.5	594.6	10.2	41.7	132.9
		250	3.82	0.25	2.0	0.5	0.27	0.26	48.1	62.4	323.4	7.7	28.1	90.2
		400	4.42	0.79	2.5	0.7	0.31	0.32	59.6	53.7	414.8	6.9	28.3	126.3
LSD0.05			0.27	0.14	0.4	0.2	0.05	0.05	13.9	21.1	102.8	1.7	8.2	19.1
Substrate			0.0001	0.0004	0.0339	0.0001	0.0001	0.0126	0.1214	0.2392	0.0001	0.0565	0.0002	0.0001
N rate			0.0001	0.0004	0.0070	0.0001	0.0135	0.0020	0.0123	0.0038	0.0022	0.0347	0.1124	0.0001
Substrate			0.0084	0.0165	0.0453	0.0114	0.0041	0.0001	0.0541	0.0532	0.0001	0.0001	0.0001	0.0026
Expt. 2														
Coarse	0	100	1.60	0.28	1.7	1.1	0.336	0.16	75.3	57.9	290.0	3.9	21.4	215.9
		250	2.18	0.40	2.1	1.2	0.35	0.24	46.9	26.2	222.7	6.0	18.5	181.5
		400	3.30	0.51	2.0	1.3	0.37	0.29	60.5	73.0	340.6	7.3	31.9	194.9
	30	100	1.70	0.32	1.7	0.9	0.28	0.19	70.0	53.6	449.2	4.5	33.4	145.0
		250	2.79	0.49	2.3	0.9	0.30	0.29	31.4	74.2	337.7	8.3	31.0	118.7
		400	2.87	0.48	2.0	0.7	0.29	0.28	38.3	59.3	348.6	7.5	35.0	119.6
Fine	0	100	1.56	0.28	2.1	1.0	0.36	0.14	71.7	38.6	82.0	3.5	22.3	217.7
		250	2.58	0.51	2.5	1.0	0.33	0.27	46.3	44.7	151.2	4.0	21.8	143.0
		400	2.99	0.61	2.3	1.0	0.34	0.32	47.4	59.9	359.9	6.2	41.8	167.0
	30	100	1.70	0.33	2.1	1.1	0.34	0.19	63.8	17.0	393.8	4.2	18.2	153.2
		250	3.14	0.60	2.5	1.0	0.33	0.31	41.9	50.3	381.0	12.5	40.5	115.7
		400	4.10	0.58	2.1	0.7	0.28	0.30	44.2	62.7	407.3	6.8	40.2	133.3
LSD0.05			0.83	0.05	0.1	0.2	0.04	0.02	10.5	20.9	70.9	4.1	7.8	18.6
Main effects							*Significance*							
SG type (T)			0.1147	0.0001	0.0001	0.1080	0.2331	0.0048	0.5752	0.0070	0.0166	0.9480	0.1604	0.0487
Peat (P)			0.0434	0.0045	0.8581	0.0001	0.0001	0.0001	0.0001	0.5161	0.0001	0.0129	0.0001	0.0001
T*P			0.1356	0.9233	0.0051	0.0001	0.0087	0.9645	0.0358	0.0956	0.0007	0.1833	0.1388	0.0005
N rate (N)			0.0001	0.0001	0.0001	0.0195	0.7201	0.0001	0.0001	0.0003	0.0001	0.0014	0.0001	0.0001
T*N			0.5450	0.0002	0.0239	0.0012	0.0345	0.0000	0.5021	0.0006	0.0001	0.0294	0.0003	0.0564
P*N			0.4603	0.0002	0.0080	0.0618	0.0013	0.0048	0.1302	0.0330	0.0001	0.6027	0.0007	0.0263
T*N*P			0.1092	0.9516	0.0913	0.9569	0.7379	0.3335	0.1221	0.0223	0.2760	0.2553	0.0208	0.1374

[z]Coarse switchgrass was processed through a hammermill equipped with 1.25- and 2.54-cm screens, whereas fine switchgrass processed through a smaller hammermill with a single 0.47-cm screen (n = 6).
LSD values are the least significant difference as determined by Fisher's test.

concentrations of these nutrients in switchgrass than peatmoss. Foliar magnesium, sulfur, manganese, copper, and zinc all varied by treatments but either showed only minor differences or showed no identifiable trend with respect to N or peatmoss rates.

In Expt. 2, foliar N content in roses showed a significant response to peat amendment (Table 5) and N rate; all other main effects and interactions were not significant. Averaging across switchgrass grades and N rates, roses grown with no peat had 2.37% foliar N, whereas roses grown in substrate amended with 30% peat had 2.72% foliar N. Foliar N and P increased with increasing N rate. Across substrates, foliar K was greatest with roses fertilized with 250 mg·L⁻¹ N. Similar to Expt. 1, calcium and iron were at or below reported sufficiency ranges for rose, whereas all other foliar nutrients were within sufficiency ranges.

Plant growth. Shoot growth was significantly affected by amendment with peatmoss, but not by N rate or its interaction with peatmoss (Table 3). Substrates with 0%, 30%, and 50% peatmoss resulted in roses with 4.9, 5.6, and 4.7 g dried shoot mass,

respectively. Root growth was marginally affected by substrate type (*P* = 0.1048) with root growth decreasing from 1.8 to 1.4 g as peatmoss level increased from 0% to 50% of substrate volume. Nitrogen rate affected RDW with RDW decreasing from 1.9 to 1.5 g as N rate increased from 100 to 400 mg·L⁻¹.

In Expt. 2, root and shoot growth were affected by switchgrass grade, peat amendment, and N rate (Table 4). Root growth decreased linearly with increasing N rate. Root growth was greatest in substrates with coarse switchgrass and no peatmoss. In this experiment and others conducted by the senior author, root growth of roses appears to increase in response to decreasing water-holding capacity. Shoot growth increased linearly or quadratically with increasing N rate among all switchgrass grade and peatmoss combinations. Averaging across N rates, no substrate combination provided superior growth among those tested.

In summary, switchgrass can be processed and modified such that it is suitable for production of short-term woody crops such as landscape shrub roses. Physical properties of switchgrass substrates will

depend on the degree to which it is ground and amended with peatmoss and other components. Container capacity of switchgrass seems primarily governed by its particle size distribution. In these experiments, switchgrass processed through a 0.47-cm screen provided ideal physical properties, whereas switchgrass processed through a larger screen required amendment with 30% or 50% peatmoss to achieve the proper ratio of AS to CC. Processing with smaller screens will require more energy and higher production costs and thus will be an important consideration in development of switchgrass substrates.

Substrate pH of 100% switchgrass has been between 6.5 and 7.5 in this and other experiments by the senior author (J.E. Altland, unpublished data) with pH increasing as the proportion of fine particles increases. Although the various species of plants grown in nurseries respond differently to substrate pH, the aforementioned range of switchgrass pH is higher than what is typically considered ideal. Furthermore, switchgrass seems poorly buffered against change from irrigation water or fertilizer amendment. Future research will

evaluate amendment with composts with the intent of buffering against pH change.

Foliar nutrient content data suggest switchgrass provides a suitable medium for delivering plant nutrients through typical nursery fertilizer methods. Foliar calcium levels were low in some treatments. Because substrate pH is typically high, amendment with lime will not likely be needed. Lime amendments supply a large portion of calcium fertility; thus, some alternative calcium source (perhaps gypsum) will be explored. Foliar iron levels were similarly low, but this can also be remedied by amendment with iron sulfate.

Overall plant growth was vigorous in all treatments regardless of substrate type. Roses have been reported to grow over a wide range of pH (McCall, 1980) and are considered better suited to well-drained substrates (J. Lee, personal communication). Thus, it is not surprising that roses in this study grew well in substrates with pH ranging from 3.76 to 6.86 or in substrates with suboptimal CC. Future experiments will evaluate amendments to lower and stabilize pH, moderate physical properties, supplement additional calcium and iron, and document substrate conduciveness to root pathogens. A wider range of plant materials with more specific requirements for pH and substrate water content will also be used.

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