Swine Lagoon Compost as Transplant Substrate for Basil, Chives, and Dill

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Summary. Sphagnum peat is a finite resource that is often used in the horticultural industry as a component in many substrates, especially for greenhouse production of transplants. Because peatlands are being depleted by vast amounts of mining, the horticultural industry is exploring alternative resources to use in substrates. Swine lagoon sludge (SLS) is an attractive option as it may provide nutrients needed to support plant growth, as well as using an agricultural waste product to address the peat shortage. A compost was developed using an in-vessel compost reactor to compost SLS with peanut hulls [15:85 (by volume) SLS:peanut hull] to produce a swine lagoon compost (SLC). A greenhouse transplant study was conducted with three species: basil (*Ocimum basilicum* 'Dark Opal'), chives (*Allium schoenoprasum*), and dill (*Anethum graveolens* 'Hera') grown in three substrates: SLC, a commercially available organic potting substrate with a nutrient charge (OM), and a commercial peat-based potting substrate with a 2-week nutrient charge (PEAT). The average height for basil, chives, and dill was significantly greater at transplant harvest when produced in the SLC substrate compared with the OM and PEAT. Airspace was greatest for SLC and lowest for OM and PEAT. Although root growth was not measured in this study, more prolific root growth throughout the plug was observed with SLC compared with OM and PEAT possibly because of the greater airspace in SLC. Substrate solution pH did not change substantially over time, whereas electrical conductivity (EC) decreased from 0.24 to 0.14 $mS\cdot cm^{-1}$. Both substrate pH and EC were within acceptable ranges for transplant production. SLC provided the physical and chemical requirements for herb transplant production without any additional fertilizers or amendments.

Sphagnum peat is a finite resource that is often used in the horticultural industry as a component in many substrates specifically in greenhouse production for transplants (Abad et al., 2001). Peat is mined from its natural wetland habitat, and excessive use has depleted much of these resources. Because of the depletion, less of the product is available, resulting in increase in price and decreased quality (Robertson, 1993). Peat also has disadvantages of which include difficulty to wet, providing no nutrients as media, and is acidic. As a result, much research has focused on alternative resources for peat in the greenhouse industry (Abad et al., 2001; Ostos et al., 2008; Raviv et al., 1998). Composts have also proved to suppress soil-borne pathogens found common in peatmoss such as plant fungi [*Fusarium oxysporum* and *Sclerotinia minor* among others (Veeken et al., 2005)].

Composts are an attractive option for peat substitutes in transplant production (Bustamante et al., 2008). Composts produced from cow and poultry manures maintained suitable physical properties for production of transplants (Bustamante et al., 2008). Research has (and is) being conducted incorporating composts to grow basil, coriander (*Coriandrum sativum*), peppermint (*Mentha ×piperita*), and thyme (*Thymus vulgaris*), among others (Bustamante et al., 2008; DeKalb et al., 2014; Herrera et al., 1997; O'Brien and Barker, 1996; Zheljazkov and Warman, 2004). O'Brien and Barker (1996) reported that shoot dry weight of peppermint transplants was larger when grown in composts derived from mixed municipal solids, mature biosolid-wood chips, agricultural wastes, and leaves. However, these authors reported limited growth with the composts containing both immature biosolids and yard wastes as a result of high salinity and ammonium (as in the case of the immature biosolid) or insufficient nutrient supply (as with the yard waste).

Raviv (2005) states that compost's usability as a safe and environmentally responsible substrate makes it an appropriate low-cost peat substitute. Since the late 1970s, the price of high-quality peat has been increasing, especially in countries that lack a native peatmoss source (Abad et al., 2001). However, a lack of knowledge and education of growers is apparent as they continue to look for "cheap products and tend to ignore the unavoidable connection between quality and cost" (Raviv, 2005). Because of the versatility among the chemical properties and nutrient content, composts can be used as a low-cost addition to soilless substrate productions. Organic residues generated by agriculture, livestock farming, forestry, and industries and cities are being successfully used for container media for ornamental production and are considered useful value-added products (Abad et al., 2001).

Swine lagoon compost resulted in a substrate with zinc (Zn), copper (Cu), pH, and EC levels that were

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
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
16.3871	$inch^3$	cm^3	0.0610
1	mmho/cm	$mS\cdot cm^{-1}$	1
28.3495	oz	g	0.0353
1.7300	$oz/inch^3$	$g\cdot cm^{-3}$	0.5780
1	ppm	$mg\cdot L^{-1}$	1
6.8948	psi	kPa	0.1450
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

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appropriate for germinating seedlings (Herring et al., 2018). A bioassay study found that germination of radish (*Raphanus sativus* 'Cherriette'), tomato (*Solanum lycopersicum* 'Moneymaker'), and marigold (*Tagetes patula* 'Janie Deep Orange') was better in the control substrate (Pro Line C/P; Jolly Gardener, Portland, ME) than in the SLC. However, numerically, germination of all the species was similar between the two substrates except for zinnia (*Zinnia elegans* 'Dreamland Red'), a salt-sensitive species, because of a high EC. Growth of seedlings of each species 28 d after sowing was the same for each substrate. The finished composts averaged 1.8% nitrogen (N), 1.5% phosphorus (P), and 0.2% potassium (K). The findings of Herring et al. (2018) indicate that SLC may be a suitable substrate for herb transplant production.

Herb production is a growing market and is becoming more popular in the vegetable industry. Vegetable producers are beginning to recognize the consumer demand of fresh herbs and are incorporating herb production into their established operations; however, little information is published about how to produce herbs commercially (Davis, 1994; Morgan, 2001). Because of the consumer demand for the product, and the lack of published information about its production, the objective of this study was to compare the growth of three herb species in SLC and two commercially available substrates.

Materials and methods

The substrates evaluated in this study included SLC, OM, and PEAT. Development of the SLC is described by Herring et al. (2018). The OM comprised aged pine bark fines, peat, soil, perlite, and worm castings (Just Natural Organic Potting Mix; Jolly Gardener). The PEAT was a conventional substrate comprising peat with aged bark fines, perlite, vermiculite, dolomitic limestone, gypsum, and a wetting agent (Pro-Line C/P). Three species, basil, chives, and dill, were grown in Raleigh, NC (lat. 35.78°N, long. 78.64°W), with a planting date of 8 June 2016. The experiment consisted of the three substrate treatments (SLC, OM, and PEAT) and three species with six replications in a randomized complete block design. Black, plastic, 72-cell inserts (1-5/9 inch cell top diameter × 2-1/3 inches deep, 3-3/5 inch^3 maximum dry volume; Landmark Plastic Co., Akron, OH) were filled with the designated transplant substrate and planted with three seeds of each species per cell. Trays were randomized in the greenhouse (85/65 °F day/night) with natural irradiance and photoperiod under fog (CoolNet Pro Fogger 0303420LL-B; M.L. Irrigation System; Laurens, SC) applied for 8 s every 8 min for germination. Clear plastic sheeting was pulled around and over the bench. Plastic sheeting was removed 12 d after planting and germination was measured. Cells were then thinned to one seedling. Plants were irrigated by hand each day throughout the remainder of the study.

The substrates were evaluated and compared through chemical and physical property analyses, and growth. Physical property analyses including total porosity, airspace, container capacity, bulk density, available water, unavailable water, and particle size distribution were conducted in the Horticultural Substrates Laboratory, Department of Horticultural Science, North Carolina State University, Raleigh. Three replications of each substrate were packed into ≈21-1/5-inch^3 cylindrical aluminum rings (3 × 3 inches) and used to determine total porosity, airspace, container capacity, and bulk density per procedures outlined in Tyler et al. (1993). Each substrate was packed into 6-3/20-inch^3 cylindrical aluminum rings (3 × 7/8 inches), with five replications per modified procedures of Bilderback and Johnson (1982) and used to determine unavailable water following procedures described in Klute (1986). Available water was calculated as container capacity minus unavailable water. To determine particle size distribution, three 100-g samples of each substrate were dried at 105 °C for 48 h and placed in a sieve shaker (Ro-tap Shaker model B; W.S. Tyler, Mentor, OH) fitted with seven sieves, 6.3, 2, 0.71, 0.5, 0.25, and 0.106 mm for 5 min. The sample from each sieve was weighed, and particle size was expressed as a percentage of the total weight of the sample.

Beginning 29 d after sowing (DAS), substrate pH and EC were measured weekly from planted cells using 1:2 (by volume) substrate to water extracts. Before extraction, cell packs were watered and allowed to drain for 3 h to establish container capacity within the substrate. For

Table 1. Initial physical properties of three transplant substrates that were used to grow basil, dill, and chives without additional fertilizer in a greenhouse trial [85/65 °F (29.4/18.3 °C) day/night] with natural irradiance and photoperiod.

Substrate[z]	Total porosity (%)[y]	Airspace (%)[x]	Container capacity (%)[w]	Available water (%)[v]	Unavailable water (%)[u]	Bulk density (g·cm^{-3})[t]
SLC	80	42 a[s]	38 b	9 b	28.7 ab	0.20 a
OM	78	20 b	59 a	30 a	29.4 a	0.20 a
PEAT	80	16 b	63 a	36 a	27.5 b	0.15 b
Optimum range[r]	>85	20–30	50–100	24–40	20–30	≤0.4
P value[q]	NS	0.01	0.0009	0.0005	0.02	0.001

[z] SLC = swine lagoon compost [15:85 (v/v) swine lagoon sludge:ground peanut hulls]; OM = aged pine bark fines, peat, soil, perlite, and worm castings; PEAT = conventional substrate of peat, aged bark fines, perlite, dolomitic limestone, gypsum, and a wetting agent.

[y] Based on percent volume of a 3-inch (7.6 cm) core at 0 kPa.

[x] Total porosity—container capacity.

[w] Measured as a percent volume of a 3-inch core at drainage.

[v] Container capacity—unavailable water.

[u] Measured as a percent volume of a 3-inch core at 1500 kPa (217.6 psi).

[t] Measured as the ratio of dry solids to the bulk volume of the substrate; 1 g·cm^{-3} = 0.5780 oz/inch^3.

[s] Means within a column with different letters are significantly different from each other based on Tukey's mean separation procedures ($P \leq 0.05$).

[r] Per Abad et al. (2001) and Noguera et al. (2003).

[q] Analysis of variance NS at $P \geq 0.05$, *P* value given otherwise.

each substrate sample, 400 mL of substrate was removed from the tray, thoroughly mixed with 800 mL of distilled water and allowed to sit for 20 min. The solution was then strained through filter paper (grade 1, 185 mm, catalog no. 1001-185; Whatman, Houston, TX) to remove solids. Extract solution EC and pH were measured using a combination EC/pH meter (HI 8424; Hannah Instruments, Ann Arbor, MI). After EC and pH measurements, substrate solution samples were submitted to the North Carolina Department of Agriculture and Consumer Services Agronomy Division, Raleigh for inorganic nitrogen (IN-N), urea, P, K, Zn, Cu, calcium (Ca), magnesium (Mg), sulfur (S), boron (B), iron (Fe), and manganese (Mn). Inorganic nitrogen fraction concentrations included nitrate nitrogen plus nitrite nitrogen (NO_3-N + NO_2-N) and ammonium nitrogen (NH_3-N + NH_4-N). Organic nitrogen fraction concentration included urea. Nitrate nitrogen was determined on ≈10-mL homogenized sample, filtered using acid-washed filter paper (Laboratory Filtration Group, Houston, TX) by nitrate hydrazine reduction (Kempers and Luft, 1988; Skalar Analytical, 1995a); ammonia was determined by a modified Berthelot reaction (adapted from Krom 1980; Skalar Analytical 1995b). The urea concentration was determined with the diacetyl monoxime thiosemicarbazide colorimetric method (Sullivan and Havlin, 1991; Skalar Analytical, 1995c) with an auto-flow spectrophotometric analyzer (San++ Segmented Flow Auto-Analyzer; Skalar Analytical, Breda, The Netherlands). Total concentrations of P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, and sodium (Na) were determined on ≈10-mL homogenized sample, filtered using acid-washed filter paper (Laboratory Filtration Group) with inductively coupled plasma–optical emission spectrometry [ICP-OES (Spectro Arcos EOP; Spectro Analytical, Mahwah, NJ)] [Donohue and Aho 1992; adapted from U.S. Environmental Protection Agency (USEPA), 2001]. Chloride concentration was determined on ≈10-mL homogenized sample,

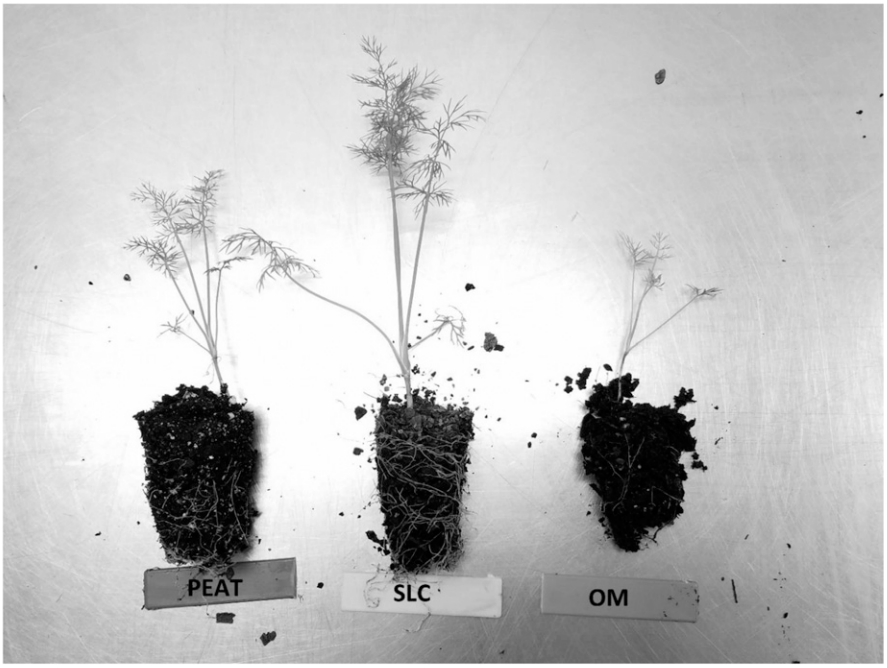

Fig. 1. Dill roots at harvest (49 d after sowing). Substrates included swine lagoon compost (SLC) [15:85 (v/v) swine lagoon sludge:ground peanut hulls]; aged pine bark fines, peat, soil, perlite, and worm castings (OM); and conventional substrate of peat, aged bark fines, perlite, dolomitic limestone, gypsum, and a wetting agent (PEAT).

Table 2. Influence of substrate type and days after seeding (DAS) on substrate pH and electrical conductivity (EC) on greenhouse-produced basil, chives, and dill transplants. Substrate 1:2 (v/v) extractions, starting at 29 DAS, were measured.

	pH			EC ($mS\cdot cm^{-1}$)[z]		
	Basil	Chives	Dill	Basil	Chives	Dill
Substrate[y]						
SLC	6.0 a[x]	6.0 a	5.8 a	0.25 a	0.22 a	0.24 a
OM	5.5 b	5.6 b	5.5 b	0.14 b	0.12 b	0.17 b
PEAT	5.6 b	5.6 b	5.5 b	0.16 b	0.13 b	0.15 b
P value[w]	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	0.0008
Sample time						
29 DAS	5.6 b	5.7 ab	5.6	0.23 a	0.17	0.24 a
36 DAS	5.8 a	5.9 a	5.7	0.17 b	0.15	0.20 ab
43 DAS	5.6 b	5.7 b	5.6	0.14 b	0.15	0.17 b
50 DAS	—[v]	5.6 b	5.6	—[v]	0.15	0.15 b
P value	0.0019	0.0028	NS	0.0022	NS	0.0061

[z] 1 $mS\cdot cm^{-1}$ = 1 mmho/cm.

[y] SLC = swine lagoon compost [15:85 (v/v) swine lagoon sludge:ground peanut hulls]; OM = aged pine bark fines, peat, soil, perlite, and worm castings; PEAT = conventional substrate of peat, aged bark fines, perlite, dolomitic limestone, gypsum, and a wetting agent.

[x] Means with different letters within a column are significantly different from each other based on Tukey's honestly significant difference means separation procedures ($P \leq 0.05$).

[w] Analysis of variance main effects of substrate and sample time. The two-way interaction DAS × substrate was NS at $P \geq 0.05$, *P* value given otherwise.

[v] Basil was harvested at 43 DAS so was not sampled at 50 DAS.

filtered using acid-washed filter paper (Laboratory Filtration Group) by the thiocyanate displacement method (Skalar Analytical, 1995d; Zall et al., 1956) with an auto-flow spectrophotometric analyzer (San++ Segmented Flow Auto-Analyzer, Skalar Analytical).

Plant heights, taken from the root collar to the tip of the shoot, were taken at harvest. Harvest dates were determined when each species reached developed transplant stage (43 d for basil and 49 d each for chives and dill). Shoots (stems and leaves) were dried at 62 °C for 24 h. After drying, samples were weighed.

All variables were subjected to analysis of variance procedures using the general linear model procedure in SAS (version 9.4; SAS Institute, Cary, NC) and *P* value was considered significant at ≤0.05 (SAS Institute, 2016). All means were separated with Tukey's honestly significant difference means separation test ($P \leq 0.05$) where appropriate. Where the substrate × species interaction was nonsignificant, main effects are discussed.

Results and discussion

Regardless of composition, the three substrates did not differ in their particle size distributions (data not shown). Substrates had an average of 4% (6.3 mm), 32% (2 mm), 31% (0.71 mm), 12% (0.5 mm), 12%

Table 3. Effect of substrate and days after seeding (DAS) on nutrient substrate concentration for basil and chives for the duration of a trial in which herbs were grown in three different substrates to test their capability to produce transplants from seed to optimal size without the use of additional fertilizer. Data collection began 29 DAS with 1:2 (v/v) extractions and were continued weekly until harvest of the species.[z]

	IN-N (ppm)[y]	NH_4-N (ppm)	NO_3-N (ppm)	P (ppm)	Mg (ppm)	Fe (ppm)	Mn (ppm)	B (ppm)
				Basil				
29 DAS								
SLC[x]	9.22 a[w]	1.59 a	7.63 a	47.43 a	26.27 a	0.04 a	0.02 a	0.10 a
OM	0.95 b	0.59 b	0.36 b	0.90 b	2.10 b	0.02 b	0 b	0.02 b
PEAT	2.68 ab	0.59 b	2.1 ab	0.17 b	5.14 b	0.03 a	0 b	0.02 b
P value[v]	0.0163	0.0017	0.0248	<0.0001	0.0005	0.0038	0.003	<0.0001
36 DAS								
SLC	2.70 a	0.67	2.03 a	27.73 a	15.02 a	0.03 a	0.007 a	0.06 a
OM	1.01 ab	0.66	0.35 b	0.81 b	1.19 b	0.02 b	0 b	0.03 b
PEAT	0.94 b	0.63	0.31 b	0.23 b	2.25 b	0.03 a	0 b	0.02 b
P value	0.0294	NS	0.0276	0.001	0.0026	0.0194	0.0041	0.0004
43 DAS								
SLC	1.28	0.43	0.84	20.39 a	10.67 a	0.05 a	0.01	0.05 a
OM	0.76	0.41	0.35	0.61 b	0.87 b	0.02 b	0	0.02 b
PEAT	0.76	0.40	0.36	0.06 b	1.57 b	0.03 b	0	0.02 b
P value	NS	NS	NS	0.0018	0.0035	<0.0001	NS	0.0104
				Chives				
29 DAS								
SLC	10.8 a	2.1	8.7 a	35.7 a	20.7 a	0.03 a	0.02 a	0.08 a
OM	1.7 b	0.6	1.2 b	0.9 b	0.8 b	0.02 b	0 b	0.03 b
PEAT	1.0 b	0.6	0.4 b	0.3 b	1.3 b	0.03 a	0 b	0.03 b
P value	0.0145	0.0425	0.0152	0.0004	0.0002	0.0011	0.0003	0.0044
36 DAS								
SLC	5.78	0.77	5.0	16.5 a	11.9 a	0.03	0.001	0.05
OM	0.99	0.67	0.32	1.62 b	1.62 b	0.02	0	0.03
PEAT	1.7	0.65	1.06	2.01 b	2.57 b	0.03	0	0.03
P value	NS	NS	NS	0.0091	0.0108	NS	NS	NS
43 DAS								
SLC	1.9 a	0.35	1.54 a	12.7 a	9.23 a	0.03	0.002	0.04 a
OM	0.65 b	0.37	0.28 b	1.96 b	2.39 b	0.03	0	0.02 b
PEAT	0.79 b	0.34	0.45 b	1.42 b	1.72 b	0.03	0	0.02 b
P value	0.0031	NS	0.0024	0.0117	0.0147	NS	NS	0.0092
50 DAS								
SLC	1.01	0.26 b	0.81	10.57 a	8.26	0.05	—	0.04
OM	0.78	0.35 a	0.44	1.62 b	1.84	0.03	—	0.02
PEAT	0.68	0.3 ab	0.38	1.82 b	2.72	0.04	—	0.02
P value	NS	0.02	NS	0.04	NS	NS	—	NS

[z] DAS × substrate interaction was significant; thus, data are shown by DAS.

[y] Nutrient solution of inorganic nitrogen (IN-N), ammonium-N (NH_4-N), nitrate-N (NO_3-N), phosphorus (P), magnesium (Mg), iron (Fe), manganese (Mn), and boron (B); 1 ppm = 1 $mg \cdot L^{-1}$.

[x] SLC = swine lagoon compost [15:85 (v/v) swine lagoon sludge:ground peanut hulls]; OM = aged pine bark fines, peat, soil, perlite, and worm castings; PEAT = conventional substrate of peat, aged bark fines, perlite, dolomitic limestone, gypsum, and a wetting agent.

[w] Means with different letters within a column and DAS are significantly different from each other based on Tukey's honestly significant difference mean separation procedures ($P \leq 0.05$).

[v] Analysis of variance NS at $P \geq 0.05$, *P* value given otherwise.

(0.25 mm), 7% (0.11 mm), and 2% (<0.11 mm). Substrate physical properties varied, except for total porosity, which was similar for all substrates (Table 1). Airspace was greatest for SLC and lowest for OM and PEAT. The opposite occurred for container capacity and available water as OM and PEAT were greatest and SLC was lowest. The SLC did not differ from OM and PEAT in unavailable water, but unavailable water values were greater for OM than PEAT. Bulk density was greatest for OM and SLC. Although root growth was not measured in this study, more prolific root growth throughout the plug was observed with SLC compared with OM and PEAT possibly because of the greater airspace in SLC as shown in Fig. 1. Composts produced from other agricultural wastes, and cow and poultry manures, have also produced suitable physical properties for production of transplants (Bustamante et al., 2008).

Table 4. Effect of substrate and days after seeding (DAS) on substrate nutrient concentration for dill. Data collection began 29 DAS with 1:2 (v/v) extractions and were continued weekly until harvest of the species.

	IN-N (ppm)[z]	NO_3-N (ppm)	P (ppm)	Ca (ppm)	Mg (ppm)	B (ppm)
Substrate[y]						
SLC	6.9 a[x]	6.2 a	18.9 a	8.0 a	12.5 a	0.06 a
OM	2.0 b	1.5 b	1.5 b	2.6 b	1.5 b	0.02 b
PEAT	1.4 b	0.9 b	1.4 b	3.7 b	2.2 b	0.02 b
P value[w]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Sample time						
29 DAS	6.2 a	5.4 a	12.3 a	7.5	7.6 a	0.04 a
36 DAS	4.4 ab	3.8 ab	6.7 ab	5.6	5.4 a	0.04 ab
43 DAS	2.0 b	1.6 b	5.4 b	5.1	4.4 a	0.03 b
50 DAS	1.1 b	0.8 b	4.7 b	6.0	4.3 a	0.03 b
P value	0.001	<0.0001	0.0391	NS	0.035	0.0005

[z] Nutrient solution of inorganic nitrogen (IN-N), nitrate-N (NO_3-N), phosphorus (P), calcium (Ca), magnesium (Mg), and boron (B); 1 ppm = 1 $mg\cdot L^{-1}$.

[y] SLC = swine lagoon compost [15:85 (v/v) swine lagoon sludge:ground peanut hulls]; OM = aged pine bark fines, peat, soil, perlite, and worm castings; PEAT = conventional substrate of peat, aged bark fines, perlite, dolomitic limestone, gypsum, and a wetting agent.

[x] Means with different letters within a column are significantly different from each other based on Tukey's honestly significant difference mean separation procedures ($P \leq 0.05$).

[w] Analysis of variance for the main effects of substrate and DAS. The two-way interaction DAS × substrate was NS at $P \geq 0.05$, *P* value given otherwise.

Table 5. Effect of substrate on germination of basil, chives, and dill and plant growth at transplant harvest. Germination counts of each species were taken at 12 d after seeding. Height was measured from the root collar to the tip of the shoot on the day of harvest. Dry weights were taken of the shoots (stems and leaves).

	Substrate[z]	Germination (%)[y]	Ht (cm)[x]	Dry wt (g)[x]
Basil	SLC	50	10 a[w]	0.21 a
	OM	54	5 b	0.01 b
	PEAT	55	6 ab	0.05 b
P value[v]		NS	0.0314	<0.0001
Chives	SLC	41	15 a	0.04
	OM	40	8 b	0.03
	PEAT	51	7 b	0.03
P value		NS	0.0165	NS
Dill	SLC	69	11 a	0.08 a
	OM	60	4 b	0.01 b
	PEAT	77	7 b	0.03 b
P value		NS	0.0027	0.0088

[z] SLC = swine lagoon compost [15:85 (v/v) swine lagoon sludge:ground peanut hulls]; OM = aged pine bark fines, peat, soil, perlite, and worm castings; PEAT = conventional substrate of peat, aged bark fines, perlite, dolomitic limestone, gypsum, and a wetting agent.

[y] Germination = (no. germinated/no. sown) × 100.

[x] 1 cm = 0.3937 inch, 1 g = 0.0353 oz.

[w] Means within a column with different letters are significantly different from each other based on Tukey's mean separation procedures ($P \leq 0.05$).

[v] Analysis of variance NS at $P \geq 0.05$, *P* value given otherwise.

Days after seeding did not interact with substrate for pH and EC when looking at the substrate solution supporting growth of each species (data not shown). The SLC substrate had a greater pH and EC than OM and PEAT for each species (Table 2). Substrate solution pH did not change substantially over time, whereas EC decreased from 0.24 to 0.14 $mS\cdot cm^{-1}$. Both substrate pH and EC were within acceptable ranges (Bunt, 1988; Raviv et al., 1986).

For basil and chives, the DAS × substrate interaction was significant for IN-N, NH_4-N, NO_3-N, P, Mg, Mn, and B (data not shown). Swine lagoon compost maintained greater IN-N concentrations than OM and PEAT throughout the 50 DAS as shown in Table 3. Inorganic nitrogen concentration decreased from ≥10 to ≥2 ppm, whereas OM and PEAT had ≥2 ppm at 29 DAS, and these concentrations decreased to ≤2 ppm. Almost all of the IN-N was in the NO_3-N form with SLC throughout which is indicative of a stable compost (California Compost Quality Council, 2001). The SLC substrate also maintained greater concentrations of P, Mg, Fe, Mn, and B than OM or PEAT over time for both basil and chives (Table 3). Phosphorus and Mg concentrations remained greater in SLC than OM and PEAT throughout the study; however, no transplants in SLC showed signs of nutrient toxicity for either nutrient (P. Herring, personal observation). For dill, the DAS × substrate interaction was largely nonsignificant; however, SLC also resulted in greater concentrations of IN-N, NO_3-N, P, Ca, Mg, Fe, Zn, Cu, and B than OM or PEAT, whereas substrate did not affect NH_4-N or K concentrations (Table 4 or data not shown).

Specific heavy metal concerns with SLC are Cu and Zn, which are given as feed supplements to increase growth performance in young pigs (Jacela et al., 2010). Before composting, the swine lagoon solids had Zn levels that slightly exceeded the USEPA target range of ≤2800 $mg\cdot L^{-1}$ with a level of 3043 $mg\cdot L^{-1}$ (Herring et al., 2018). Mixing the swine lagoon solids with peanut hulls [15:85 (by volume) SLS:peanut hull] and composting lowered Zn levels to 871 $mg\cdot L^{-1}$

and below. Copper in the swine lagoon solids were within the EPA limit (1500 $mg\cdot L^{-1}$) before composting, nevertheless, composting also lowered Cu levels (Herring et al., 2018). Using the compost developed by Herring et al. (2018) in this study, the SLC maintained greater Zn and Cu (Zn average = 0.04 ppm; Cu average = 0.01 ppm) concentrations than OM (Zn average = 0.02 ppm; Cu average = 0.01 ppm) and PEAT (Zn average = 0.03 ppm; Cu average = 0.01 ppm); however, all substrates had acceptable levels (Zn $\leq$0.5 ppm; Cu $\leq$3.0 ppm) (Misra, 1995; Panou-Filotheou et al., 2001).

Perhaps, the nutrient of greatest environmental concern with animal wastes is P (Jongbloed and Lenis, 1998; Sharpley et al., 1994). Substrate solution concentrations of P in SLC averaged $\approx$700 times greater than OM and PEAT across the species (Tables 3 and 4). Phosphorus in the substrate solution of SLC-grown transplants decreased over time from 47.43 ppm (basil) at 29 DAS to 10.57 ppm (chives) at 50 DAS for all species (Table 3). Although no P toxicity symptoms were observed, P remediation (Penn et al., 2001) of runoff water leaving a greenhouse using the SLC substrate is recommended.

Transplant growth was evaluated at germination and at maturity (Table 5). Germination of each species was similar (50% to 60%), regardless of substrate and appears to be in the expected range of chives and dill (Maynard and Hochmuth, 2007). The SLC and PEAT supported germination slightly better for dill; however, the SLC and OM resulted in slightly lower germination for chives. Height for basil, chives, and dill transplants was significantly greater with transplants produced in SLC than in OM and PEAT; however, there was no significant difference between SLC and PEAT for basil (Table 5). Harvest dry weights were also significantly greater for basil and dill when grown in SLC when compared with OM and PEAT. Dry weight of chives was similar regardless of substrate.

These results suggest that SLC can be used alone as a transplant substrate to produce basil, chives, and dill transplants of similar quality to commercially available peat-based products with no fertilizer applied. Research is continually adding to this field, as compost is an attractive option as a peat substitute (DeKalb et al., 2014; Kahn et al., 2005; O'Brien and Barker, 1996).

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