Swine Lagoon Compost: Analysis as Transplant Substrate for 'Traviata' Eggplant, 'Clemson Spineless' Okra, and 'Moneymaker' Tomato

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Additional index words. *Abelmoschus esculentus*, peanut hull, *Solanum lycopersicum*, *Solanum melongena*, swine waste, vegetable

Summary. **Composted swine (*Sus domesticus*) lagoon solids may provide a nutrient rich alternative to peatmoss (*Sphagnum* sp.) in a transplant substrate while dispersing the concentrated nutrients of this waste product in a cost effective, environmentally conscientious manner. The objective of this study was to evaluate the physical and chemical characteristics of swine lagoon solids composted with peanut (*Arachis hypogaea*) hulls and evaluate the utility of this substrate to support growth of vegetable transplants. Swine lagoon solids were composted in an in-vessel compost reactor with peanut hulls 15:85 v/v producing a transplant substrate, swine lagoon compost (SLC). A greenhouse study was conducted with three vegetable species: 'Moneymaker' tomato (*Solanum lycopersicum*), 'Traviata' eggplant (*Solanum melongena*), and 'Clemson Spineless' okra (*Abelmoschus esculentus*) grown in SLC, an organic potting mix (OM), and a peatmoss-based substrate (PEAT). 'Traviata' eggplant, 'Clemson Spineless' okra, and 'Moneymaker' tomato transplants produced in SLC substrate were significantly greater in height and dry weight than those produced in either the OM or PEAT. Based on these findings SLC can provide both the physical and chemical requirements needed for vegetable transplant production without additional amendments or fertilizers.**

Due to its favorable physical and chemical properties, peatmoss (*Sphagnum* sp.) has, for some time, been the main component of substrates for vegetable transplant production (Abad et al., 2001; Raviv et al., 1998). However, the high price of quality peatmoss, and scarcity in countries without natural peatmoss resources has led to an ongoing search for peatmoss substitutes (Raviv et al., 1998; Robertson, 1993). Therefore, substitutes for peatmoss are needed.

Much of the more than 67 billion kilograms of manure (American Society of Agricultural and Biological Engineers, 2010) produced by the 115 million hogs (*Sus domesticus*) farmed in the United States annually (U.S. Department of Agriculture, 2015) is captured in open anaerobic lagoons. Although manure is detained in the lagoon, solids settle and must be periodically dredged to maintain the functionality of the lagoon. Buildup of solids reduces the lagoon's treatment volume, which subsequently slows the biological decomposition and creates strong odors (Cantrell et al., 2008).

When dewatered and dried, swine lagoon solids may benefit horticultural plant production by providing all, or part, of a plant's nutrient requirements (Williams et al., 2015). However, excessively high nutrient concentrations can lead to electrical conductivity (EC) high enough to damage plant roots and contribute to environmental pollution (Garcia-Gomez et al., 2002; Williams et al., 2015). Copper and zinc are heavy metals of particular concern with swine lagoon solids because these metals are used as feed supplements to increase growth performance in young pigs (Jacela et al., 2010) and thus tend to be found in levels higher than acceptable for plant production by the U.S. Environmental Protection Agency (EPA). An additional challenge when using air-dried swine lagoon solids is the formation of hard aggregates of varying sizes requiring additional processing before application (A.C. Noah, H.T. Kraus, and P.L. Herring, personal observation). Further composting of these swine lagoon solids may improve nutrient value by binding mineral nutrients into stable organic structures (Burton and Turner, 2003) as well as eliminating the hard aggregates formed in the drying process. If the swine lagoon solids could be removed from the lagoon and composted, a useful product could be produced and benefit both the swine and horticultural crop production industries.

Composts derived from various organic wastes or agricultural byproducts have been evaluated for use in vegetable transplant production. Composts produced from biosolids have been evaluated for production of various vegetable transplants including tomato [*Solanum lycopersicum* (Bletosos

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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
0.4536	lb	kg	2.2046
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

and Gantidis, 2004; Pinamonti, et al., 1997)], eggplant [*Solanum melongena* (Bletosos and Gantidis, 2004)], and cauliflower [*Brassica oleracea* var. *botrytis* (Kahn et al., 2005)] with positive results. Evaluations of various composts derived from agricultural animal waste have largely shown that composts can be used as a partial, and sometimes complete, alternative for peatmoss (Fitzpatrick, 2001; Veeken et al., 2005) but fewer studies have focused on the use of composted swine lagoon wastes for this purpose.

These authors developed a substrate by composting swine lagoon solids with peanut (*Arachis hypogaea*) hulls 15:85 v/v resulting in a substrate with a 1.8N–1.5P–0.2K analysis, and a pH and EC that were appropriate for germinating seedlings (Herring et al., 2017). Although the raw swine lagoon solids had high copper and zinc levels, blending these solids with peanut hulls and composting the blend lowered copper and zinc levels to suitable levels. A bioassay analysis of this substrate indicated that it may be suitable for transplant production. Therefore, the objectives of this study were to evaluate the physical and chemical characteristics of swine lagoon solids composted with peanut hulls and the utility of this substrate to support growth of vegetable transplants.

Materials and methods

The substrates evaluated in this study included 1) swine lagoon solids composted with ground peanut hulls 15:85 v/v (SLC), 2) an organic potting medium with worm castings as a nutrient charge (OM), and 3) a commercial peatmoss-based potting medium with a 2-week inorganic nutrient charge (PEAT). No additional nutrients or liming agents were added to the SLC. The OM comprised aged pine (*Pinus* sp.) bark fines, peatmoss, perlite, and worm castings (Just Natural Organic Media; Jolly Gardener, Portland, ME). The PEAT was a conventional substrate comprising peatmoss with aged bark fines, perlite, vermiculite, dolomitic limestone, gypsum, and a wetting agent (Pro-Line C/P, Jolly Gardener).

Three vegetable species were grown: 'Moneymaker' tomato (*Solanum lycopersicum*), 'Traviata' eggplant (*Solanum melongena*), and 'Clemson Spineless' okra (*Abelmoschus esculentus*) in a greenhouse at the Marye Anne Fox Teaching Laboratory in Raleigh, NC (lat. 35.78°N, long. 78.64°W) beginning June 2016. Each species was grown in each of three substrate treatments (SLC, OM, and PEAT) with six replications in a randomized complete block design. Two sets of trays were used for each substrate × species combination. Each tray with black plastic horticultural 72-cell inserts (1-5/8 inch cell top diameter × 2-1/3 inches deep, 3-3/5 inch^3 maximum dry volume; Landmark Plastic Co., Akron, OH) was filled with the designated substrate and sown with three seeds per cell of each designated species per cell, two trays per species per replication. One set of trays (six replications) was used for plant growth analyses and one set (six replications) was used for substrate chemical property analyses. 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. Germination was counted 12 d after sowing and seedlings were thinned leaving only one seedling per cell. Then plastic sheeting was removed, and plants were watered by hand.

The substrates were evaluated and compared through chemical and physical analyses, and growth experiments. 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, air space, container capacity, and bulk density per procedures outlined in Tyler et al. (1993). Three replications of each substrate were packed into 6-3/20-inch^3 cylindrical aluminum rings (3 × 7/8 inches) per modified procedures of Bilderback et al. (1982) and used to determine unavailable water following procedures described in Klute (1986). Available water was calculated as container capacity – 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 shaker (Ro-tap model B; W.S. Tyler, Mentor, OH) fitted with seven sieves, 6.3 mm (1/4 inch), 2 mm (No. 10), 0.71 mm (No. 25), 0.5 mm (No. 35), 0.25 mm (No. 60), and 0.106 mm (No. 140) 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 15 d after sowing, pH and EC were measured (six replications) weekly using 1:2 v/v substrate to water extracts. Before extraction, trays were watered by hand and allowed to drain for 3 h to establish container capacity within the substrate. For each substrate sample, 400 mL of planted substrate was thoroughly mixed with 800 mL of distilled, deionized water and allowed to sit for 20 min. The solution was then strained through Whatman #1 filter paper (Grade 1, 185 mm, Cat 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, Woonsocket, RI). After EC and pH measurements, substrate solution samples were submitted to the North Carolina Department of Agriculture and Consumer Services, Raleigh for solution analyses. Inorganic-nitrogen (IN-N) fraction concentrations include nitrate plus nitrite (NO_3 + NO_2) and ammonium (NH_3 + NH_4). Organic nitrogen fraction concentration included urea. Nitrate was determined on a 10-mL sample filtered again using acid washed filter paper (Laboratory Filtration Group, Houston, TX) by nitrate-hydrazine reduction (Kempers and Luft, 1988; Skalar Analytical, 1995a). Ammonium was determined by a modified Berthelot reaction (Krom, 1980; Skalar Analytical, 1995b) and urea concentration was determined with the diacetyl monoxime thiosemicarbazide colorimetric method (Skalar Analytical, 1995c; Sullivan and Havlin, 1991) with an auto-flow spectrophotometric analyzer (San++ Segmented Flow Auto-Analyzer; Skalar Instruments, Breda, The Netherlands). Total concentrations of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), and sodium (Na) were

Table 1. Total porosity, air space, container capacity, available water, unavailable water, and bulk density of swine lagoon compost, a commercial organic substrate, and commercial peatmoss-based substrate (n = 3).

Substrate[z]	Total porosity (%)[y]	Air space (%)[x]	Container capacity (%)[w]	Available water (%)[v]	Unavailable water (%)[u]	Bulk density ($g \cdot cm^{-3}$)[t]
SLC	80	42 a[s]	38 b	9 b	29 ab	0.20 a
OM	78	20 b	59 a	30 a	29 a	0.20 a
PEAT	80	16 b	63 a	36 a	27 b	0.15 b
Optimum[r]	>85	20–30	50–100	24–40	20–30	≤0.4
ANOVA[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, peatmoss, soil, perlite, and worm castings as a nutrient charge; PEAT = conventional substrate of peatmoss, aged bark fines, perlite, dolomitic limestone, gypsum, a wetting agent, and a 2-week inorganic nutrient charge.
[y]Based on percent volume of a 3-inch (7.6 cm) core at 0 kPa.
[x]Total porosity – container capacity.
[w]Measured as percent volume of a 3-inch core at drainage and represents the volume of water held in the substrate.
[v]Container capacity – unavailable water and represents the volume of water in the substrate that is available for plant uptake.
[u]Based on percent volume of a 3-inch core at 1500 kPa (217.6 psi) and represents the volume of water in the substrate that is not available for plant uptake.
[t]Bulk density is measured as the ratio of dry solids to the bulk volume of the substrate; 1 $g \cdot cm^{-3}$ = 0.5780 $oz/inch^3$.
[s]Means between substrates within a column with different letters are significantly different from each other based on Tukey's honestly significant difference means separation procedures ($P \leq 0.05$).
[r]Per Abad et al. (2001) and Bunt (1988).
[q]ANOVA = analysis of variance. Nonsignificant (NS) ≥ 0.05, *P* value given otherwise.

determined on a 10-mL sample filtered again using acid washed filter paper (Laboratory Filtration Group, Houston, TX) with inductively coupled plasma-optical emission spectrometry (Arcos EOP; Spectro Analytical, Mahwah, NJ) (Donohue and Aho, 1992; U.S. EPA, 2001).

Plant heights and stem caliper were assessed when each species reached fully developed transplant stage and were 42, 22, and 30 d after sowing for 'Traviata' eggplant, 'Clemson Spineless' okra, and 'Moneymaker' tomato, respectively. Plant height was measured from the root collar to the apical meristem of the shoot. Stem caliper was measured directly below the cotyledon node. Shoots (stems and leaves) were removed at the substrate surface, dried at 62 °C for 24 h, and then weighed.

All variables were subjected to analysis of variance (ANOVA) procedures using the PROC GLM procedure in SAS (version 9.4; SAS Institute, Cary, NC), and *P* was considered significant at ≤0.05. All means were separated with Tukey's honestly significant difference means separation test ($P < 0.05$) where appropriate. Where the species × substrate interaction is nonsignificant, main effects are presented.

Results and discussion

Regardless of composition, the SLC, OM, and PEAT were not significantly different in the distribution of particles collected on each of the sieve sizes (data not shown). Average percentage of the total samples for each sieve size were 4 (6.3 mm), 32 (2 mm), 31 (0.71 mm), 12 (0.5 mm), 12 (0.25 mm), 7 (0.11 mm), and 2 (<0.11 mm). Substrate air and water holding capacities varied but not the total porosity, which was not significantly different for all substrates (Table 1). This indicated that the particles of each substrate nested together differently resulting in different pore sizes. Air space was statistically greater for SLC and lower for OM and PEAT. Although root growth was not measured in this study, more prolific root growth throughout the plug was observed in all species when grown in SLC compared with OM and PEAT (Fig. 1), possibly due to the greater air space in SLC. The opposite was true for container capacity and available water, as OM and PEAT had statistically greater container capacity than SLC. The unavailable water content of SLC did not differ significantly from those of OM and PEAT, but OM had a significantly greater unavailable water content than PEAT. Bulk density was statistically

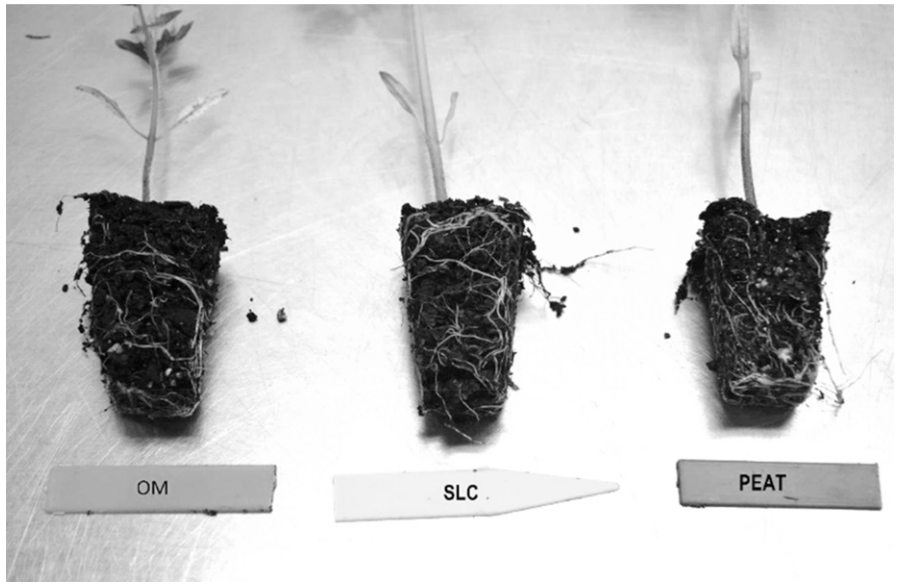

Fig. 1. 'Moneymaker' tomato root growth 30 d after sowing in substrates composed of OM (aged pine bark fines, peatmoss, soil, perlite, and worm castings as a nutrient charge), SLC (swine lagoon compost 15:85 v/v swine lagoon sludge:ground peanut hulls), and PEAT (conventional substrate of peatmoss, aged bark fines, perlite, dolomitic limestone, gypsum, a wetting agent, and a 2-week inorganic nutrient charge), respectively.

Table 2. Substrate pH and electrical conductivity (EC) of substrate extracts (1:2 v/v substrate to water) used to grow 'Clemson Spineless' okra, 'Moneymaker' tomato, and 'Traviata' eggplant transplants in either swine lagoon compost, a commercial organic substrate, or a commercial peatmoss-based substrate as effected by sample time and substrate over a period of 15 d after seeding through 43 d (n = 6).

	pH			EC ($mS \cdot cm^{-1}$)[z]		
Sample time (d)	Okra	Tomato	Eggplant	Okra	Tomato	Eggplant
15	6.0	5.6 ab[y]	5.6 ab	0.15 b	0.10 b	0.22 a
22	6.0	5.7 a	5.6 a	0.23 a	0.20 a	0.25 a
29	–	5.4 b	5.4 b	–	0.10 b	0.12 b
36	–	–	5.6 ab	–	–	0.12 b
43	–	–	5.5 ab	–	–	0.13 b
ANOVA[x]	NS	NS	0.04	0.01	0.0001	0.0001
Substrate[w]						
SLC	5.9 a	6.0 a	6.0 a	0.32 a	0.21 a	0.28 a
OM	5.4 b	5.4 b	5.0 b	0.14 b	0.10 b	0.12 b
PEAT	5.3 b	5.4 b	5.0 b	0.11 b	0.13 b	0.10 b
ANOVA	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

[z]1 $mS \cdot cm^{-1}$ = 1 mmoh/cm.
[y]Means with different letters within a column are significantly different from each other based on Tukey's honestly significant difference means separation procedures ($P \leq 0.05$).
[x]Analysis of variance of main effects of sample time and substrate are shown. The two-way interaction sample time × substrate was nonsignificant (NS) at $P \leq 0.05$.
[w]SLC = swine lagoon compost 15:85 v/v swine lagoon sludge:ground peanut hulls; OM = aged pine bark fines, peatmoss, soil, perlite, and worm castings as a nutrient charge; PEAT = conventional substrate of peatmoss, aged bark fines, perlite, dolomitic limestone, gypsum, a wetting agent, and a 2-week inorganic nutrient charge.

greater for OM and SLC than for PEAT. With the low profile (2-1/3 inches) of a transplant tray where less free water is pulled from the substrate by gravity a substrate with higher air space and lower container capacity, as with the SLC may be provide favorable root growth conditions.

The sample time × substrate interactions for substrate solution pH and EC were not significant therefore, the data were pooled and main effects of sample time and substrate on pH and EC are show (Table 2). Substrate pH did not change substantially over time. The EC of substrate with 'Traviata' eggplant decreased significantly over time while EC in substrates with 'Clemson Spineless' okra and 'Moneymaker' tomato increased significantly. Substrate extract EC did not differ significantly between OM and PEAT. However, substrate extracts from SLC had significantly higher pH and EC than OM and PEAT. However, all substrates had acceptable pH and EC ranges (Bunt 1988; Raviv et al., 1986). The higher EC levels in SLC were likely due to higher nutrient concentrations in this substrate and may result in greater plant growth.

'Traviata' eggplant germinated at the same rate in SLC and OM but with lesser success in PEAT (Table 3). Germination of 'Clemson Spineless'

Table 3. Germination percentage, 12 d after sowing, and plant growth measurements at transplant maturity for 'Traviata' eggplant, 'Clemson Spineless' okra, and 'Moneymaker' tomato grown in either swine lagoon compost, a commercial organic substrate, or a commercial peatmoss-based substrate as effected by substrate (n = 6).

	Substrate[z]	Germination (%)	Ht (cm)[y]	Dry wt (g)[x]	Caliper (mm)[w]
Eggplant	SLC	100 a[v]	9 a	10 a	3 a
	OM	100 a	2 c	1 b	1 c
	PEAT	60 b	5 b	3 b	2 b
ANOVA[u]		0.001	0.0001	0.0001	0.0001
Okra	SLC	90	16 a	8 a	2.4 a
	OM	90	13 b	6 c	2.0 b
	PEAT	90	14 ab	7 b	1.9 b
ANOVA		NS	0.0327	0.0001	0.0034
Tomato	SLC	80 b	14 a	6 a	3 a
	OM	90 a	5 c	1 c	1 c
	PEAT	90 a	7 b	3 b	2 b
ANOVA		0.0012	0.0001	0.0001	0.0001

[z]SLC = swine lagoon compost 15:85 v/v swine lagoon sludge:ground peanut hulls; OM = aged pine bark fines, peatmoss, soil, perlite, and worm castings as a nutrient charge; PEAT = conventional substrate of peatmoss, aged bark fines, perlite, dolomitic limestone, gypsum, a wetting agent, and a 2-week inorganic nutrient charge.
[y]Measured from root collar to tip of shoot; 1 cm = 0.3937 inch.
[x]Shoots (stems and leaves) dried at 62°C (143.6°F) for 48 h; 1 g = 0.0353 oz.
[w]Measured directly below cotyledon scar; 1 mm = 0.0394 inch.
[v]Means with different letters within a column are significantly different from each other based on Tukey's honestly significant difference means separation procedures ($P \leq 0.05$).
[u]Analysis of variance. Nonsignificant (NS) ≥ 0.05, *P* value given otherwise. ANOVA of main effect of substrate by species is shown.

okra was not significantly affected by substrate, whereas 'Moneymaker' tomato germinated at a significantly lower rate in SLC than in OM or PEAT, which were not significantly different from each other. However, Herring et al. (2017) found no significant difference in 'Moneymaker' tomato germination when examining SLC and a peatmoss based potting substrate in three bioassays. Plant height was significantly greater for 'Traviata' eggplant and 'Moneymaker' tomato transplants produced in SLC than in OM and PEAT, whereas 'Clemson Spineless' okra transplant height was not significantly different in SLC and PEAT (Table 3). 'Clemson Spineless' okra height was lower in OM than in SLC. Dry weight and caliper were significantly greater for all species grown in SLC when compared with OM and PEAT substrates. While species grew differently in the substrates, SLC supported transplant growth better than or as well as OM and PEAT; however, nutrient release over time may have exceeded plant uptake.

For 'Traviata' eggplant, the sample time interacted with substrate for IN-N, NH_4, NO_3, P, K, Ca, Mg, S, Fe, Mn, and B, but not for Zn and Cu, indicating that the relationship between nutrient release in the substrate and uptake by 'Traviata' eggplant varied over the 43 d. Through the first 22 d after sowing, the SLC substrate had more IN-N, NH_4, and NO_3 than OM and more IN-N and NH_4 than PEAT (Table 4). At 15 d after sowing, NH_4-N and NO_3-N concentrations each comprised ≈50% of the IN-N. From 29 d after sowing onward, N concentrations in the SLC were low (<1.4 ppm). Nitrogen concentration in OM remained at or below 1 ppm throughout the experiment. The initial inorganic nutrient charge added to the PEAT resulted in nearly 5 ppm NO_3 at 15 d after sowing but less than 0.8 ppm from 22 d through 43 d after sowing. The SLC also maintained higher P, Ca, Mg, and B concentrations throughout the 43 d production time for 'Traviata' eggplant transplants. Initially, P concentrations in SLC were high (>60 ppm) and remained >10 ppm P throughout. Effluent discharged from production areas using the SLC substrate should be managed to remove excess P. Potassium concentrations in SLC were higher than OM and PEAT at 15 d after sowing but declined quickly and were either not different or lower than OM and PEAT throughout the remaining 43 d. Boron concentration ranged from 0.02 to 0.2 ppm, well below toxicity levels (22 ppm B) (Bunt, 1988). Higher B may be advantageous as it is the most widely deficient micronutrient in vegetable crops (Swiader and Ware, 2002). Extract from SLC with 'Traviata' eggplant had higher Zn (0.06 ppm) and Cu (0.02 ppm) levels than substrate extract OM or PEAT (data not shown).

For 'Clemson Spineless' okra and 'Moneymaker' tomato, substrate did not interact with sample time, indicating that nutrient release and uptake rate were matched over the 43 d. Thus, the data were pooled and main effects of substate are shown (Table 5).

Table 4. Inorganic nitrogen (IN-N), ammonium (NH_4), nitrate (NO_3), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), and boron (B) concentrations from substrate extracts (1:2 v/v substrate to water) used to grow 'Traviata' eggplant in either swine lagoon compost, a commercial organic substrate, or a commercial peatmoss-based substrate as effected by substrate at each sample time beginning with 15 d after seeding through 43 d (n = 6).

		IN-N[y]	NH_4	NO_3	P	K	Ca	Mg	Fe	Mn	B
Sample time (d)	Substrate[z]	(ppm)									
15	SLC	28.5 a[x]	11.6 a	16.9 a	62.7 a	20.9 a	11.6 a	28.7 a	0.05 a	0.04 a	0.13 a
	OM	0.9 b	0.5 b	0.4 b	0.7 b	3.2 b	1.0 b	0.4 b	0.02 b	0.00 b	0.02 b
	PEAT	4.8 b	0.5 b	4.3 ab	1.1 b	7.1 ab	5.2 ab	3.2 b	0.03 b	0.00 b	0.02 b
	ANOVA[w]	0.01	0.007	0.03	0.0002	0.03	0.005	0.0004	0.0001	0.0006	0.0004
22	SLC	17.4 a	3.0 a	14.0 a	63.0 a	9.5	15.0 a	34.0 a	0.05 b	0.03 a	0.10 a
	OM	0.9 b	0.6 b	0.4 b	0.4 b	6.1	3.0 b	1.0 b	0.04 c	0.00 b	0.02 b
	PEAT	1.0 b	0.6 b	0.3 b	1.0 b	4.9	6.0b	3.0 b	0.07 a	0.00 b	0.02 b
	ANOVA	0.0006	0.0006	0.0007	0.0001	NS	0.0001	0.0001	0.0008	0.0020	0.0001
29	SLC	1.4	0.6	0.8	25.0 a	0.6 b	7.0 a	12.0 a	0.04 a	0.01	0.06 a
	OM	0.8	0.5	0.2	0.6 b	3.0 a	2.0 b	0.7 b	0.02 b	0.00	0.02 b
	PEAT	1.3	0.5	0.8	0.2 b	2.0 a	3.0 b	1.0 b	0.04 a	0.00	0.02 b
	ANOVA	NS	NS	NS	0.0001	0.0002	0.0001	0.0001	0.003	NS	0.0001
36	SLC	0.8	0.7	0.2	12.0 a	1.2	5.3	6.0 a	0.06 a	0.00	0.03 a
	OM	0.9	0.7	0.2	4.0 ab	3.3	2.9	2.0 ab	0.03 b	0.00	0.02 b
	PEAT	0.9	0.6	0.2	0.4 b	2.4	2.6	1.0 b	0.04 ab	0.00	0.02 b
	ANOVA	NS	NS	NS	0.02	NS	NS	0.03	0.009	NS	0.01
43	SLC	1.0	0.6	0.4	19.0 a	0.3 c	7.0 a	10.0 a	0.05 a	0.00	0.04 a
	OM	1.0	0.5	0.5	0.6 b	4.0 a	2.0 b	1.0 b	0.02 c	0.00	0.02 b
	PEAT	1.0	0.6	0.5	0.1 b	2.0 b	3.0 b	1.0 b	0.03 b	0.00	0.02 b
	ANOVA	NS	NS	NS	0.0001	0.0001	0.0001	0.0001	0.0001	NS	0.0001

[z]SLC = swine lagoon compost 15:85 v/v swine lagoon sludge:ground peanut hulls; OM = aged pine bark fines, peatmoss, soil, perlite, and worm castings as a nutrient charge; PEAT = conventional substrate of peatmoss, aged bark fines, perlite, dolomitic limestone, gypsum, a wetting agent, and a 2-week inorganic nutrient charge.

[y]IN-N fraction concentrations include NO_3+ NO_2 plus NH_4; 1 ppm = 1 $mg \cdot L^{-1}$.

[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]ANOVA = Analysis of variance of the effect of substrate within each sample time. Nonsignificant (NS) at $P \geq 0.05$. P value given otherwise. The two-way sample time × substrate interaction was significant.

Table 5. Inorganic nitrogen (IN-N), ammonium (NH_4), nitrate (NO_3), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), zinc (Zn), and boron (B) concentrations from substrate extracts (1:2 v/v substrate to water) used to grow 'Clemson Spineless' okra and 'Moneymaker' tomato grown in either swine lagoon compost, a commercial organic substrate, or a commercial peatmoss-based substrate as effected by substrate at each sample time beginning with 15 d after seeding through 43 d (n = 6).

	IN-N[y]	NH_4	NO_3	P	K	Ca	Mg	S	Mn	Zn	B
Substrate[z]	(ppm)										
Okra											
SLC	8.0 a[x]	3.0 a	5.0 a	50.0 a	6.0 a	11.0 a	23.0 a	7.0 a	0.03 a	0.1 a	0.1 a
OM	1.0 b	0.6 b	0.05b	1.0 b	4.0 ab	3.0 b	1.0 b	8.0 b	0.00 b	0.0 b	0.0 b
PEAT	1.0 b	0.6 b	0.05b	0.5 b	3.0 b	5.0 b	2.0 b	11.0 b	0.00 b	0.0 b	0.0 b
ANOVA[w]	0.0001	0.0004	0.004	0.0001	0.03	0.005	0.0004	0.0001	0.0006	0.0004	0.0001
Tomato											
SLC	4.0 a	3.0 a	3.0 a	25.0 a	3.0 b	8.0 a	16.6	6.0 b	0.01 a	0.04 a	0.05 a
OM	0.9 b	0.6 b	0.3 b	1.0 b	5.0 a	2.0 c	1.3	7.0 b	0.00 b	0.03 b	0.02 b
PEAT	1.0 b	0.5 b	0.6 b	0.3 b	3.0 b	5.0 b	2.2	10.0 a	0.00 b	0.02 b	0.02 b
ANOVA	0.002	0.003	0.006	0.0001	0.005	0.0001	NS	0.0008	0.0001	0.001	0.0001

[z]SLC = swine lagoon compost 15:85 v/v swine lagoon sludge:ground peanut hulls; OM = aged pine bark fines, peatmoss, soil, perlite, and worm castings as a nutrient charge; PEAT = conventional substrate of peatmoss, aged bark fines, perlite, dolomitic limestone, gypsum, a wetting agent, and a 2-week inorganic nutrient charge.
[y]IN-N fraction concentrations include NO_3+ NO_2 plus NH_4; 1 ppm = 1 $mg{\cdot}L^{-1}$.
[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 of the effect of substrate within each sample time. Nonsignificant (NS) at $P \geq 0.05$. P value given otherwise. The two-way sample time × substrate interaction was NS at $P \leq 0.05$.

The SLC provided more IN-N, NH_4, NO_3, P, Ca, Mg, Mn, Zn, and B to 'Clemson Spineless' okra and 'Moneymaker' tomato transplants than OM and PEAT did. Phosphorus concentrations in the extracts of SLC were numerically twice as high in 'Clemson Spineless' okra than in 'Moneymaker' tomato. More K was in the substrate solution of OM than of SLC or PEAT for 'Moneymaker' tomato, whereas K concentrations in the substrate solutions of SLC and PEAT were not significantly different for 'Clemson Spineless' okra. Potassium concentrations in the substrate solutions may have differed due to nutrient release in the substrate or plant uptake and growth rates. Sulfur concentrations in PEAT were higher than in SLC with both 'Moneymaker' tomato and 'Clemson Spineless' okra. Substrate extract from SLC with 'Clemson Spineless' okra and 'Moneymaker' tomato contained higher Zn and Cu concentrations than extract from OM and PEAT (Table 5 and data not shown).

These results suggest that swine lagoon solids, when composted with peanut hulls, produced a growing media that could be used alone, with no starter charge of fertilizer, as a horticultural transplant substrate. 'Moneymaker' tomato, 'Traviata' eggplant, and 'Clemson Spineless' okra transplants grown in swine lagoon compost were of equal or greater size than when grown in a commercial peatmoss based or a commercial organic substrate. Zinc and copper levels in the swine lagoon compost were lower than EPA guidelines. Unfortunately, phosphorous concentrations in the swine lagoon compost substrate were high enough that phosphorous remediation of the leachate water in the greenhouse or runoff water leaving a greenhouse should be practiced.

Literature cited

Abad, M., P. Noguera, and S. Bures. 2001. National inventory of organic wastes for use as growing media for ornamental potted plant production: Case study in Spain. Bioresource. Technol. 77:197–200, https://doi.org/10.1016/s0960-8524(00)00152-8.

American Society of Agricultural and Biological Engineers. 2010. Manure production and characteristics. 13 Apr. 2017. <http://large.stanford.edu/publications/coal/references/docs/ASAEStandard.pdf>.

Bilderback, T.E., W.C. Fonteno, and D.R. Johnson. 1982. Physical properties of media composed of peanut hulls, pine bark, and peat moss and their effects on azalea growth. J. Amer. Soc. Hort. Sci. 107:522–525.

Bletosos, F.A. and N.D. Gantidis. 2004. The effect of municipal sewage sludge on growth of transplants and fruit quality of eggplant (*Solanum melongena*) and tomato (*Lycopersicon esculentum*). Agrochimica 48(3): 104–114.

Bunt, A.C. 1988. Media and mixes for container-grown plants: A manual on the preparation and use of growing media for pot plants. 2nd ed. Unwin Hyman, London, UK.

Burton, C. and C. Turner. 2003. Manure management: Treatment strategies for sustainable agriculture. Silsoe Res. Inst., Bedford, UK, https://doi.org/10.1016/j.livsci.2006.04.001.

Cantrell, K.B., J.P. Chastain, and K.P. Moore. 2008. Geotextile filtration performance for lagoon sludges and liquid animal manures dewatering. Trans. ASABE 51:1067–1076, https://doi.org/10.13031/2013.24526.

Donohue, S.J. and D.W. Aho. 1992. Determination of P, K, Ca, Mg, Mn, Fe, Al, B, Cu, and Zn in plant tissue by inductively coupled plasma emission spectroscopy, p. 37–40. In: C.O. Plank (ed.). Plant analysis reference procedures for the southern region of the United States. 4 Nov. 2021. <https://aesl.ces.uga.edu/sera6/PUB/PlantAnalysisReferenceProcedures.pdf>.

Fitzpatrick, G.E. 2001. Compost utilization in ornamental and nursery crop production systems, p. 135–149. In: P.J. Stoffella and B.A. Kahn (eds.). Compost utilization in horticultural cropping systems. Lewis Publ., Boca Raton, FL.

Garcia-Gomez, A., M.P. Bernal, and A. Roig. 2002. Growth of ornamental plants in two composts prepared from agroindustrial wastes. Bioresour. Technol. 83:81–87,

https://doi.org/10.1016/s0960-8524(01)00211-5.

Herring, P.L., A.C. Noah, and H.T. Kraus. 2017. Maturation of peanut hull and swine lagoon compost. Acta Hort. 1266:261–267.

Jacela, J.Y., J.M. DeRouchey, M.D. Tokach, R.D. Goodband, J.L. Nelssen, D.G. Renter, and S.S. Dritz. 2010. Feed additives for swine: Fact sheet—high dietary levels of copper and zinc for young pigs. J. Swine Health Prod. 18:87–91.

Kahn, B.A., J.K. Hyde, J.C. Cole, P.J. Stoffella, and D.A. Graetz. 2005. Replacement of a peat-lite medium with compost for cauliflower transplant production. Compost Sci. Util. 13:175–179, https://doi.org/10.1080/1065657X.2005.10702238.

Kempers, A.J. and A.G. Luft. 1988. Re-examination of the determination of environmental nitrate as nitrite by reduction with hydrazine. Analyst (Lond.) 113:1117–1120, https://doi.org/10.1039/AN9881301117.

Klute, A. 1986. Methods of soil analysis: Part 1, Physical and mineralogical methods, 2nd ed. Amer. Soc. Agron., Soil Sci. Amer., Madison, WI, https://doi.org/10.1002/gea.3340050110.

Krom, M.D. 1980. Spectrophotometric determination of ammonia: A study of a modified Berthelot reaction using salicylate and dichloroisocyanurate. Analyst (Lond.) 105:305–316, https://doi.org/10.1039/an9800500305.

Pinamonti, F., G. Stringari, and G. Zorzi. 1997. Use of compost in soilless cultivation. Compost Sci. Util. 5(2):38–46, https://doi.org/10.1080/1065657X.1997.10701872.

Raviv, M., Y. Chen, and Y. Inbar. 1986. Peat and peat substitutes as growth media for container grown plants, p. 257–287. In: Y. Chen and Y.A. Dordrecht (eds.). The role of organic matter in modern agriculture. Martinus Nijhoff, Leiden, The Netherlands.

Raviv, M., B. Zaidman, and Y. Kapulnik. 1998. The use of compost as a peat substitute for organic vegetable production. Compost Sci. Util. 6(1):46–52, https://doi.org/10.1080/1065657X.1998.10701908.

Robertson, R.A. 1993. Peat, horticulture and the environment. Biodivers. Conserv. 2:541–547, https://doi.org/10.1007/bf00056747.

Skalar Analytical. 1995a. Nitrate + nitrite, p. 190–192. In: SAN++ segmented flow analyzer: Water analysis. Vol. 6. Skalar Anal., Breda, The Netherlands.

Skalar Analytical. 1995b. Ammonia, p. 73–75. In: SAN++ segmented flow analyzer: Water analysis. Vol. 6. Skalar Anal., Breda, The Netherlands.

Skalar Analytical. 1995c. Urea, p. 241–243. In: SAN++ segmented flow analyzer: Water analysis. Vol. 6. Skalar Anal., Breda, The Netherlands.

Sullivan, D.M. and J.L. Havlin. 1991. Flow injection analysis of urea nitrogen in soil extracts. Soil Sci. Soc. Amer. J. 55:109–113, https://doi.org/10.2136/sssaj1991.03615995005500010019x.

Swiader, J.M. and G.W. Ware. 2002. Producing vegetable crops. 5th ed. Interstate Publ., Danville, IL.

Tyler, H.H., S.L. Warren, T.E. Bilderback, and K.B. Perry. 1993. Composted turkey litter: II.Effect on plant growth. J. Environ. Hort. 11:137–141.

U.S. Department of Agriculture. 2015. Overview of the United States hog industry. 19 Nov. 2021. <https://downloads.usda.library.cornell.edu/usda-esmis/files/rr171x21v/cz30pw658/js956j577/hogview-10-29-2015.pdf>.

U.S. Environmental Protection Agency. 2001. Method 2007 trace elements in water, solids, and biosolids by inductively coupled plasma-atomic emission spectrometry, revision 5.0. EPA-821-R-01-010. 4 May 2020. <https://www.epa.gov/sites/default/files/2015-08/documents/method_200-7_rev_5_2001.pdf>.

Veeken, A.H.M., W.J. Blok, F. Curci, G.C. Coenen, A.J. Termorshuizen, and H.V.M. Hamelers. 2005. Improving quality of composted biowaste to enhance disease suppressiveness of compost-amended, peat based potting mixes. Soil Biol. Biochem. 37:2131–2140, https://doi.org/10.1016/j.soilbio.2005.03.018.

Williams, M., H. Kraus, and E. Riley. 2015. Dealing with the poo: Utilizing sine lagoon compost as an amendment to pine bark. Southern Nursery Assoc. Res. Conf. 60:41–44.