ABSTRACT

HERRING, PAIGE LEIGH. The Use of Swine Lagoon Sludge for Herb Transplants and Fresh Cut Field Production. (Under the direction of Helen T. Kraus and Chris Gunter.)

In 2012, the USDA reported 284 farms in North Carolina growing greenhouse vegetables and fresh cut herbs, a 44% increase from 2007. Producers, becoming aware of this trend, are beginning to complement their main cropping system with herbs with similar production methods, adding to the increasing herb production in North Carolina. Many vegetable producers are looking for ways to incorporate herb production into their operations while keeping costs of production low. Sphagnum peat is a finite resource that is often times used in the horticultural industry as a component in many substrates, especially greenhouse production of transplants. Due to the depletion of peatlands the cost is increasing for quality peat. Composted swine lagoon sludge (SLS) is an attractive opportunity, as it may provide a portion, if not all, of the nutrients needed to support plant growth, as well as using a waste product in an environmentally friendly manner.

A compost was developed using an in-vessel compost reactor to compost SLS with peanut hulls [15:85 (v/v)] to produce a compost (SLC). A greenhouse study was conducted produce transplants of three species: Ocimum basilicum L. ‘Dark Opal’ (basil), Allium schoenoprasum L. (chives), and Anethum graveolens L. ‘Hera’ (dill) in three substrates: SLC, a commercially available organic potting substrate with a nutrient charge (OM), and a commercial peat-based potting substrate with a two-week nutrient charge (PEAT). The average height for basil, chives, and dill was significantly greater at when produced in the SLC substrate compared to the OM and PEAT. Harvest dry weights were also significantly greater for basil and dill when grown in SLC. Based on these results swine lagoon compost have provided both the physical and chemical requirements for herb transplant production. SLC produced transplants without any additional fertilizers or amendments.

To test the utility of the SLS as a fertilizer for fresh cut herb production, Ocimum basilicum L. “Dark opal’ (basil), Origanum vulgare L. ‘hirtum’ (oregano), Mentha spp. L. (mint), Anethum graveolens L. ‘Hera’ (dill), Allium schoenoprasum L. (chives) and Foeniculum vulgare Mill. (fennel) were grown in in field trials utilizing full (80 lbs. N per acre) and half
(40 lbs. N per acre) rates of SLS or turkey litter. Growth and yield of these species were also compared to a conventional fertilizer program. Total fresh weight of basil and mint produced similar yields in the SLS and the control. Growth of dill, oregano, chives, and fennel was not affected by rate or source of nutrients, possibly due to the fertilizer nature or the soils at planting.
The Use of Swine Lagoon Sludge for Herb Transplants and Fresh Cut Field Production

by

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DEDICATION

To everyone that has supported me in every endeavor and has continued to walk my career path wherever it takes me. You all know who you are.

Especially to mama, daddy, Morgan, Daniel, Caiden, Aunt Brenda, and Grandmama Katie for every pep-talk and helpful nudge when my road would get tough.
BIOGRAPHY

Paige grew up Goldsboro, North Carolina. More specifically the one stoplight town of Rosewood. She developed a love for plants at a young age working in the vegetable garden and flower beds around her home, as well as her grandmother’s. She followed this love for agriculture into high school, and was active in the agricultural program at Rosewood High School, as well as in their FFA Chapter. She continued this passion at the University of Mount Olive and graduated magna cum laude with a Bachelors of Science in Agricultural Education in 2015. Paige, with her love for knowledge and passion for agriculture, specifically horticulture, enrolled at North Carolina State University and graduated in December of 2017 with a Masters of Horticultural Science and a minor in Agriculture and Extension Education.
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LITERATURE REVIEW

Waste Production

Many nutrient sources are available for plant producers. The use of animal waste as alternative nutrient sources has been and continues to be a viable option for plant production (Alvarenda, et al., 2015; Chong, 2005; Ikenganyia, et al., 2014). In North Carolina (N.C.), poultry litter, turkey litter, cow manure, and swine manure are applied to many agricultural fields for their nutrient and organic matter benefits (Bustamante, et al., 2008; Chong, 2005; Duffera, et al., 1999b; Moore, et al., 2005).

North Carolina produces more than 8.7 million hogs in over 60 percent of the state (National Agricultural Statistics Service, 2016). These hogs produce approximately 584 kg of fresh manure per finished animal (American Society of Agricultural and Biological Engineers, 2010). Hog waste is washed from beneath the hogs’ pens and this slurry is captured and contained in open anaerobic lagoons. The lagoons are comprised of an anaerobic treatment volume, manure and wastewater storage volume, volume for net rainfall, a freeboard (the distance between the normal maximum operating water surface and the top of the barrier), and sludge storage (Cantrell, et al., 2008). Multiple barns generally wash into the same lagoon, often leading to excess slurry accumulation. The solids (sludge) settle out of the slurry and accumulate in the bottom of the lagoon. Sludge storage volume is generally underestimated when maintaining a lagoon (Cantrell, et al., 2008). However, sludge can accumulate for ten to fifteen years before removal is necessary to maintain proper function
(Moore, et al., 2005). There are limited ways to use the sludge/slurry mixture once it is removed from the lagoon. Occasionally, the sludge is stored for later use (Cantrell, et al., 2008); however, usage of this material could include land application to local crop land or pasture. Regardless of disposal method, a high concentration of this nutrient rich waste remains in close proximity of hog production. With swine producers increasing the number of hogs they can produce, there is an increase in waste, resulting in more frequent sludge removal. The removal is costly and time consuming. A plan for the development of saleable products from this nutrient rich waste to recuperate money spent is needed.

Waste Processing & Composting

A study, conducted by Moore et al. (2005), tested swine lagoon sludge (SLS) from nine different lagoons. The samples were segregated by stage of production (sow, nursery, finishing). Moore et al. (2005) found that nitrogen was mineralized and available for plants from all stages of hog production; however, nursery farm SLS carries higher contents of copper (Cu) and zinc (Zn) than sow and finishing farm SLS (Minnich & McBride, 1986). Nursery swine generally have diets that consist of feed with elevated Cu and Zn levels to increase growth performance (Jacela J. Y., et al., 2010). Kornegay and Harper (1997) state, “the diet for prestarter nursery swine generally contains 16 times as much Zn as swine in all other phases” and Cu levels of three to eight times the amount from a finishing farm lagoon. The impacts of these elements on crop production can be detrimental.
The US Environmental Protection Agency (EPA) issued a rule, 40 CFR Rule, that classifies biosolids in one of three categories: Class A, Class A Exceptional Quality (EQ), or Class B (Environmental Protection Agency, n.d.). The biosolids are classified based on the level of pathogenic organisms in the material, as well as the ability to meet/exceed the Vector Attraction Reduction (insects and rodents) requirements. Some of the pathogenic organisms of interest are ascarids (roundworms) (*Ascaris lumbricoides* and *Toxacara*), whipworms (*Trichuris* sp.), tapeworms (*Hymenolepis* sp. and *Taenia* sp.), amoeba (*Entamoeba coli*), and giardia (*Giardia lamblia*).

Specifically, The Part 503 rule of the 40 CFR rule, published in February 1993 and effective in March 1993, contains rules to direct safe and beneficial usage of biosolids (Environmental Protection Agency, n.d.). These requirements apply when sewage sludge biosolids are, “applied to land to condition the soil or fertilize crops or other vegetation grown in the soil; placed on a surface disposal site for final disposal; or fired in a biosolids incinerator” (Walker, et al., 1994). The Part 503 rule’s purpose is the protection of public health and environmental safety from anticipated adverse effects of contaminants and pollutants present in biosolids.

Murphy Brown LLC, a subsidiary of Smithfield® Foods, has achieved Class A EQ status for the SLS at Ingold Farms in Garland, N.C. which allows land application of the sludge to be applied without site restrictions. The SLS is dredged from the lagoon using a tiller attachment that cuts the sludge from the bottom of the lagoon (Williams, 2016). It is pumped
into a tank and thoroughly mixed with a polymer (PT1051, PolyTec Inc., Mooresville, N.C.).
The SLS polymer mix is then pumped into a geotextile bag (TITANTube OS425/OS425A,
Flint Industries, Metter, GA) resting on a plastic lined reservoir sloped to one side to allow
the water to drain from the bag and back into the lagoon (Williams, 2016). Swine manure is
difficult to utilize when taken from the geotextile bags after dewatering due to its gelatinous
state. When air dried, the swine manure forms large clumps that are inconsistent in size and
difficult to evenly distribute. To ease mixing into substrate, such as a potting substrate,
further processing is needed (Williams, 2016). Composting swine lagoon sludge (SLC) is an
attractive option as it may transform this raw material into a more usable material.

Standard composting guidelines should be followed to create a successful product (Marriott
& Zaborski, 2016). Typical guidelines include an initial C:N ratio between 25:1 and 40:1
(Mulch and Soil Council, n.d.). Once loaded into an in-vessel composting system a
temperature of 55C to 76.7C must be reached and maintained within this range for at least
three days. If a static or aerated pile is utilized, a temperature of 55C to 76.7C for 15 days
with turning the material a minimum of at least five times allows for adequate composting by
the Mulch and Soil Council’s guidelines (Mulch and Soil Council, n.d.). Composting
eliminates a large percentage of pathogens carried in animal waste, meeting EPA Class A
biosolid standards.

There are several considerations for determining whether a compost can be utilized in plant
production. These include the degree of stability or maturity (which implies stable organic
matter content and the absence of phytotoxic compounds), pH and electrical conductivity, water and air holding capacities, nutrient content and availability, as well as, a lack of excessive heavy metals (Bernal, et al., 1998). O’Brien and Barker (1996) state how important maturity is in composts when being used for a plant growing substrate.

Substrate Development and Utilization

Sphagnum peat is a finite resource that is often times used in the horticultural industry, specifically greenhouse production, as a component in many substrate mixes (Abad, et al., 2001). Peat is mined from its natural wetland habitat, and excessive use has depleted much of the wetlands (Robertson, 1993). Due to the depletion, less of the product is available, as well as an increase in pricing and decrease in quality (Robertson, 1993). As a result, much research has focused on alternative resources for peat in the greenhouse industry (Ostos, et al., 2008; Raviv, et al., 1998; Robertson, 1993).

Composts are becoming an attractive option for peat substitutes in transplant production (Bustamante, et al., 2008). Research has (and is) being conducted using various herbs including Coriandrum sativum L. (coriander), Ocimum basilicum L. (basil), Mentha × piperita L. (peppermint), Thymus vulgaris L. (thyme), among others (Bustamante, et al., 2008; DeKalb, et al., 2014; Herrera, et al., 1997; O’Brien & Barker, 1996; Zhelijazkov & Warman, 2004).
In a review article, Raviv (2005) discusses compost and its usability as a safe and environmentally responsible substrate, as well as the variability among the chemical properties and nutrient content. He states that a lack of knowledge and education for growers is possibly a reason why growers do not use composts. Physical properties of a substrate can often be improved by using a compost based product (Raviv, 2005). More chemical analyses and plant growth trials are needed for determining compost maturity. Composts can be used as a low-cost addition to soilless substrate productions; however, in most cases, only 10 to 20% by volume of a compost can be added to other substrate components.

Composts produced from cow and poultry manures maintained suitable physical properties for production of lettuce (Lactuca sativa), chard (Beta vulgaris), broccoli (Brassica oleracea) and coriander (Coriandrum sativum) transplants (Bustamante, et al., 2008). O’Brien and Barker (1996) reported that shoot dry weight of peppermint transplants was larger in the composts derived from mixed municipal solids, mature biosolid-woodchips, 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 biosolids) or insufficient nutrient supply (as with the yard waste).

Chong (2005) reported that acceptable container-growing substrate could be derived from individual or combined raw or composted spend mushroom compost, turkey litter compost, paper mill sludge, municipal waste compost, corrugated cardboard, apple pomace, wood
chips from pallets, pulverized glass, and different types of tree barks. While the porosity and aeration of individual composts made with materials listed were comparable to that of pine bark, the pH and EC varied with each product but had little detrimental effects on the growth of the test nursery species.

Fertilizer Development and Utilization

Composted wastes provide many benefits as a fertilizer and soil amendment. These include, but are not limited to: increased microbial activity, increased soil fertility, improved soil structure on clayey soils, and improved water retention in sandy soils (Marriott & Zaborski, 2016).

The composting of wastes [agricultural (poultry, cow, swine sludge), municipal sewage sludge, industrial waste (paper mill waste, agro industrial)] for use as soil amendments and fertilizers is an ongoing exploration. Alvarenda et. al (2015), Bernal (1998), Chong (2005), Vanotti (2006), and Williams (2016), among others have used composted swine manure solid or slurry in the trials in which they conducted.

The use of composted swine slurry as a soil amendment has proven to be successful in production of Oba super 11 hybrid maize grown in Ultisol soil type (Ikenganyia, et al., 2014). Ikenganyia et al. concluded the swine slurry, after being air dried for 41 days, added sufficient nutrients to support plant growth from seed to mature plant size. The highest application of swine slurry (27 t ha⁻¹) had a dry grain weight increase of 128.43 percent over
the control, and also had the largest plant height and maize grain yield. Additionally, the soil chemical properties showed an increase in total nitrogen, available phosphorus, organic carbon, organic matter content, pH, base saturation, calcium, magnesium, potassium, and sodium.

Swine Lagoon Sludge as an Amendment in Soil and Substrate

Duffera et al. (1999a) conducted a study using SLS incorporated with rock flour to develop a value-added product. Rock flour, a waste of the aggregate (rock) industry, was combined with swine waste to maximize the disposal of two waste products. The two were pelletized and made into a swine sludge flour (SSF). Laboratory incubation techniques were to evaluate the nutrient source and metal content the SSF would provide in four different soil types. With SSF having a C:N ratio of 8:1, rapid mineralization of added organic N occurred.

Another study conducted by Duffera et al. (1999b) included greenhouse evaluation of the SSF as a fertilizer source. Common bermuda grass, sweet corn, sorghum, and field beans, representing agricultural crops that have a range of different nutrient demands during their vegetative growth, were grown in pots. The study exhibited increasing rates of conventional fertilizers and SSF increased dry matter yield in all tested crops. The highest application of SSF did not increase soluble salts and decrease growth as occurred with the higher rates of ammonium nitrate ($\text{NH}_4\text{NO}_3$). High concentrations of nitrogen as ammonium ($\text{NH}_4\text{-N}$) were found in the soil during the first two weeks after SSF application, while nitrogen as nitrate
(NO$_3$-N) were low. By the second and fourth week after application low concentrations of
NH$_4$-N were found and high concentrations of NO$_3$-N were found (Duffera, et al., 1999b).
The conclusion supports the hypothesis, SSF could be used as a fertilizer source that would
be acceptable to reach optimum growth.

Vanotti et al. (2006) used composted swine manure solids mixed with cotton gin waste to see
if a value-added product could be successfully developed. The solids and cotton gin waste
with the addition of wood chips were composted. The material was placed in bins with
agitation machinery allowing the product to be rotated 5 to 6 times per week speeding up
composting. These researchers found that swine manure could be developed into a value-
added product for use as a compost, soil amendment, or fertilizer with acceptable electrical
conductivity (EC), pH, total nitrogen, carbon, phosphorus, copper, zinc, and ammonia levels.

Herb Production

Herb production is becoming more popular in the vegetable industry, however, there is little
information on how to commercially produce herbs (Davis, 1994). Many vegetable producers
are looking for ways to incorporate herb production into their operations. Often times,
producers will complement their main cropping system with herbs with similar production
methods (Morgan, 2001). This increase in diversification may produce more income for the
farmers (Davis, 1993).
Herbs, fresh cut herbs more specifically, are increasing in consumer demand. Morgan (2001) describes the fresh cut herb market as “…one of the fastest growing specialty crop markets.” Consumers are driving a demand to have fresh cut herbs year round and are using the dried and preserved products less. Advancements in modified storage and more attractive marketing also aid in the progressive selling of fresh cut herbs (Morgan, 2001).

A few distinct families represent the most common commercially grown herb species. These include (but are not limited to): the mint family (Lamiaceae, formerly Labiate), the parsley family (Apiaceae), the onion (Allium) family (Amaryllidaceae), and tarragon (belonging to the Asteraceae family). These families of herbs include peppermint, spearmint, sage, oregano, thyme, parsley, cilantro, dill, fennel, chives, garlic chives, and tarragon (Morgan, 2001).

In 2012, the USDA reported 284 farms in North Carolina growing greenhouse vegetables and fresh cut herbs, a 44% increase from 2007. The value for this production is over $8.4 billion dollars (USDA, National Agricultural Statistics Service, 2012). Basil is the most produced herb worldwide, having the largest demand for fresh cut basil (Moore, et al., 2005). Other popular fresh cut herbs include Italian parsley, chives, dill, cilantro, rosemary, sage, mint, oregano, and thyme.

Swine lagoon sludge is in great abundance, and can be used in a positive manner when processed or spread correctly. North Carolina alone produces approximately 8.7 million hogs
yearly, accumulating a lot of nutrient-rich waste waiting to be used. Research continuing to be conducted shows that swine lagoon waste can be used in more ways than just agricultural spray fields. This research investigates the development of swine lagoon waste based value-added products that can be used as a transplant substrate for greenhouse production, as well as a one-time application fertilizer for field production of herbs.
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SWINE LAGOON COMPOST AS TRANSPLANT SUBSTRATE FOR BASIL, CHIVES, AND DILL

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Abstract

Sphagnum peat is a finite resource that is often times used in the horticultural industry as a component in many substrates, especially for greenhouse production of transplants. Because peatlands have been depleted by vast amounts of mining, the horticultural industry is exploring alternative resources to use in its substrates. Composted swine lagoon sludge (SLS) is an attractive option, as it may provide a portion, if not all, of the nutrients needed to support plant growth, as well as using a waste product in an environmentally friendly manner to address the peat shortage. A compost was developed using an in-vessel compost reactor to compost SLS with peanut hulls [15:85 (v/v)] to produce a swine lagoon compost (SLC). A greenhouse study was conducted with three species: *Ocimum basilicum* L. ‘Dark Opal’ (basil), *Allium schoenoprasum* L. (chives), and *Anethum graveolens* L. ‘Hera’ (dill) 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 two-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 to the OM and PEAT. Total fresh weight of basil and mint produced similar yields in the SLS and the control. Swine lagoon
compost provided the physical and chemical requirements for herb transplant production without any additional fertilizers or amendments.
Introduction

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. Due to the depletion, less of the product is available, resulting in an increase in pricing and decrease in quality (Robertson, 1993). 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 are becoming 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 using comports to grow *Coriandrum sativum* L. (coriander), *Ocimum basilicum* L. (basil), *Mentha × piperita* L. (peppermint), and *Thymus vulgaris* L. (thyme), among others (Bustamante, et al., 2008; DeKalb, et al., 2014; Herrera, et al., 1997; O'Brien & Barker, 1996; Zhelijazkov & Warman, 2004).

Raviv (2005) discussed the two main horticultural uses of comports being soil amendments as an ingredient in container substrate. He states that compost’s usability as a safe and environmentally responsible substrate makes it an appropriate low-cost peat substitute; however, a lack of knowledge and education for growers is apparent as they continue to look for “cheap products and tend to ignore the unavoidable connection between quality and cost”
(Raviv, 2005). Due to the versatility among the chemical properties and nutrient content composts can be used as a low-cost addition to soilless substrate productions.

Composts produced from cow and poultry manures maintained suitable physical properties for production of transplants (Bustamante, et al., 2008). O’Brien and Barker (1996) reported that shoot dry weight of peppermint transplants was larger when grown in composites derived from mixed municipal solids, mature biosolid-woodchips, agricultural wastes, and leaves. However, these authors reported limited growth with the composites containing both immature biosolids and yard wastes as a result of high salinity and NH$_4$ (as in the case of the immature biosolid) or insufficient nutrient supply (as with the yard waste).

Swine lagoon sludge composted with peanut hulls (15:85 v/v) (SLC) resulted in a substrate with zinc, copper, pH, and EC levels that were appropriate for germinating seedlings (Herring, Noah, & Kraus, 2017). A bioassay study found that germination of *Raphanus sativus* ‘Cherriette’ (radish) *Lycopersicum esculentum* ‘Moneymaker’ (tomato), and *Tagetes patula* ‘Janie Deep Orange’ (marigold) was better in the control substrate (Jolly Gardener Pro Line C/P, Jolly Gardener, Portland, Maine) than in the SLC. However numerically, germination of all the species was similar between the two substrates except for *Zinnia*, a salt sensitive species, due to a high electrical conductivity. Growth of seedlings of each species 28 days after sowing was the same for each substrate. The finished composites averaged 1.8% N, 1.5% P, and 0.2% K. The findings of Herring et. al (2017) indicate that SLC may be a
suitable substrate for herb transplant 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: 1) swine lagoon sludge composted with ground peanut hulls (SLC); 2) a commercially available organic potting substrate with a nutrient charge (OM); and 3) a commercial peat-based potting substrate with a two-week nutrient charge (PEAT). Development of the SLC [15:85 (v/v) peanut hull : swine lagoon sludge] is described by Herring et al. (2017). The OM is commercially available and is comprised of aged pine bark fines, peat, soil, perlite, and worm castings (Jolly Gardener Just Natural Organic Potting Mix, Jolly Gardener, Portland, Maine). The PEAT is a conventional substrate comprised of peat with aged bark fines, perlite, vermiculite, dolomitic limestone, gypsum and a wetting agent (Jolly Gardener Pro-Line C/P, Jolly Gardener, Portland, Maine). Three species; Ocimum basilicum L. ‘Dark Opal’ (basil), Allium schoenoprasum L. (chives), and Anethum graveolens L. ‘Hera’ (dill), were grown at Marye Anne Fox Teaching Laboratory on the North Carolina State University campus in Raleigh, N.C. (35.78°N/78.64°W) beginning 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 (3.2 cm cell top diameter x 4.4 cm deep, 28 cm³ max dry volume, Landmark Plastic Co., Akron, Ohio) were filled with the designated transplant substrate and planted with three seeds of each species per cell. Trays were
randomized in the greenhouse (29.4 °C day/18.3 °C night) with natural irradiance and photoperiod under fog (CoolNet Pro Fogger 0303420LL-B, M.L. Irrigation System; Laurens, S.C.) applied for 8 s every 8 m for germination. Clear plastic sheeting was pulled around and over the bench. Plastic sheeting was removed 12 days after planting and germination was measured.

The substrates were evaluated and compared through chemical and physical properties analyses, and growth experiments. Physical property analyses including total porosity (TP), airspace (AS), container capacity (CC), bulk density (BD), available water (AW), unavailable water (UAW), and particle size distribution were conducted in the Horticultural Substrates Laboratory, Department of Horticultural Science, N.C. State Univ., Raleigh, N.C.

Three replications of each substrate were packed into 347.5 cm$^3$ cylindrical aluminum rings (7.6 cm diameter, 7.6 cm high) and used to determine TP, AS, CC, and BD per procedures outlined in Tyler et al. (1993). There were five replications of each substrate packed into 101.4 cm$^3$ cylindrical aluminum rings, (7.6 cm diameter, 2.2 cm high) per modified procedures of Bilderback et al. (1982) and used to determine UAW following procedures described in Klute (1986). Available water was calculated as CC - UAW. To determine particle size distribution, three 100 g samples of each substrate were dried at 105 °C for 48 h and placed in a Ro-tap Shaker (Model B, W.S. Tyler, Mentor, Ohio) fitted with seven sieves, 6.3 mm, 2 mm, .71 mm, 0.5 mm, 0.25 mm, 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 days after sowing, substrate pH and electrical conductivity (EC) were measured weekly from planted cells using 1:2 v/v substrate to water extracts. Before extraction, trays were watered and allowed to drain for 3 hours to establish container capacity within the substrate. For 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 (185mm, Cat No 1001-185, Whatman, UK) to remove solids. Extract solution EC and pH were measured using a combination EC/pH meter (HI 8424, Hannah Instruments, Ann Arbor, Miss.). After EC and pH measurements, substrate solution samples were submitted to the North Carolina Department of Agriculture & Consumer Services Agronomic Services Raleigh, N.C., for inorganic nitrogen (IN-N), urea, P, K, Ca, Mg, S, B, CU, Fe, Mn, and Zn. Inorganic-nitrogen (IN-N) fraction concentrations include nitrate-nitrogen plus nitrite-nitrogen (NO$_3$N + NO$_2$N) and ammonium nitrogen (NH$_3$N + NH$_4$N). Organic nitrogen fraction concentration includes urea. NO$_3$N was determined on ~10 mL homogenized sample, filtered using acid washed filter paper (Laboratory Filtration Group, Houston, Texas) by nitrate-hydrazine reduction (Kempers & Luft, 1988; Skalar Analytical B.V., 1995a); NH$_4$N is determined by a modified Berthelot reaction (adapted from Krom 1980; Skalar Analytical 1995b); and urea concentration was determined with the diacetyl monoxime thiosemicarbazide colorimetric
method (Sullivan & Havlin, 1991; Skalar Analytical B.V., 1995c) with an auto-flow spectrophotometric analyzer (San++ Segmented Flow Auto-Analyzer, Skalar Instruments; Breda, The Netherlands). Total concentrations of P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, and Na were determined on ~10 mL homogenized sample, filtered using acid washed filter paper (Laboratory Filtration Group, Houston, Texas) with Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) (Spectro Arcos EOP, Spectro Analytical: A Division of Ametek; Mahwah, N.J.) (Donohue and Aho 1992; adapted USEPA 2001). Chloride concentration was determined on ~10 mL homogenized sample, filtered using acid washed filter paper (Laboratory Filtration Group, Houston, Texas) by the thiocyanate displacement method (Skalar Analytical, 1995d; Zall, et al., 1956) with an auto-flow spectrophotometric analyzer (San++ Segmented Flow Auto-Analyzer, Skalar Instruments; Breda, The Netherlands).

Plant heights measured 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 days for basil and 49 days 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 (ANOVA) procedures using procedures general linear model (GLM) in SAS (version 9.4) and P was considered significant at ≤ 0.05 (SAS, 2016). All means were separated with Tukey’s Honestly Significant Difference means separation test (P<0.05) where appropriate.
Results and Discussion

Regardless of composition, substrates did not differ in their particle size distributions (data not shown). Average percentage of the total samples for each sieve size were 4 (6.3mm), 32 (2mm), 31 (0.71mm), 12 (0.5mm), 12 (0.25mm), 7 (0.11mm), and 2 (<0.11). Yet, substrate physical properties varied, except for total porosity which was similar for all substrates (Table 1). Air space was highest for SLC and lowest for OM and PEAT. The opposite was true for CC and AW as OM and PEAT were highest and SLC was lowest. Unavailable water was highest in OM and lowest in PEAT while SLC was similar to both. Bulk density was highest for OM and SLC. While root growth was not measured in this study, more prolific root growth throughout the plug was observed with SLC compared to OM and PEAT possibly due to the greater AS in SLC as shown in Fig. 1. Composts produced from other agricultural wastes, cow and poultry manures, have also produced suitable physical properties for production of transplants (Bustamante, et al., 2008).

The sample time x substrate interaction was non-significant for pH and EC of the substrate solution supporting growth of each species (data not shown). The SLC substrate had a higher pH and EC than OM and PEAT for each species (Table 2). Substrate solution pH did not change substantially over time while EC decreased from 0.24 to 0.14 mS/cm. Both substrate pH and EC were with acceptable ranges (Bunt, 1988; Raviv, et al., 1986).
For basil and chives, the sample time x substrate interaction was significant for IN-N, NH$_4$, NO$_3$, P, Mg, Mn, and B (data not shown). SLC maintained higher IN-N concentrations than OM and PEAT throughout the 49 days. (Fig 2). IN-N concentration decreased from ≥ 10 ppm to ≥ 2 ppm while OM and PEAT had ≥ 2 ppm at sample time A and these concentrations decreased to ≤ 2 ppm. Almost all of the 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 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 higher than OM and PEAT throughout the study; however, no transplants in SLC showed signs of toxicity for either nutrient (personal observation). For dill, the sample time x substrate interaction was largely nonsignificant; however, SLC also resulted in higher concentrations of IN-N, NO$_3$, P, Ca, Mg, Fe, Zn, Cu, and B than OM or PEAT while substrate did not affect NH$_4$ or K concentrations (Table 4).

Specific heavy metal concerns with SLC are copper (Cu) and zinc (Zn) which are given as feed supplements to increase growth performance in young pigs (Jacela J. Y., et al., 2010). Prior to composting, the swine lagoon solids had Zn levels that slightly exceeded the EPA target range of ≤2800 mg·L$^{-1}$ with a level of 3043 mg·L$^{-1}$ (Herring, Noah, & Kraus, 2017). Composting lowered Zn levels to 871 mg·L$^{-1}$ and below. Copper met the EPA limit (1500 mg·L$^{-1}$) before composting, nevertheless, composting also lowered Cu levels (Herring, Noah, & Kraus, 2017). Using the compost developed by Herring et al. (2017) in this study, the SLC
maintained higher Zn and Cu (Zn average = 0.04 ppm; Cu average = 0.01 ppm) concentrations than OM and PEAT, however, all substrate had acceptable levels (Zn ≤ 0.5 ppm; Cu ≤ 3.0 ppm) (Misra, 1995; Panou-Filotheou, et al., 2001).

Perhaps the nutrient of greatest environmental concern with animal wastes is P (Jonhbloed & Lenis, 1998; Sharpley, et al., 1994). Substrate solutions of P in SLC averaged ~700 times greater than OM and PEAT across the species (Tables 3 & 4). P in the substrate solution of SLC grown transplants decreased over time from 32.29 ppm at sample time A to 12.39 ppm at sample time D for all species (Table 3). While no P toxicity symptoms were observed, P remediation (Penn, et al., 2001) of runoff water leaving a greenhouse using the SLC substrate should be recommended.

Transplant growth was evaluated at germination and at maturity. Germination of each species was similar, regardless of substrate (Table 5). Maynard and Hochmuth (2007) report germination of chives to be approximately 50%, and dill to be 60% when germinating from seed. The SLC and PEAT germinated slightly better than the average for dill; however, the SLC and OM produced slightly lower than the average germination for chives. Height for basil, chives, and dill transplants was significantly greater with transplants produced in SLC than in OM and PEAT. Harvest dry weights were also significantly greater for basil and dill when grown in SLC when compared to OM and PEAT. Dry weight of chives was similar regardless of substrate.
These results suggest SLC can be used alone as a transplant substrate to produce basil, chives, and dill transplants of the same quality in comparison to using commercially available peat based products. 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 & Barker, 1996).
Literature Cited


Table 1. Total porosity (TP), air space (AS), container capacity (CC), available water (AW), unavailable water (UAW), and bulk density (BD) of three transplant substrates.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>TP</th>
<th>AS</th>
<th>CC</th>
<th>AW</th>
<th>UAW</th>
<th>BD</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLC</td>
<td>80</td>
<td>42a</td>
<td>38b</td>
<td>9b</td>
<td>29ab</td>
<td>0.20a</td>
</tr>
<tr>
<td>OM</td>
<td>78</td>
<td>20b</td>
<td>59a</td>
<td>30a</td>
<td>29a</td>
<td>0.20a</td>
</tr>
<tr>
<td>PEAT</td>
<td>80</td>
<td>16b</td>
<td>63a</td>
<td>36a</td>
<td>27b</td>
<td>0.15b</td>
</tr>
<tr>
<td>Optimum</td>
<td>&gt;85</td>
<td>20-30</td>
<td>4-10</td>
<td>24-40</td>
<td>20-30</td>
<td>≤0.4</td>
</tr>
</tbody>
</table>

P Values

| Substrates: | NS | 0.01 | 0.0009 | 0.0005 | 0.02 | 0.001 |

Substrates: Swine lagoon compost 15:85 swine lagoon sludge:peanut hulls (v/v) (SLC), Aged pine bark fines, peat, soil, perlite, and worm castings (Jolly Gardener Just Natural Organic Potting Mix) (OM), and conventional substrate of peat with aged bark fines, perlite, vermiculite, dolomitic limestone, gypsum and a wetting agent (Jolly Gardener Pro-Line C/P) (PEAT).

Based upon percent volume of a 7.6 cm core at 0kPa.

TP-CC.

Measured as percent volume of a 7.6 cm core at drainage.
Table 1. (continued)

^CC-UAW

^Based upon percent volume of a 7.6 cm core at 1500 kPa.

^BD is measured as the ratio of dry solids to the bulk volume of the substrate.

^Means within a column with different letters are significantly different from each other based on Tukey’s mean separation procedures (P ≥ 0.05).

^Per Abad et al. (2001) and Noguera et al. (2003)

^Analysis of variance (ANOVA). Nonsignificant at P ≥ 0.05, P-value given otherwise.
Table 2. Substrate pH and EC as affected by sample time and substrate composition for each herb species

<table>
<thead>
<tr>
<th>Substrate&lt;sup&gt;z&lt;/sup&gt;</th>
<th>pH</th>
<th>EC</th>
<th>Sample Time&lt;sup&gt;y&lt;/sup&gt;</th>
<th>pH</th>
<th>EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLC</td>
<td>6.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Basil</td>
<td>5.6b</td>
<td>5.7ab</td>
</tr>
<tr>
<td>OM</td>
<td>5.5b</td>
<td>5.6b</td>
<td>Chives</td>
<td>5.8a</td>
<td>5.7</td>
</tr>
<tr>
<td>PEAT</td>
<td>5.6b</td>
<td>5.6b</td>
<td>Dill</td>
<td>5.5b</td>
<td>5.6b</td>
</tr>
</tbody>
</table>

P-value<sup>w</sup> <0.0001 <0.0001 <0.0001 0.0002 <0.0001 0.0008

<sup>z</sup>Substrates include: Swine lagoon compost 15:85 swine lagoon sludge:peanut hulls (v/v) (SLC), Aged pine bark fines, peat, soil, perlite, and worm castings (Jolly Gardener Just Natural Organic Potting Mix) (OM), and conventional substrate of peat with aged bark fines, perlite, vermiculite, dolomitic limestone, gypsum and a wetting agent (Jolly Gardener Pro-Line C/P) (PEAT).

<sup>y</sup>Species tested: Ocimum basilicum L. ‘Dark Opal’ (basil), Allium schoenoprasum L. (chives), Anethum graveolens L. ‘Hera’ (dill)
Table 2. (continued)

*Means with different letters within a column are significantly different from each other based on Tukey's honestly significant difference means separation procedures (P≤0.05)

**Analysis of variance of main effects of substrate and sample time are shown. The two-way interaction sample time x substrate was NS at P ≥ 0.05, P-value given otherwise.

*Sample time A was 29 days after seeding. Each sample time thereafter were conducted 7 days following the previous sampling.
Table 3. Effect of substrate and sample time on nutrient concentration for basil and chives

<table>
<thead>
<tr>
<th></th>
<th>P(^\text{v})</th>
<th>Mg</th>
<th>Fe</th>
<th>Mn</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Basil</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sample time A</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLC(^\text{x})</td>
<td>47.43a(^\text{w})</td>
<td>26.27a</td>
<td>0.04a</td>
<td>0.02a</td>
<td>0.10a</td>
</tr>
<tr>
<td>OM</td>
<td>0.90b</td>
<td>2.10b</td>
<td>0.02b</td>
<td>0b</td>
<td>0.02b</td>
</tr>
<tr>
<td>PEAT</td>
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<td>5.14b</td>
<td>0.03a</td>
<td>0b</td>
<td>0.02b</td>
</tr>
<tr>
<td>P-value(^\text{t})</td>
<td>&lt;0.0001</td>
<td>0.0005</td>
<td>0.0038</td>
<td>0.003</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td><strong>Sample time B</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLC</td>
<td>27.73a</td>
<td>15.02a</td>
<td>0.03a</td>
<td>0.007a</td>
<td>0.06a</td>
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<td>OM</td>
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<td>1.19b</td>
<td>0.02b</td>
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<td>0.03b</td>
</tr>
<tr>
<td>PEAT</td>
<td>0.23b</td>
<td>2.25b</td>
<td>0.03a</td>
<td>0b</td>
<td>0.02b</td>
</tr>
<tr>
<td>P-value</td>
<td>0.001</td>
<td>0.0026</td>
<td>0.0194</td>
<td>0.0041</td>
<td>0.0004</td>
</tr>
<tr>
<td><strong>Sample time C</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLC</td>
<td>20.39a</td>
<td>10.67a</td>
<td>0.05a</td>
<td>0.01</td>
<td>0.05a</td>
</tr>
<tr>
<td>OM</td>
<td>0.61b</td>
<td>0.87b</td>
<td>0.02b</td>
<td>0</td>
<td>0.02b</td>
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<tr>
<td>PEAT</td>
<td>0.06b</td>
<td>1.57b</td>
<td>0.03b</td>
<td>0</td>
<td>0.02b</td>
</tr>
<tr>
<td>P-value</td>
<td>0.0018</td>
<td>0.0035</td>
<td>&lt;.0001</td>
<td>NS</td>
<td>0.0104</td>
</tr>
<tr>
<td><strong>Chives</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sample time A</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLC</td>
<td>35.7a</td>
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<td>0.08a</td>
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<td>0.03b</td>
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<tr>
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<td>1.3b</td>
<td>0.03a</td>
<td>0b</td>
<td>0.03b</td>
</tr>
<tr>
<td>P-value</td>
<td>0.0004</td>
<td>0.0002</td>
<td>0.0011</td>
<td>0.0003</td>
<td>0.0044</td>
</tr>
<tr>
<td><strong>Sample time B</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>SLC</td>
<td>16.5a</td>
<td>11.9a</td>
<td>0.03</td>
<td>0.001</td>
<td>0.05</td>
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<tr>
<td>OM</td>
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<td>1.62b</td>
<td>0.02</td>
<td>0</td>
<td>0.03</td>
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</table>
Table 3. (continued)

<table>
<thead>
<tr>
<th></th>
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<th>OM</th>
<th>PEAT</th>
<th>P-value</th>
<th>P-value</th>
<th>P-value</th>
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<tr>
<td>PEAT</td>
<td>2.01b</td>
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<td>0.03</td>
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</tr>
<tr>
<td>P-value</td>
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<td>0.0108</td>
<td>NS</td>
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</table>

Sample time C

<table>
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<tr>
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<th>OM</th>
<th>PEAT</th>
<th>P-value</th>
<th>P-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLC</td>
<td>12.7a</td>
<td>9.23a</td>
<td>0.03</td>
<td>0.002</td>
<td>0.04a</td>
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<tr>
<td>OM</td>
<td>1.96b</td>
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<tr>
<td>PEAT</td>
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<td>0.02b</td>
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<tr>
<td>P-value</td>
<td>0.0117</td>
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<td>NS</td>
<td>NS</td>
<td>0.0092</td>
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Sample time D

<table>
<thead>
<tr>
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<th>SLC</th>
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<th>PEAT</th>
<th>P-value</th>
<th>P-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLC</td>
<td>10.57</td>
<td>8.26</td>
<td>0.05</td>
<td>-</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>OM</td>
<td>1.62</td>
<td>1.84</td>
<td>0.03</td>
<td>-</td>
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</tr>
<tr>
<td>PEAT</td>
<td>1.82</td>
<td>2.72</td>
<td>0.04</td>
<td>-</td>
<td>0.02</td>
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</tr>
<tr>
<td>P-value</td>
<td>0.04</td>
<td>NS</td>
<td>NS</td>
<td>-</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

*Sample time x substrate interaction, shown by sample time.

*Nutrient solution of phosphorus (P), magnesium (Mg), iron (Fe), manganese (Mn), and boron (B).

*Species tested: *Ocimum basilicum* L. ‘Dark Opal’ (basil), *Allium schoenoprasum* L. (chives)

*Sample time A was 29 days after seeding. Each sample time thereafter were conducted 7 days following the previous sampling.

*Substrates include: Swine lagoon compost 15:85 swine lagoon sludge:peanut hulls (v/v) (SLC), Aged pine bark fines, peat, soil, perlite, and worm castings (Jolly Gardener Just Natural Organic
Table 3. (continued)

Potting Mix) (OM), and conventional substrate of peat with aged bark fines, perlite, vermiculite, dolomitic limestone, gypsum and a wetting agent (Jolly Gardener Pro-Line C/P) (PEAT).

\(^{a}\)Means with different letters within a column are significantly different from each other based on Tukey's honestly significant difference means separation procedures (P≤0.05).

\(^{1}\)Analysis of variance (ANOVA). Nonsignificant at P ≥ 0.05, P-value given otherwise.
Table 4. *Anethum graveolens* L. ‘Hera’ (dill) 1:2 (v/v) nutrient solution values for each sample time for each substrate. (ppm)

<table>
<thead>
<tr>
<th>Substrate&lt;sup&gt;y&lt;/sup&gt;</th>
<th>IN-N&lt;sup&gt;z&lt;/sup&gt;</th>
<th>NO₃</th>
<th>P</th>
<th>Ca</th>
<th>Mg</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLC</td>
<td>6.9a&lt;sup&gt;x&lt;/sup&gt;</td>
<td>6.2a</td>
<td>18.9a</td>
<td>8.0a</td>
<td>12.5a</td>
<td>0.06a</td>
</tr>
<tr>
<td>OM</td>
<td>2.0b</td>
<td>1.5b</td>
<td>1.5b</td>
<td>2.6b</td>
<td>1.5b</td>
<td>0.02b</td>
</tr>
<tr>
<td>PEAT</td>
<td>1.4b</td>
<td>0.9b</td>
<td>1.4b</td>
<td>3.7b</td>
<td>2.2b</td>
<td>0.02b</td>
</tr>
</tbody>
</table>

| P-value<sup>y</sup> | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

| Sample Time<sup>x</sup> | | | | | | |
|-------------------------| | | | | | |
| A                       | 6.2a | 5.4a | 12.3a | 7.5 | 7.6a | 0.04a |
| B                       | 4.4ab| 3.8ab| 6.7ab| 5.6 | 5.4a| 0.04ab |
| C                       | 2.0b | 1.6b | 5.4b | 5.1 | 4.4a| 0.03ab |
| D                       | 1.1b | 0.8b | 4.7b | 6.0 | 4.3a| 0.03ab |

| P-value<sup>x</sup> | 0.001 | <0.0001 | 0.0391 | NS | 0.035 | 0.0005 |

<sup>z</sup>1:2 Nutrient Solution of inorganic nitrogen (IN-N), nitrate (NO₃), phosphorus (P), calcium (Ca), magnesium (Mg), and boron (B).

<sup>y</sup>Substrates include: Swine lagoon compost 15:85 swine lagoon sludge:peanut hulls (v/v) (SLC), Aged pine bark fines, peat, soil, perlite, and worm castings (Jolly Gardener Just Natural Organic Potting Mix) (OM), and conventional substrate of peat with aged bark fines, perlite, vermiculite, dolomitic limestone, gypsum and a wetting agent (Jolly Gardener Pro-Line C/P) (PEAT).

<sup>x</sup>Means with different letters within a column are significantly different from each other based on Tukey's honestly significant difference means separation procedures (P≤0.05).
Table 4. (continued)

\(^v\)Analysis of variance (ANOVA) for the main effects of substrate and sample time. Non-significant sample time x substrate interaction. Nonsignificant at \( P \geq 0.05 \), P-value given otherwise.

\(^u\)Sample time A was 29 days after seeding. Each sample time thereafter were conducted 7 days following the previous sampling.
<table>
<thead>
<tr>
<th>Substrate(^z)</th>
<th>Germination(^y)</th>
<th>Height(^x)</th>
<th>Dry Weight(^w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basil(^v)</td>
<td>SLC</td>
<td>0.50</td>
<td>10a(^u)</td>
</tr>
<tr>
<td></td>
<td>OM</td>
<td>0.54</td>
<td>5b</td>
</tr>
<tr>
<td></td>
<td>PEAT</td>
<td>0.55</td>
<td>6ab</td>
</tr>
<tr>
<td>Chives</td>
<td>SLC</td>
<td>0.41</td>
<td>15a</td>
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<tr>
<td></td>
<td>OM</td>
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<td>8b</td>
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<tr>
<td>Dill</td>
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<td>0.77</td>
<td>7b</td>
</tr>
</tbody>
</table>

| P-value\(^t\)   | NS               | 0.0314      | <0.0001        |
| P-value         | NS               | 0.0165      | NS             |
| P-value         | NS               | 0.0027      | 0.0088         |

\(^z\) Substrates include: Swine lagoon compost 15:85 swine lagoon sludge:peanut hulls (v/v) (SLC), Aged pine bark fines, peat, soil, perlite, and worm castings (Jolly Gardener Just Natural Organic Potting Mix) (OM), and conventional substrate of peat with aged bark fines, perlite, vermiculite, dolomitic limestone, gypsum and a wetting agent (Jolly Gardener Pro-Line C/P) (PEAT).

\(^y\) Germination % were taken for each species in each substrate at 12 days.

\(^x\) Measured from root collar to tip of shoot.

\(^w\) Shoots (stems and leaves) dried at 62°C for 48hrs.
Table 5. (continued)

Species tested: *Ocimum basilicum* L. ‘Dark Opal’ (basil), *Allium schoenoprasum* L. (chives), and *Anethum graveolens* L. ‘Hera’ (dill).

Means within a column with different letters are significantly different from each other based on Tukey mean separation procedures (p>0.05).

Analysis of variance (ANOVA). Nonsignificant at P ≥ 0.05, P-value given otherwise.
Figure 1. *Anethum graveolens* L. ‘Hera’ (dill) roots at harvest (49 days) after sowing. Substrates include: Swine lagoon compost 15:85 swine lagoon sludge:peanut hulls (v/v) (SLC), Aged pine bark fines, peat, soil, perlite, and worm castings (Jolly Gardener Just Natural Organic Potting Mix) (OM), and conventional substrate of peat with aged bark fines, perlite, vermiculite, dolomitic limestone, gypsum and a wetting agent (Jolly Gardener Pro-Line C/P) (PEAT).
Figure 2. Average nitrogen concentrations for inorganic-N, nitrate, and ammonium, in 1:2 (v/v) nutrient solutions for all species at each sample time.
DRIED SWINE LAGOON SLUDGE AS FERTILIZER FOR FIELD PRODUCTION OF FRESH CUT HERBS

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Subject Category: Crop Production: Herb


Abstract.

In 2012, the USDA reported 284 farms in North Carolina growing greenhouse vegetables and fresh cut herbs, a 44% increase from 2007. Producers, aware of rising consumer interest in herbs, are beginning to complement their main cropping system with herbs having similar production methods to their cropping systems to generate more income while also adding to the increasing herb production in North Carolina. Many vegetable producers are looking for ways to incorporate herb production into their operations while keeping costs of production low. Swine lagoon sludge (SLS) can be an attractive option for growers, especially with North Carolina being the second largest hog producer in the nation, for a low cost fertilizer due to the high concentration of nutrients available in the waste. To test the utility of the SLS as a fertilizer for fresh cut herb production, *Ocimum basilicum* L. ‘Dark Opal’ (basil), *Origanum vulgare* L. ‘hirtum’ (oregano), *Mentha spp.* L. (mint), *Anethum graveolens* L. ‘Hera’ (dill), *Allium schoenoprasum* L. (chives) and *Foeniculum vulgare* Mill. (fennel) were grown in the summer (basil, oregano, mint, and dill) and fall (chives and dill) in 2016 in field trials. Dried swine lagoon sludge 4N-2.6P-0.83K (SLS) and aerobically composted turkey litter (All Natural Landscapers’ Choice, Sustane Natural Fertilizer, Inc., Cannon Falls,
Minn.) 4N-2.6P-3.3K (TL) at two rates (89.7 kg, and 44.9 kg N per ha) were tested. Potassium chloride (0N-0P-49.8K) at a rate of 55.6 kg was added to the SLS treatment to match the K$_2$O in the TL. Potassium nitrate 15.5N-0P-0K (YaraLiva Tropicote, Yara Belle Plaine Inc., Regina, Saskatchewan) and potassium chloride 0N-0P-49.8K was utilized as the control fertilizer at a rate of 89.7 kg N, and 65.1 kg K per ha. Total fresh weight of basil and mint produced similar yields in the SLS and the control. Growth of dill, oregano, chives, and fennel was not affected by rate or source of nutrients, possibly due to the fertilizer nature or the soils at planting.
Introduction

North Carolina produces more than 8.7 million hogs in over 60 percent of the state (National Agricultural Statistics Service, 2016). These hogs produce approximately 584 kg of fresh manure per finished animal (American Society of Agricultural and Biological Engineers, 2010). Hog waste is washed from beneath the hogs’ pens and this slurry is captured and contained in open anaerobic lagoons. The solids (sludge) settle out of the slurry and accumulate in the bottom of the lagoon. Sludge storage is generally underestimated when maintaining a lagoon (Cantrell, et al., 2008) and often accumulates for ten to fifteen years before removal is necessary to maintain proper function of the lagoon (Moore, et al., 2005). However, there are limited ways to use the sludge once removed. Occasionally, the sludge is stored for later use (Cantrell, et al., 2008) or usage of this material could include land application to local crop land or pasture. Regardless of disposal method, a high concentration of this nutrient rich waste usually remains in close proximity of hog production. With swine producers increasing the number of hogs they can produce, there is an increase in waste resulting in more frequent sludge removal as many of the lagoons are reaching the maximum level.

Herb production is becoming more popular in the vegetable industry; however, there is little information on how to commercially produce herbs (Davis, 1994). Many vegetable producers are looking for ways to incorporate herb production into their operations while keeping costs of production low. Often times, producers will complement their main cropping system with
herbs with similar production methods (Morgan, 2001). This increase in diversification may produce more income for the farmers (Davis, 1993).

In 2012, the USDA reported 284 farms in North Carolina growing greenhouse vegetables and fresh cut herbs, a 44% increase from 2007 in North Carolina. The value of sale for this production is over $8.4 billion dollars (USDA, National Agricultural Statistics Service, 2012). Herbs, fresh cut herbs specifically, are increasing in consumer demand and are driving these increases. Morgan (2001) describes the fresh cut herb market as “…one of the fastest growing specialty crop markets.” Consumers want to have fresh cut herbs year round and are using the dried and preserved products less. Basil is the most produced herb worldwide, due to the largest demand for fresh cut basil (Moore, et al., 2005). Other popular fresh cut herbs include *Petroselinum crispum* (Mill) Nyman (Italian parsley), *Allium schoenoprasum* L. (chives), *Anethum graveolens* L. Hera (dill), *Coriandrum sativum* L. (cilantro), *Rosmarinus officinalis* L. (rosemary), Salvia officinalis L. (sage), *Mentha spp*. L. (mint), *Origanum vulgare* L. ‘hirtum’ (oregano), and *Thymus vulgaris* L. (thyme). Advancements in modified storage and more attractive marketing also aids in the progressive selling of fresh cut herbs (Morgan, 2001).

Duffera et al. (1999a) conducted a study using swine lagoon sludge (SLS) to incorporate with rock flour to develop a value-added product. Rock flour, a waste to the aggregate (rock) industry, was combined with swine waste to maximize the disposal of two waste products. The two were pelletized to create a processed swine sludge flour (SSF). With SSF having a C:N ratio of 8:1, rapid mineralization of added organic N occurred.
Another study conducted by Duffera et. al. (1999b) included greenhouse evaluation of the SSF as a fertilizer source. Common bermuda grass, sweet corn, sorghum, and field beans, representing agricultural crops that have a range of different nutrient demands during their vegetative growth were grown in pots. The study concluded that increasing rates of conventional fertilizers and SSF increased dry matter yield in all tested crops.

The US Environmental Protection Agency (EPA) issued the 40 CFR Rule that classifies biosolids in one of three categories: Class A, Class A Exceptional Quality (EQ), or Class B (Environmental Protection Agency, n.d.). The biosolids are classified based on the level of pathogenic organisms in the material, as well as the ability to meet/exceed the Vector Attraction Reduction (rodent) requirements. Specifically, The Part 503 rule of the 40 CFR rule, published in February 1993 and effective in March 1993, contains rules to direct safe and beneficial usage of biosolids (Environmental Protection Agency, n.d.). Murphy Brown LLC, a subsidiary of Smithfield® Foods, has achieved Class A EQ status for the SLS at Ingold Farms in Garland, North Carolina which allows land application of the sludge to be applied without site restrictions. Achieving this Class A EQ status can be, and is beneficial allowing for the sludge to be removed and applied with no monitoring; however, possible usages for the sludge are still needed. Therefore, the objective of this study was to test the utility of dried SLS as a fertilizer for field production of fresh cut herbs.
Materials and Methods

A factorial treatment arrangement of two nutrient sources: 1) dried swine lagoon sludge 4N-2.6P-0.83K (SLS) and 2) aerobically composted turkey litter (All Natural Landscapers’ Choice, Sustane Natural Fertilizer, Inc., Cannon Falls, Minn.) 4N-2.6P-3.3K (TL) and two rates (89.7kg, and 44.9 kg N per ha) were arranged in a randomized complete block design with six replications. Potassium chloride (0N-0P-49.8K) at a rate of 55.6 kg was added to the SLS treatment to match the K$_2$O in the TL. Potassium nitrate 15.5N-0P-0K (YaraLiva Tropicote, Yara Belle Plaine Inc., Regina, Saskatchewan) and potassium chloride 0N-0P-49.8K were utilized as the control fertilizers at a rate of 89.7 kg N, and 65.1 kg K per ha. In the summer (May to August) of 2016, *Ocimum basilicum* L. ‘Dark Opal’ (basil), *Origanum vulgare* L. ‘hirtum’ (oregano), *Mentha spp.* L. (mint), and *Anethum graveolens* L. ‘Hera’ (dill) were grown at the Horticultural Crops Research Station (35°01'30.6”N 78°16'59.5”W) in Clinton, N.C. (Lynchburg sandy loam). During the Fall (August to December) 2016 *Allium schoenoprasum* L. (chives) and *Foeniculum vulgare* Mill. (fennel) were grown at the N.C.SU Horticultural Field Lab (35°47'33.4”N 78°41'59.3”W) Raleigh, N.C. (Cecil gravelly sandy loam). Rates of N and K per ha. were based on soil samples taken before nutrients were applied.

Swine lagoon sludge was dredged from an open, anaerobic lagoon in Garland, North Carolina (Murphy Brown, LLC, Warsaw, N.C.) using a tiller attachment to cut the sludge off the lagoon bottom and pumped to a holding tank where a polymer (PT1051, PolyTec Inc., Mooresville, N.C.) was added and thoroughly mixed with the sludge. The sludge and
polymer mixture was pumped into a geotextile bag (TITANTube OS425/OS425A, Flint Industries, Metter, GA) situated on a plastic lined, recessed reservoir with a slight slope to one side. Water filtered out of the bag was pumped from the reservoir back into the lagoon. The sludge/polymer mix in the bag drained for two years before use. Once removed from the bag, the SLS was spread, under shelter, on a solid concrete surface, and air dried to 21% moisture content.

The nutrient composition of the SLS was analyzed prior to the application by North Carolina Department Agriculture & Consumer Services Agronomic Services Raleigh, N.C.. Nitrogen (N) and carbon (C) concentrations were determined by oxygen combustion gas chromatography with an elemental analyzer (NA1500 or EA1112; CE Elantech Instruments; Lakewood, NJ) (Association of Official Analytical Chemists, 1990; Campbell & Plank, 1992). Inorganic-nitrogen (IN-N) fraction concentrations include nitrate-nitrogen plus nitrite-nitrogen ($\text{NO}_3^{-}$-N + $\text{NO}_2^{-}$-N) and ammonium-nitrogen ($\text{NH}_3$-N + $\text{NH}_4$-N). $\text{NO}_3$-N was determined by nitrate-hydrazine reduction (Kempers & Luft, 1988; Skalar Analytical B.V., 1995) and $\text{NH}_4$-N was determined by modified Berthelot reaction (Jacela J. Y., et al., 2010) with an autoflow spectrophotometric analyzer (San++ Segmented Flow Auto-Analyzer, Skalar Instruments; Breda, The Netherlands). Total concentrations of phosphorus (P), potassium (K), calcium (Ca), sulfur (S), magnesium (Mg), boron (B), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), sodium (Na), nickel (Ni), cadmium (Cd), and lead (Pb) were determined with inductively coupled plasma-optical emission spectrometry (ICP-OES) (Spectro Arcos EOP, Spectro Analytical: A Division of Ametek; Mahwah, NJ) [ (Donohue &

Ten initial soil samples were taken from each field and compiled into three composite samples per location. Final soil samples were collected at a depth of 0 to 15 cm on the day of final harvest for both trials. Three representative soil samples were taken per basil plot (summer trial) and chive plot (fall trial) then blended to form a composite sample for each plot. All samples were analyzed at the North Carolina Department of Agriculture & Consumer Service Soil and Plant Analysis Lab, Raleigh, N.C.. Samples were dried at 62°C for 5 days, ground in a hammer mill and sieved through an 18 mesh (1mm) screen. Each soil sample (1.25g) was combusted at 490°C for 6 hours. The resulting ash was dissolved in 10 mL 6 N HCl and diluted to 50 mL with distilled deionized water. Phosphorus concentrations were determined by P-2000 Inductively coupled plasma emissions spectrophotometer (Perkin Elmer, Norwalk, Conn.). Nitrogen concentration was determined using 10 mg samples in a Perkin Elmer 2400 CHN elemental analyzer (Perkin, Elmer). Prior to the summer trial, seeds were sown in a peat-based potting medium with a two-week nutrient charge (Jolly Gardener Pro-Line C/P, Jolly Gardener, Portland, Maine) in a greenhouse at Marye Anne Fox Teaching Laboratory at North Carolina State University, Raleigh, N.C. (35.78°N/78.64°W) with natural irradiance and photoperiod under fog (CoolNet Pro Fogger 0303420LL-B, M.L. Irrigation System; Laurens, South Carolina) applied for 8 s every 8 m for germination. Clear plastic sheeting was pulled around and over the bench. After germination plastic sheeting
was removed and all species were fertilized twice weekly at a rate of 100 ppm N (20N-4.4P-16.6K, Peters Professional, Everris, Dublin, OH). Upon reaching maturity, each species was transferred to a polyethylene covered hoop house at N.C.SU Horticulture Field Lab (35°79′N–78°69′W) Raleigh, N.C. for hardening-off where overhead irrigation was provided cyclically three times daily (8:00 AM, 12:00 PM, 4:00 PM). During hardening (20N-4.4P-16.6K Peters Professional, Everris, Dublin, OH) fertilization was continued at a rate of 100 ppm N twice weekly. After 2 weeks, transplants were moved to a black weed barrier covered full sun, growing area and held until field transplantation. For the summer trial, planting rows were 1.5 m on center and each plot was 3 m long with one row of crops per plot and 1.2 m of row between each plot. Nutrient source and N rate were weighed for each treatment combination and applied by hand after the field had been plowed to 20 cm. Black plastic mulch (1.75 mm black polyethylene mulch, 152.4 cm-wide, Berry Hill Drip Irrigation, Buffalo Junction, VA) was pulled over a shaped bed (30.5 cm deep) and 0.91 L·hr drip tape (Netafim Irrigation, Fresno, CA) was laid 2.5 cm below the soil surface and 10 cm from center all in one action. A 1.9 cm polyethylene hose (The Toro Company, Bloomington, MN) was placed perpendicular to the drip tape at the end of the field. Drip tape was attached with valves to the polyethylene hose. Planting was done by hand. The within row spacing for basil, oregano, and dill was 30 cm providing 10 plants per plot. The within row spacing for mint was 37.5 cm providing 8 plants per plot. Outside rows and planted rows bordering drive rows were designated as border rows and removed from data collection to reduce any possible edge effect on the internal rows. Irrigation was provided throughout the growing season as necessary to maintain crop growth, approximately once a week for three hours. No
additional nutrients were applied. Weeding was conducted manually as necessary throughout the experiment. Fungicides, herbicides, and insecticides were sprayed on a weekly regime as designated by the research station. Appropriate amounts of Manzate (UPL Australia Limited, Bella Vista, Australia), Kocide (Kocide LLC, Columbia, MD), Tanos (Dupont, Wilmington, DE), Presidio (Valent, Raleigh, N.C.), Asana (Dupont, Wilmington, DE), Previcur (Bayer, Research Triangle Park, N.C.), and Sevin (Bayer, Research Triangle Park, N.C.) were sprayed throughout the study.

Dill was planted on 18 May; basil, mint, and chives were planted on 27 May. Fresh cuts were taken when the plants had established commercial maturity, and were repeated every two weeks. The fresh cuts were weighed (Bench scale FG-150KBM, A&D, San Jose, CA) on site within one hour. Dill was harvested one time, after flower, at 54 days (11 July). A final harvest of basil, mint, and oregano, regardless of maturity, was conducted on 8 August.

For the Fall study, seeds were sown and seedlings cared for as described above. When fully developed, each species was transferred to a black weed barrier covered, full sun, growing area at N.C.SU Horticulture Field Lab (35°79"N –78°69"W) to allow hardening-off and held until field transplantation. Irrigation was provided cyclically three times daily (8:00am, 12:00pm, 4:00pm) and fertilized twice weekly at a rate of 100 ppm N (20N-4.4P-16.6K).

The fall trial field was prepared in a similar manner as above except rows were 2.1 m on center and each plot was .9 m long with two rows of crops per plot and .6 m of row between each plot. Nutrient treatments were again weighed for each treatment combination and
applied by hand. Irrigation was applied 1.5 h a day from 22 Aug. to 19 Oct. and 1.5 h three
days a week for the remainder of the study. Planting was completed by hand. Fungicides,
herbicides, and insecticides were sprayed on a weekly regime as designated by the research
technician. Appropriate amounts of Presidio (Valent, Raleigh, N.C.), Carbaryl (Drexel
Chemical, Memphis, TN) and Sevin (Bayer, Research Triangle Park, N.C.) were sprayed as
required. The within row spacing for chives was 17.5 cm providing 12 plants per plot in a
staggered arrangement. Spacing for fennel was 35 cm providing 6 plants per plot. Chives
were planted 24 Aug. and fennel was planted on 26 Aug. Chives and fennel were harvested
by cutting ~2.5 cm above ground level when reaching commercial maturity (Bench scale FG-
150KBM, A&D, San Jose, CA) within 1 hour. Chives were harvested at 56 and 99 days.
Fennel was harvested at 89 days.

All variables were subjected to analysis of variance (ANOVA) using procedures general
linear model (GLM) and Tukey Honestly Different Significant means separation procedures
where appropriate in SAS, Version 9.4 (SAS, 2016) and were considered significant at \( P \leq
0.05 \). Species were analyzed separately. When nutrient source x N rate interactions were non-
significant, only main effects are presented.

Results and Discussion

The soil pH of both the Lynchburg sandy loam (for the summer trial) and the Cecil gravelly
loam (for the fall trial) was appropriate for herb production. The CEC and Ca level were
lower and the P level was higher for the Lynchburg sandy loam than the Cecil gravelly sandy
loam (Tucker & Debaggio, 2000). However, both soils were fertile and expected to support herb growth.

The nutrient source x nutrient interaction was non-significant for CEC, P, K, Ca, Mg, S, Zn, and Cu to the Lynchburg sandy loam but was significant for the P and K levels of the Cecil gravelly loam. With the Lynchburg sandy loam, the control fertilizer increased the Ca levels more than the SLS while the reverse was true for Mg levels. Other than these impacts, source and rate of nutrient applied did not affect nutrient levels at harvest. With the Cecil gravelly sandy loam, both source and rate of nutrient impacted the P and K levels at harvest while none of the other nutrient levels were affected. When the 100% nutrient rate was applied to the Cecil gravelly sandy loam, the TL resulted in higher P levels than the SLS or the control while TL and control had higher K levels than SLS. At the 50% rate, only the P concentration in the soil was affected with SLS having greater P than control. Neither of the metals of concern with SLS (Zn and Cu) were significantly higher in the soil than the TL or the control.

For total harvested fresh weights, the three-way interaction of species x nutrient source x rate was nonsignificant for all species; however, the growth of each species were affected by nutrient source differently. The significant differences found for total fresh weights between species were to be expected. Total fresh weight of basil and mint was impacted by the source of the nutrient while yields of dill, oregano, chives, and fennel were not (Table 3). Both basil and mint produced similarly when fertilized with SLS and the control. Harvestable yield of
dill, mint, oregano, chives, and fennel were similar when comparing the two waste-based fertilizers to the control (Table 4).

Many published studies show the effects of animal manures on growth of field grown produce (Abo Elazm, 2008; El-Naggar, et al., 2015; Ghosh, 2004; Sifola & Barbieri, 2006). However, there are few published research findings defining the nutrient rates or sources for herb production. The number of leaves per plant of three cultivars of basil in a field setting was the greatest with 100 kg N ha\(^{-1}\) however once the N reached 300 kg N ha\(^{-1}\) no further increases were found. Abo Elazm (2008) found the highest values of the fresh cut and dry weight of marjoram (\textit{Origanum majorana}) was obtained using poultry manure with phosphorein (phosphate dissolving bacteria) or yeast biofertilizers. A study conducted in Egypt testing three cultivars of basil using cow manure also showed success in greater fresh mass when using the higher rate of 80 m\(^3\)/fed and 6 g/l of biofertilizer (El-Naggar, et al., 2015).

In this work, when swine lagoon solids were applied as a fertilizer to fertile soils basil and mint produced the same as the control. Growth of dill, oregano, chives, and fennel was not affected by nutrient source or rate, possibly due to the fertile nature of the soils at planting. SLS could be used as a fertilizer in fresh cut field production; however, to be more precise, more research is needed to define a more prescriptive fertility recommendation for herb production.
Literature Cited


Sifola, M. I. and Barbieri, G. 2006. Growth, yield and essential oil content of three cultivars of basil grown under different levels of nitrogen in the field. Scientia Hort. 108:408-413.


Table 1. Initial soil nutrient concentrations$^z$.

<table>
<thead>
<tr>
<th>Location</th>
<th>pH</th>
<th>CEC$^y$</th>
<th>P$^x$</th>
<th>K</th>
<th>Ca$^w$</th>
<th>Mg$^w$</th>
<th>S</th>
<th>Zn</th>
<th>Cu</th>
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</thead>
<tbody>
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<td>Lynchburg sandy loam$^v$</td>
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<td>82</td>
<td>162</td>
<td>47</td>
<td>16</td>
<td>12</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Cecil gravelly sandy loam$^u$</td>
<td>6.7</td>
<td>22</td>
<td>24</td>
<td>185</td>
<td>76</td>
<td>15</td>
<td>23</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

$^z$Ten soil samples were taken prior to fertilizer application from a depth of 0 to 15 cm from each field and compiled into 3 composite samples per location.

$^y$Cation exchange capacity, meq·100 cm$^3$

$^x$ P, K, S, Zn, and Cu measured as mg·L$^{-1}$.

$^w$ Ca and Mg expressed as percent of CEC.

$^v$ Summer trial (May to August 2016)

$^u$ Fall season trial (August to December 2016)
Table 2. Main effect of nutrient source\textsuperscript{z} on Lynchburg sandy loam and Cecil gravelly sandy loam for both nutrient rates (100\% and 50\%).

<table>
<thead>
<tr>
<th></th>
<th>CEC\textsuperscript{y}</th>
<th>P\textsuperscript{x}</th>
<th>K</th>
<th>Ca\textsuperscript{w}</th>
<th>Mg</th>
<th>S</th>
<th>Zn</th>
<th>Cu</th>
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<td></td>
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<tr>
<td>SLS</td>
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<td>10560a</td>
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<td>CON</td>
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<td>102</td>
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</table>

\textsuperscript{z}Fertilizer included: Dried swine lagoon sludge (SLS) applied at 100\% N per plot (89.7 N kg per ha) (SLS100), SLS at 50\% N per plot (44.7 N kg per ha) (SLS50),
Table 2. (continued)

aerobically composted turkey litter (All Natural Landscapers’ Choice, Sustain (Natural Fertilizer) (TL) applied at 100% N per plot (89.7 kg N per plot) (TL100), TL applied at 50% N per plot (44.7 kg N per plot) (TL50), Potassium nitrate 15.5N-0P-0K; YaraLiva Tropicote; applied at 100% N per plot

\(^y\) Cation exchange capacity, meq·100 cm\(^3\)

\(^x\) P, K, S, Zn, and Cu measured as mg·L\(^{-1}\)

\(^w\) Ca and Mg measured as percent of CEC.

\(^v\) Warm season trial

\(^u\) Means within a column with different letters are significantly different from each other based on Tukey mean separation procedures (p>0.05).

\(^t\) Analysis of variance. NS ≥ 0.05, P-value given otherwise. Analysis of variance of main effect of nutrient source at full and half rate is shown. Each rate was analyzed separately with the control.

\(^s\) Cool Season Trial
Table 3. Effect of nutrient source on fresh weights for each species.

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Basil</th>
<th>Dill</th>
<th>Mint</th>
<th>Oregano</th>
<th>Chives</th>
<th>Fennel</th>
</tr>
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<tbody>
<tr>
<td>SLS</td>
<td>5804.2ab</td>
<td>1038.6</td>
<td>2640.4a</td>
<td>880.5</td>
<td>102.0</td>
<td>250.2</td>
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<tr>
<td>TL</td>
<td>5176.2b</td>
<td>1035.4</td>
<td>2042.5b</td>
<td>808.7</td>
<td>94.9</td>
<td>323.6</td>
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<tr>
<td>CON</td>
<td>5895.8a</td>
<td>735.2</td>
<td>2277.5ab</td>
<td>668.5</td>
<td>145.3</td>
<td>418.8</td>
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</tbody>
</table>

ANOVA

|       | P=0.0245 | NS    | P=0.035 | NS    | NS    | NS    |

**Fertilizer included:** Dried swine lagoon sludge (SLS) applied at 100% N per plot (89.7 N kg per ha) (SLS100), SLS at 50% N per plot (44.7 N kg per ha) (SLS50), aerobically composted turkey litter (All Natural Landscapers’ Choice, Sustane Natural Fertilizer) (TL) applied at 100% N per plot (89.7 kg N per plot) (TL100), TL applied at 50% N per plot (44.7 kg N per plot) (TL50), Potassium nitrate 15.5N-0P-0K; YaraLiva Tropicote; applied at 100% N per plot

**Species tested:** Ocimum basilicum L. ‘Dark Opal’ (basil), Origanum vulgare L. ‘hirtum’ (oregano), Mentha spp. L. (mint), Anethum graveolens L. ‘Hera’ (dill), Allium schoenoprasum L. (chives), Foeniculum vulgare Mill. (fennel).

**Means within a column with different letters are significantly different from each other based on Tukey mean separation procedures (p>0.05).**

**Analysis of variance. Nonsignificant at P ≥ 0.05, P-value given otherwise.**
Table 4. Effect of nutrient source and rate on fresh weights for each species

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Basil</th>
<th>Dill</th>
<th>Mint</th>
<th>Oregano</th>
<th>Chives</th>
<th>Fennel</th>
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<tbody>
<tr>
<td>SLS100</td>
<td>5213bc</td>
<td>1115</td>
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<td>740</td>
<td>100</td>
<td>236</td>
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<td>SLS50</td>
<td>5139c</td>
<td>962</td>
<td>1995</td>
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<td>949</td>
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<td>812</td>
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<td>5896ab</td>
<td>735</td>
<td>2278</td>
<td>689</td>
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<td>419</td>
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</table>

ANOVA \(^w\) 0.0065 NS NS NS NS NS NS

\(^z\)Fertilizer included: Dried swine lagoon sludge (SLS) applied at 100% N per plot (89.7 N kg per ha) (SLS100), SLS at 50% N per plot (44.7 N kg per ha) (SLS50), aerobically composted turkey litter (All Natural Landscapers’ Choice, Sustane Natural Fertilizer) (TL) applied at 100% N per plot (89.7 kg N per plot) (TL100), TL applied at 50% N per plot (44.7 kg N per plot) (TL50), Potassium nitrate 15.5N-0P-0K; YaraLiva Tropicote; applied at 100% N per plot


\(^x\)Means within a column with different letters are significantly different from each other based on Tukey mean separation procedures (p>0.05).

\(^w\)Analysis of variance. Nonsignificant at P ≥ 0.05, P-value given otherwise.
APPENDIX
Appendix. Seed sources for swine lagoon compost as transplant substrate for basil, chives, and dill (chapter one).

<table>
<thead>
<tr>
<th>Botanical Name:</th>
<th>Common Name:</th>
<th>Sources:</th>
<th>Location:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bioassay</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><em>Tagetes</em> patula ‘Janie Deep Orange’</td>
<td>Marigold</td>
<td>Park Seed Co.</td>
<td>Greenwood, S.C.</td>
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<tr>
<td><em>Lycopersicum esculentum</em> ‘Moneymaker’</td>
<td>Tomato</td>
<td>Park Seed Co.</td>
<td>Greenwood, S.C.</td>
</tr>
<tr>
<td><em>Raphanus sativus</em> ‘Cherriette’</td>
<td>Radish</td>
<td>Park Seed Co.</td>
<td>Greenwood, S.C.</td>
</tr>
</tbody>
</table>

| Transplant Study | | | |
| *Allium schoenoprasum* L. | Chives | Johnny's Selected Seeds | Winslow, Maine |
| *Anethum graveolens* L. ‘Hera’ | Dill | Johnny's Selected Seeds | Winslow, Maine |