ABSTRACT

WILLIAMS, MARY THERESA DOROTHY. The Potential of Sludge: Amending Pine Bark with Swine Lagoon Sludge Solids for Greenhouse and Nursery Production of Ornamental Crops. (Under the direction of Helen T. Kraus.)

Many alternative substrates are available and have been investigated that meet the needs of plants in both the greenhouse and nursery industries. The challenge is to find an amendment that not only extends the supply of pine bark but is also locally sourced and offers an inexpensive nutrient package. Swine lagoon solids may be useful and are available in vast quantities in North Carolina. The objective of these studies was to investigate the impact of swine lagoon solids on ornamental horticultural crops in both a greenhouse and nursery setting.

A greenhouse study was conducted as a randomized complete block design with four replications and a factorial arrangement of five nitrogen (N) rates and three species to evaluate the impacts on plant growth in a substrate composed of pine bark amended with swine lagoon solids (SLS 9:1 v/v; n=20). An industry control substrate (9:1 pine bark:mortar sand, v/v) amended with 1.8 $kg \cdot m^{-3}$ (3 $lbs \cdot yd^{-3}$) dolomitic lime and 0.89 $kg \cdot m^{-3}$ (1.5 $lbs \cdot yd^{-3}$) micronutrients was included for comparison (n=4). Ammonium nitrate (34.9-0-0) was used to apply fertilizer solutions of varying N rates: 12.5, 25, 50, 100, or 200 $mg \cdot L^{-1}$ to be applied to the PB:SLS substrate. A complete fertilizer (20-10-20) was applied daily to the control substrate and supplied 100 $mg \cdot L^{-1}$ N, 50 $mg \cdot L^{-1} P_2O_5$, 100 $mg \cdot L^{-1} K_2O$. Growth of *Pennisetum alopecuroides* ‘Hameln’, *Musa velutina*, and *Rudbeckia fulgida* ‘Goldsturm’ shoots and roots were largely unaffected by N rate applied to the SLS substrate, and growth in the SLS substrate was generally not different than in the control. The SLS substrate

maintained higher macro and micro nutrient levels than the control substrate throughout the 112 day experiment. Higher applied N rates increased contents of N, phosphorus, calcium, magnesium, sulfur, iron, manganese, zinc, copper, and boron but did not increase plant growth, so are not worth the expense and potential environmental impact. Based on these data, *Pennnisetum alopecuroides*, *Musa velutina*, and *Rudbeckia fulgida* can be grown in a 9:1 PB:SLS substrate with only 12.5 mg/L N applied with each irrigation and no additional nutrients or lime added.

A nursery study was designed as a randomized complete block with six replications and a factorial arrangement of four nitrogen (N) rates and four species, *Buddleia davidii* "Potter's Purple', *Forsythia* x *intermedia* 'Courdijai', *Gardenia jasminoides* 'Radicans', and *Rhaphiolepis indica* 'Conia' to evaluate the impacts on plant growth when grown in a substrate composed of pine bark (PB) amended with swine lagoon sludge (SLS 9:1 PB v/v; n=24). The industry control substrate from the greenhouse study was included for comparison (n=4). The only observed growth differences from the control substrate were larger *Forsythia* x *intermedia* 'Courdijau' plants grown in SLS with 2 g N and smaller *Gardenia jasminoides* 'Radicans' in SLS with 0 g N applied. *Buddleia davidii* 'Potter's Purple' growth was greater in the control substrate than in the SLS substrate at all N rates. *Rhaphiolepis indica* 'Conia' growth showed no differences between the substrates and N rates. The SLS substrate maintained higher EC than the control at each sample time until July 20, 2015 where they were similar suggesting that slow release nitrogen application could be delayed as much as 31 days after potting in an SLS amended substrate.

These studies show the potential use of swine lagoon sludge amendments in pine bark substrates for both greenhouse and nursery production by reducing the need for additional nutrients.

The Potential of Sludge: Amending Pine Bark with Swine Lagoon Sludge Solids for Greenhouse and Nursery Production of Ornamental Crops.

by
Mary Theresa Dorothy Williams

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Horticultural Science

Raleigh, North Carolina

2016

APPROVED BY:

Helen T. Kraus Committee Chair	Anthony V. LaBude
John J. Classen	Michelle S. McGinnis Technical Consultant

DEDICATION

For my family- be they family by blood or family by love. And for my dad, and his dad, and all the amazing teachers in my life, especially Helen.

BIOGRAPHY

Terri was raised mostly in Charlotte, North Carolina by her parents Helen and Fred Williams with her siblings: Karl, Mari, Carrie, Tom, Annie, and Ed. She graduated from North Carolina State University in 2014 with a B.S. in Horticultural Science and a minor in Plant Biology. Terri currently lives in Raleigh, North Carolina with her dogs, Nuni, Quest, Phan, and Oh My.

ACKNOWLEDGMENTS

I would like to thank my beloved major professor, Dr. Helen T. Kraus, for her patience and guidance through this degree program; I would have lost my mind without you. I would also like to thank my committee for all their insightful help with my writing. To Liz Riley, thank you is not enough to say for the friendship and help you have given me! You are my rock. To my research group mates, Abbey Noah and Paige Herring, the dream lives on in you. Don't ever forget the power of the poo. Lesley Judd you have been a guiding light of inspiration and a wonderful friend. Abby, my dearest friend - Plants rule! And a huge thanks to Bryan Byers, Diane Mays, and the great undergraduates who helped!

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

Pine bark is the primary potting media for the nursery industry and has been since the 1970's; repurposing pine bark as potting material came about as a way to dispose of a waste product after lumber production. Bark can be used in a variety of different ways, including fuel for pulp and sawmills, landscaping uses, cork, particle board, animal bedding, and for more specialized products, such as incense or spices. Currently, timber processing mills are moving overseas leaving the nursery industry in short supply of the pine bark generally used for potting media. The price is increasing while the quality of the pine bark is decreasing in regards to consistency and aging (Lu et al., 2006 and Warren et al., 2007). This situation puts growers in a difficult place, and has induced them to work to overcome the shortages, high prices, and quality issues by making use of other products or amending pine bark to stretch their supplies (Worley et al., 2008).

Pine bark, when aged properly, is structurally almost perfect for container nursery production. The multiple fracture sites on milled bark allows for water and nutrient penetration and for root hairs and fungal hyphae attachment (Airhart et al., 1978). The porous nature of pine bark also is a drawback, allowing rapid water percolation leading to increased frequency of irrigation and fertigation.

The addition of waste products to pine bark is familiar, and studies have researched materials ranging from vermicompost swine manure (McGinnis et al., 2009) to turkey litter (Tyler et al., 1993a & b) to composted cotton stalks and swine waste (Warren et al., 2007). Calcined clays can be used as an 8% (by volume) amendment to pine bark to increase

buffering and water holding capacity as well as to reduce nutrient leaching in bark based substrates, although costs associated with these clay products challenges their adoption by growers (Owens, et al., 2007). Locally available materials are preferred as they add less cost for shipping and are usually easy to acquire. Another quality growers are looking for in pine bark amendments is an addition of nutrients; added nutrients would reduce the need for costly fertilizers which could lead to wasteful runoff and environmental contamination.

North Carolina is currently a leader in swine production, with hogs making up $26,419,703 of the state's $420,145,646 farm cash receipts (USDA ERS, 2015), and an 8.7 million pig population (USDA NASS, 2016). Using swine manure and sludge as a nutrient source is a traditional way to retain the nutrients that would otherwise be lost through site runoff or lagoon volatilization (USDA NRCS, 1992).

When hog farming was done on a small scale (pre 1960's), production was mostly in open lots or in pastures. The accumulated solid manure was scraped from the lots and stored in piles or was left in the pastures. In the 1960's slotted cement flooring came into use, allowing the solid manure to be stored in pits below the animals and decreasing the space needed per animal. This reduction in space needed per animal meant more animals could be efficiently raised in large scale production systems (US EPA, 2015). The need to effectively manage the manure and its nutrients increased in tandem with the increase in production, and led to the use of lagoons to manage nutrients and odor prior to land application (Barker and Zublena, 1996a).

The waste produced by the intensively managed hog production units in North Carolina is captured in engineered lagoons which are used as storage and anaerobic treatment

systems and average approximately 2.5 acres each. Lagoons are designed to evenly distribute the waste: length to width ratios are generally 4:1 with at least 6ft liquid depth for adequate gas dissipation and anaerobic activity (Barker, 1996). There is generally an effluent pipe at the opposite end of the lagoon from the influent, which is used to draw liquid out for field application via irrigation system (Barker, 1996). A partial dewatering of the lagoon is an alternative for removing accumulated sludge solids by mixing the sludge with liquids and then field applying the slurry mixture (Barker, 1996). Unfortunately, the radius of acceptance for field application is narrow due to the odor and lack of knowledge as to the nutrient benefits, as well as due to the sheer weight and volume of the liquid or sludge slurry. Dewatering the solid swine sludge reduces many of the distasteful aspects, such as the odor and composting renders the waste pathogen free, and reduces many of the vectors that were attracted to the fresh waste, such as flies (Keener et al., 2001).

While waste management practices have been under scrutiny for decades, water pollution has been a major issue, especially in North Carolina, where much of the hog production is located in the eastern part of the state where the soil is sandy and very porous. Humenik et al. (1974) suggested criteria for waste handling systems, including energy capture systems and field application in regulated schedules and loads to make efficient use of nutrients. Alternative management systems for swine waste continue to be funded by major hog producers in North Carolina. The goal of the research is to create environmentally superior technology (EST) that is economically feasible for the producers and also meets a long list of performance standards including eliminating discharge into groundwater,

atmospheric emissions of ammonia and foul odors, and pathogen release (Humenik et al., 2004).

Filter beds, used widely in the treatment of municipal sewage, are multistep processes to remove biological solids, nutrients, and phosphate precipitates. They are made of silica sand or anthracite filter media, and have layers of decreasing grit to capture particles in liquid waste. Depths range from 30-40 inches in depth up to 6-10 feet depending on the location of inflow and outflow. The more shallow beds have inflow from the top and outflow at the bottom; while the deeper beds can have inflow at the top and bottom with outflow in the middle of the filter media (US EPA, 1974). Using a polymer to flocculate the solids and facilitate dewatering is helpful in keeping the filter beds in use for longer periods of time. Vanotti et al. (2005) used portions of the Deskins method (F.D. Deskins Company, Inc., Alexandria, Ind.) for dewatering municipal sludge on fresh swine manure using an organic polymer polyacrylamide (PAM) (Magnifloc c-1596, Cytec Industries, Inc., West Paterson, N.J.) to separate the solids prior to filtering through a sand filter bed. This process was successful in dewatering the manure, removing up to 84% of the total solids and improving drainage of the sand filter bed and decreased organic nitrogen and phosphorus in the manure particles suspended in solution by as much as 92% (Vanotti et al., 2005).

Further utilization of polymers has been done in conjunction with geotextile bags for larger scale dewatering processes of dairy lagoon solids (Worley et al., 2008) with liquid aluminum sulfate (alum) also added to increase the coagulation of the solids and to bind with phosphorus to remove from the solution by forming insoluble aluminum phosphate (as shown by Moore and Miller, 1994, in poultry litter). The results of the tests using geotextile

bags and chemical amendments showed that the removal of phosphorus and organic nitrogen was significantly increased (Worley et al., 2008) while the amount of ammonium nitrogen and potassium was reduced in the resulting dewatered material.

Swine lagoon sludge contains a more than adequate nutrient package for many plants (Barker and Zublena, 1996b); incubation studies showed pelletized processed swine lagoon sludge solids were an adequate source of phosphorus, but some plants, such as row crops, would require supplemental application of nitrogen (Duffera et al, 1999a). The swine sludge was dewatered and mixed with rock flour (a waste product from rock aggregate production) and pelletized before incorporation with four soil types from North Carolina: Goldsboro loamy sand (fine-loamy, siliceous, subactive, thermic Aquic Paleudults), Hiwassee clay loam (fine, kaolintic, thermic Typic Rhodudults), Portsmouth fine sandy loam (fine loamy over sandy or sandy-skeletal mixed, thermic Typic Umbraquults), and Conaby Muck (coarse-loamy, mixed, nonacid, thermic Histic Humaquepts). The soil/swine sludge was incubated in polyethylene bags at 25° for 0, 1, 2, 4, 8, 12, and 16 weeks, and analyzed for plant available ammonium as nitrogen (NH_4-N) and nitrate as nitrogen (NO_3-N). The amount of extractable inorganic nitrogen variety among soil types, and was between 24% and 35% recovery of the total nitrogen applied (Duffera et al., 1999a); analysis of phosphorus available showed increased levels after four weeks of incubation, and by the end of the sixteen weeks incubation showed 15-50% recovery of total phosphorus applied.

It has also been reported that the shoot dry weights of bermudagrass (*Cynodon dactylon* L. Pers.), sweet corn (*Zea mays* L. var. silver queen), sorghum (*Sorghum bicolor* L. var. DK-54), and field bean (*Phaseolus vulgaris* L. var. blue lake) in the Ap horizon of a

Norfolk sandy loam soil mixed with processed swine lagoon sludge were similar or superior to growth with a conventional inorganic fertilizer (Duffera et al., 1999b).

Keener et al. (2001) mixed swine lagoon waste with bedding materials (shavings and sawdust) and composted it in aerobic reactor vessels (for 28 days) or in a windrow (for 74 days). It was then used to amend pine bark in increasing amounts: 0, 4, 8, and 16% (v/v). Rooted cuttings were planted of three species, juniper "Blue Pacific", Taxus "Berry Hill", and Deutzia 'Cracillus', in 2L containers of the compost and bark mix, with 5g slow release fertilizer (Osmocote 14-14-14 without micronutrients). Control pots were similarly planted with a bark mix containing aged pine bark, sphagnum peat, and silica sand (80:15:5, v/v), and were also treated with 5g slow release fertilizer (Osmocote 15-9-12 with micronutrients). The plants were grown for 9 weeks in a greenhouse setting and watered as needed. Growth of Deutzia 'Cracillus' was shown to be significantly (P=0.05) greater in pine bark amended with 4% (v/v) composted swine waste than in a bark control mix (Keener et al., 2001). After one year the Taxus "Berry Hill" was also significantly greater in the 4% compost mix than the control or the higher rates of compost. However, no growth differences were seen in the juniper "Blue Rug" even after a year. Keener et al. (2001) felt that the data from their study indicated the usefulness of composted swine manure as an organic nutrient source and amendment for woody shrubs.

The application of vermicomposted (fresh) swine manure at 20% has been shown to increase plant dry weight in *Hibiscus moscheutos* L. 'Luna Blush' as much as 58% compared to 100% pine bark in a greenhouse setting (McGinnis et al., 2009).

Utilizing composted turkey litter as an amendment (at 4, 8, 12, 16% by volume) to pine bark increased available water but decreased air space (Tyler, et al., 1993a). Tyler et al. (1993a) emphasized the need to evaluate both the physical and chemical properties of an amendment to pine bark before adoption by the containerized plant production industries (nurseries and greenhouses). Therefore, before implementing a new substrate mix into an operation, impacts on plant growth, nutrient availability within the substrate, and changes to fertility programs must be considered. With many alternative substrates available, growers are looking for the most locally available substrate with the least increase in cost, and the ready availability of swine lagoon waste is an attractive option.

However, little research has evaluated the growth of herbaceous perennials in containerized plant production with SLS as the only source of nutrients. Therefore, the objective of this study was to evaluate the impact of increasing amounts of swine lagoon compost to pine bark on plant growth.

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Chapter One

Dealing with the Sludge: Amending Pine Bark with Swine Lagoon Solids for Greenhouse Production

(In the format appropriate for submission to the Journal of Environmental Horticulture)

Dealing with the Sludge: Amending Pine Bark with Swine Lagoon Solids for Greenhouse Production

M.T. Williams[1], H.T. Kraus, and E.D. Riley

Department of Horticultural Science

North Carolina State University

Raleigh, NC 27695-7609

Abstract: A study was conducted as a randomized complete block design with four replications and a factorial arrangement of five nitrogen (N) rates and three species to evaluate the impacts on plant growth in a substrate composed of pine bark (PB) amended with swine lagoon sludge (SLS) (9:1 v/v). An industry control substrate (9:1 PB:mortar sand, v/v) amended with 1.8 $kg \cdot m^{-3}$ (3 $lbs \cdot yd^{-3}$) dolomitic lime and 0.89 $kg \cdot m^{-3}$ (1.5 $lbs \cdot yd^{-3}$) micronutrients was included for comparison (n=4). The plants were grown in the greenhouse with natural irradiance and photoperiod for 112 days. Ammonium nitrate (34.9-0-0) was used to mix fertilizer solutions of varying N rates: 12.5, 25, 50, 100, or 200 $mg \cdot L^{-1}$ to be applied to the PB:SLS substrate; no additional nutrients or lime were applied to the PB:SLS substrate. A complete fertilizer (20-10-20) was applied daily to the control substrate and supplied 100 $mg \cdot L^{-1}$ N, 50 $mg \cdot L^{-1} P_2O_5$, 100 $mg \cdot L^{-1} K_2O$. Growth of Pennisetum, Musa, and Rudbeckia shoots and roots were largely unaffected by N rate applied to the SLS substrate. Growth in the SLS substrate was generally not different than in the control. The control substrate had lower concentrations of NO_3 and Ca than the SLS substrate at all N rates even though a complete fertilizer solution was being applied at each fertigation event. The SLS substrate maintained higher macro and micro nutrient levels than the control substrate throughout the 112 day experiment. Higher N applied rates increased contents of N, P, Ca, Mg, S, Fe, Mn, Zn, Cu, and B but not growth. Based on these data, Pennisetum, Musa,

and Rudbeckia can be grown in a 9:1 PB:SLS substrate with only 12.5 mg/L N applied with each irrigation and not additional nutrients or lime added.

[1]Graduate Research Assistant, Associate Professor, and Postdoctoral Associate, respectively.

Additional index words: substrate amendment, plant growth, substrate physical and chemical properties

Species used in this study: *Pennisetum alopecuroides* 'Hameln', fountain grass; *Musa velutina*, ornamental banana; *Rudbeckia fulgida* 'Goldsturm', black eyed susan.

Significance to the Industry

The greenhouse industry might be able to use swine lagoon solids as an amendment to standard substrates as an alternative to peat moss when growing herbaceous perennials. *Musa velutina* H. Wendl & Drude, *Rudbeckia fulgida* Aiton 'Goldsturm', and *Pennisetum alopecuroides* (Linneaus) Sprengel 'Hameln' grew as well in the swine lagoon solids substrate as in the control substrate with only 12.5 mg/L N applied. No added macro- or micronutrients, other than N, or lime were required.

Introduction:

Pine bark is widely used in greenhouse plant production systems. Pine bark is a waste material from the lumber industry (Warren et al., 2007) and has physical (Airhart et al., 1978; de Boodt et al., 1972; Pokorny, 1979) and chemical (Wright and Niemiera, 1987) properties that make it ideal for greenhouse use: pine bark has ample fracture sites for root attachment; micro and macro pore space for air flow and water storage; low nutrient input allowing

growers to tailor their fertilizer schedule to crop needs; and pine bark is very light making it economical to transport. Unfortunately much of the lumber production has moved overseas (Lu et al., 2006) leaving growers with decreasing quantities and quality of pine bark. In addition, the conscious trend towards more sustainable practices in nursery and greenhouse production (Dennis et al., 2010) has caused growers to investigate alternative substrates such as paper mill sludge (Unal, 2015), distillery wastes (Bustamante et al., 2007), and waste products like manure for use as an amendment as well as an organic nutrient source (Keener et al., 2001; Duffera et al., 1999a; McGinnis et al., 2009). Processed swine lagoon solids have been applied to agricultural crops such as corn (*Zea mays*) and sorghum (*Sorghum bicolor*) (Duffera et al., 1999b) and to bermudagrass (*Cynodon dactylon*) (Burns et al., 1990; Read et al., 2008) to assess the effect on plant growth. Long term application (1970-1974) of liquid swine manure to corn showed similar grain yields in the swine treated fields as in the fields fertilized with inorganic fertilizer (Evans et at., 1977), while long term application (1973-1983) of swine lagoon waste on bermudagrass (*Cynodon dactylon*) only produced higher dry matter yields at the rate of 17.2 mg ha^{-1} per year (mean) (Burns et al., 1990). McGinnis et al. (2009) amended pine bark with 20% (by volume) vermicomposted (fresh) swine manure and found shoot dry weights of *Hibiscus moscheutos* L. 'Luna Blush' grown in the vermicompost substrate to average 58% greater than that of pine bark substrate grown plants. No research could be found that evaluated swine lagoon waste for use in short term crop production other than McGinnis et al. (2009) which used vermicomposted fresh manure. Therefore, the objective of this study was to evaluate the impacts on herbaceous perennial

plant growth and nutrient uptake in a pine bark substrate amended with swine lagoon sludge solids and fertigated daily with increasing rates of N.

North Carolina is one of the top hog producers in the US, with approximately 16% of the state's farm cash receipts coming from hog production (USDA, 2015). Duplin County, NC has a population in excess of 2.2 million hogs producing untreated waste that rivals that of New York City (Food & Water Watch, 2015), which, when used as an amendment to pine bark, could contribute to a reduction of fertilizer use in the nursery and greenhouse industry. Swine lagoon waste has been researched as both an amendment (Choudhary et al., 1996 and Keener et al., 2001) and as a nutrient source (Duffera et al., 1999a & b and Read, et al., 2008) for bermuda turfgrass (*Cynodon dactylon*) (Burns et al. 1990). Vermicomposted fresh swine waste has been shown to increase plant dry weight of *Hibiscus moscheutos* L. 'Luna Blush' as much as 58% in container grown plants (McGinnis et al., 2009). However, the use of swine lagoon sludge in nursery production of ornamental plants needs further analysis. Therefore the objective of the research was to evaluate the growth of several woody ornamental species when grown in a pine bark substrate amended with swine lagoon sludge so that appropriate substrate air and water characteristics were achieved. Additionally, the impact of the swine lagoon sludge on substrate pH and EC as well as the nutrient release rate and plant uptake of nutrients was evaluated for their impacts on plant growth.

Materials and Methods

A study was conducted as a randomized complete block design with four replications and a factorial arrangement of five nitrogen (N) rates and three species to evaluate the

impacts on plant growth in a substrate composed of pine bark amended with dewatered swine lagoon sludge (SLS) (9:1 v/v) (pH 5.6) (n=20). An industry control substrate (9:1 pine bark:mortar sand, v/v) (pH 5.8) amended with 1.8 $kg \cdot m^{-3}$ (3 $lbs \cdot yd^{-3}$) dolomitic lime and 0.89 $kg \cdot m^{-3}$ (1.5 $lbs \cdot yd^{-3}$) micronutrients (Parker Bark Company, Rose Hill, NC) was included for comparison (n=4). No lime or micronutrients were added to the SLS substrate. Swine lagoon sludge was dredged from a lagoon in Garland, North Carolina (Murphy Brown, LLC, Warsaw, NC) 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, NC) was added and thoroughly mixed with the sludge. The sludge and polymer mix 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 and was pumped from the reservoir back into the lagoon. The sludge/polymer mix in the bag was allowed to drain for two years before use. Once removed from the bag, the swine lagoon sludge (SLS) were spread on plastic and allowed to air dry in a plastic covered hoop house for two weeks prior to mixing with the pine bark (PB).

Waste samples were submitted to the NCDA&CS (North Carolina Department of Agriculture and Consumer Services, Agronomic Division Raleigh, NC) for analysis. 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) (AOAC 1990b; Campbell 1992). Inorganic-nitrogen (IN-N) fraction concentrations include nitrate-nitrogen plus nitrite-nitrogen (NO_3-N + NO_2-N and ammonium-nitrogen (NH3-N + NH4-N). NO_3-N is determined by nitrate-hydrazine

reduction (Kempers 1988; Skalar Analytical 1995b) and NH_4-N is determined by modified Berthelot reaction (adapted from Krom 1980; Skalar Analytical 1995a) 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) are determined with inductively coupled plasma-optical emission spectrometry (ICP-OES) (Spectro Arcos EOP, Spectro Analytical: A Division of Ametek; Mahwah, NJ) (Donohue and Aho 1992; adapted USEPA 2001), after closed-vessel nitric acid (HNO_3) digestion in a microwave digestion system (MARS 6 Microwaves; CEM Corp.; Matthews, NC) (Campbell and Plank 1992) (Table 1).

On February 5, 2015 seedling liners of *Musa velutina* H. Wendl & Drude (musa), *Rudbeckia fulgida* Aiton 'Goldsturm'(rudbeckia), and *Pennisetum alopecuroides* (Linneaus) Sprengel 'Hameln'(pennisetum), grown in 10.16 cm containers, were potted into 3.8L (1 gal) containers (Classic 500, Nursery Supplies, Inc., Chambersburg, PA) filled with either the 9:1 pine bark (PB):SLS or the control substrate. The plants were grown in the Marye Anne Fox Teaching Laboratory (35.78°N/78.64°W) greenhouse (26.67C (80F) day/18.33C (65F) night temperature) with natural irradiance and photoperiod for 112 days. Ammonium nitrate (34.9-0-0) was used to mix fertilizer solutions of varying N rates: 12.5, 25, 50, 100, or 200 $mg \cdot L^{-1}$ to be applied to the PB:SLS substrate; no additional nutrients or lime were applied to the PB:SLS substrate. A complete fertilizer (20-10-20) (Peters' Professional, Everris, Dublin, OH) was applied daily to the control substrate and supplied 100 $mg \cdot L^{-1}$ N, 50 $mg \cdot L^{-1} P_2O_5$, 100 $mg \cdot L^{-1} K_2O$. Concentrated stock solutions of each N rate and the industry control

nutrient solution were applied with a fertigation system using low-volume spray stakes (PC Spray Stake, Netafilm, LTD., Tel Aviv, Israel) and a Dosatron D161 proportional injector (Dosatron, Inc., Clearwater, FL). Between each nitrogen application the Dosatron and appropriate irrigation lines were flushed with distilled water, drained, and primed with the next nitrogen rate before application. Cyclic irrigation was applied twice daily; irrigation water contained an average of 0.83 $mg \cdot L^{-1}$ N, 0.21 $mg \cdot L^{-1}$ P, and 3.44 $mg \cdot L^{-1}$ K with a pH of 7.83.

Leaching fraction (LF = volume leached ÷ volume applied) was measured every two weeks and irrigation volume was adjusted to maintain a 0.2 LF. Additionally substrate solution was collected every two weeks (on 3/5, 3/17, 4/3, 4/17, 4/28, 5/12, and 5/27) using the pour-through nutrient extraction method (Wright, 1986). Substrate solution electrical conductivity (EC) and pH were measured using a combination EC/pH meter (HI 8424, Hannah Instruments, Ann Arbor, MI). After EC and pH measurements, substrate solution samples were submitted to the NCDA&CS (North Carolina Department of Agriculture and Consumer Services, Agronomic Division Raleigh, NC) for inorganic nitrogen (IN-N), urea, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Z) analyses. The IN-N fraction concentrations include nitrate + nitrite nitrogen (NO_3-N + NO_2-N) and ammonium nitrogen (NH_4-N). NO_3-N was determined on a homogenized sample (~20 mL) by nitrate-hydrazine reduction (Kempers, 1988; Skalar Analytical, 1995b) and NH_4-N was determined by a modified Berthelot reaction (adapted from Krom, 1980; Skalar Analytical, 1995a), with an auto-flow spectrophotometric analyzer (San++ Segmented Flow AutoAnalyzer, Skalar Instruments;

Breda, The Netherlands). Total concentrations of P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, and B were determined with an inductively coupled plasma (ICP) spectrophotometer (USEPA, 2001) (Optima 3300 DV ICP emission spectrophotometer; Perkin Elmer Corporation; Shelton, CT).

Substrate physical properties were determined initially at potting (February 5, 2015) and after harvest (June 2, 2015). Total porosity (TP), airspace (AS), container capacity (CC), and bulk density (BD) analyses were conducted in the Horticultural Substrates Laboratory, Department of Horticultural Science, N.C. State Univ., Raleigh, NC. Three replications of each substrate were packed into 347.5 cm3 cylindrical aluminum 23 rings (7.6 cm diameter, 7.6 cm height) and they were used to determine TP, AS, CC, and BD according to procedures outlined in Tyler et al. (1993a).

Particle size data was collected and analyzed on both the SLS substrate and the control substrate at the time of initial potting (February 5, 2015) and at harvest (June 2, 2015). Samples of the substrates were oven dried at 105°C for 48 hours. The samples were portioned into three 100 g subsamples and sorted on a Ro-Tap Sieve Shaker (Model B, W.S. Tyler, Mentor, Ohio) with six sieve sizes (6.3mm, 2mm, 0.71mm, 0.5mm, 0.25mm, and 0.11mm) and a solid pan. The subsamples were then shaken through the sieves for 5 minutes and then the contents of each sieve and the pan were weighed. Particle size was expressed as a percentage of the total weight of the sample.

After nine weeks (63 days), shoots of *Musa velutina* and at sixteen weeks (112 days) shoots of *Rudbekia fulgida* ‘Goldsturm’ and *Pennisetum alopecuroides* ‘Hameln’ were removed and roots washed free of substrate. Shoot and root dry weights (oven dried at

40C/104F for four days) were determined and used for growth comparisons. After dry weights were measured, shoot samples were submitted to the North Carolina Department of Agriculture and Consumer Services, Agronomic Division, Raleigh, North Carolina for grinding and tissue analyses (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, and Na). Foliar N concentration was determined by oxygen combustion gas chromatography with an elemental analyzer (NA 1500; CE Elantech Instruments, Lakewood, N.J.) (Campbell and Plank, 1992). Foliar P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn concentrations were determined with an inductively coupled plasma (ICP) spectrometer (Donohue and Aho, 1992) (Optima 3300 DV ICP Emission Spectrometer; Perkin Elmer Corp., Shelton, CT) following open-vessel nitric acid digestion in a microwave digestion system (CEM Corp., Matthews, NC) (Campbell and Plank, 1992). Foliar content was calculated as shoot dry weight x nutrient concentration.

All data were subjected to analysis of variance (ANOVA) and regression analyses and means were separated using single degree of freedom, linear contrasts, and were considered significant at $P \leq 0.05$.

Results and Discussion

The substrate by sample time interaction was not significant for all physical properties (data not shown). Based on physical property testing done by Williams et al. (2015) a 9:1 PB:SLS substrate was chosen anticipating that the physical properties would be similar to the 9:1 PB:sand industry control substrate. Although the SLS and control substrates were not significantly different in TP, AS, CC, or AW at each sample time, they did differ in UAW, and BD (Table 2). The SLS substrate had greater UAW (32%) but lower BD

(0.22g·cc^{-3}) than the control substrate. Both the control and the SLS substrates had changes in TP, CC, AW, and BD over the 16 week (112 days) study. TP and CC increased between the initial (85 and 55% for TP and CC, respectively) and final measurement (86 and 60% for TP and CC, respectively). Available water increased between the initial (26%) and the final measurement (32%). BD decreased between the initial measurement (0.26g·cc^{-3}) and the final measurement (0.21g·cc^{-3}).

The substrate by sample time interaction was significant for the particle size distribution of the 0.25mm and 0.11mm ranges, and the solid pan (data not shown). Particles larger in size than 0.71mm were greater in the SLS substrate than in the control substrate, while control had a greater amount of particles smaller than 0.5mm range (data not shown). The distribution for the 0.25 and 0.11mm ranges in the SLS substrate was similar to the control substrate at the initial measurement, but after 16 weeks (112 days) the SLS substrate was lower than the control substrate (data not shown). The particle distribution in the solid pan for the control substrate was greater than the SLS substrate, but at the final measurement the two substrates were similar in particle size distribution (data not shown).

Growth of Pennisetum, Musa, and Rudbeckia shoots and roots were largely unaffected by N rate applied to the SLS substrate (Table 3). Additionally, growth of these species in the SLS substrate was generally not different than in the control with the exception of root growth of Musa and Rudbeckia, which was larger in the control substrate than most of N rates applied to the SLS substrate.

Substrate solution pH of the SLS substrate and the control substrate remained within recommended ranges throughout the project for all species (data not shown). Additionally,

the N rate x sample time interaction was non-significant. The lowest substrate solution pH (5.0) was found in the 200 mg/L N on May 12, 2015, while the highest (6.3) was found in the control at the last sample date (data not shown). The species x N rate interaction was significant for pH and EC. Substrate solution pH and EC levels were affected by N rate (Table 4). Substrate solution pH decreased and EC increased as N rate increased for Pennisetum and Rudbeckia. The control substrate maintained higher pH and lower EC than the SLS substrate.

The concentrations of nutrients in the SLS substrate responded differently to sample time and N rate for each species. For Pennisetum, the interactions between nitrogen rate and sample time were not significant for all concentrations of nutrients in the SLS substrate solution (data not shown) except Ca ($p \leq 0.0033$), Mn ($p \leq 0.0006$), and Zn ($p \leq 0.0036$). Concentrations of urea, NH_4-N, NO_3-N, P, K, Ca, Mg, S, Fe, Mn, Zn, B, Cl, and Na in the SLS substrate with Pennisetum solution decreased over the 8 weeks while Fe and Cu concentrations were not affected by time (Table 5 and data not shown). Rate of N applied to Pennisetum grown in the SLS substrate affected concentrations of NO_3-N, P, K, Ca, Mg, Fe, Mn, Zn, Cu, B, and Na (Table 5 and data not shown). Concentration of NO_3-N, Ca, Mg, Mn,, Zn, B and Na increased as N rate applied increased while concentrations of P, K, Fe, and Cu decreased with higher N rates.

Substrate solution of containers with Musa growing in them was only sampled three times and the nutrient concentrations in the SLS substrate solution were affected by the interaction between N rate and sample time for NO_3-N ($p \leq 0.0002$), P ($p \leq 0.0003$), K $p \leq 0.0014$), Ca ($p \leq 0.0003$), Mg ($p \leq 0.0006$), S ($p \leq 0.0133$), Mn ($p \leq 0.0008$), Zn ($p \leq 0.0123$), Cu

($p \leq 0.0144$), and Na ($p \leq 0.0185$). Concentrations of NH_4-N, P, K, Ca, Mg, S, Mn, Zn, Cu, B, Cl, and Na in the SLS substrate solution decreased by at least 50% over the 6 weeks (data not shown). Concentrations of NO_3-N and Ca, in the SLS substrate solution increased linearly with increasing N rate at 4 and 6 weeks (Table 6). The control substrate had lower concentrations of NO_3-N and Ca than the SLS substrate at all N rates even though a complete fertilizer solution was being applied at each fertigation event.

The concentration of NO_3-N ($p \leq 0.0413$), P ($p \leq 0.0118$), K ($p \leq 0.0135$), Ca ($p \leq 0.0235$), Mg ($p \leq 0.019$), Mn ($p \leq 0.0028$), Zn ($p \leq 0.0055$), B ($p \leq 0.0004$), Cl ($p \leq 0.0001$), and Na ($p \leq 0.0094$) in the SLS substrate solution with Rudbeckia were affected by the interaction between nitrogen rate and sample time. Concentrations of these nutrients in the SLS substrate did not decrease as much as (a minimum of 15%) in containers with Rudbeckia as they did with Musa (Table 6 and data not shown). This is likely due to the slower growth rates of Rudbeckia compared to Musa. Rate of N applied to Musa growing in the SLS substrate affected the NO_3-N and Fe concentrations only, with the concentration of Fe decreased linearly with increasing N rates while the NO_3-N concentration tended to increase (Table 6 and data not shown).

Even though there were greater concentrations of NO_3-N, Ca, Mg, Mn, Zn, B and Na in the substrate solution of Pennisetum with higher N rates, N rate did not significantly impact the foliar N, Ca, Mg, Mn, Zn or B concentrations (Tables 5 & 9 and data not shown). However, there were significant linear increases in N, P, Ca, Mg, S, Fe, Mn, Zn, Cu, and B Pennisetum foliar concentrations with increasing N rate. In general all N rates applied to Pennisetum grown in the SLS substrate resulted in foliar nutrient concentrations similar to

the control with only the 200 mg/L N rate producing significantly higher foliar N, P, Ca, Mg, Fe, Mn, Zn, and B concentrations than the control.

Similarly, the substrate solution of Musa grown with SLS were higher in NO_3 and Ca as N rate applied increased however, N rate did not impact foliar concentrations of N, P, K, Ca, Mg, S, Fe, Mn, or Cu but did affect foliar Zn and B concentrations (Tables 7 & 9 and data not shown). However, Musa grown in the SLS substrate at all N rates had greater N, P, Ca, Mg, Mn, Zn, and Cu than the when grown in the control (Table 9 and data not shown). Potassium, S, Fe, and B foliar concentrations of Musa grown in the SLS substrates at all N rates were similar to the control.

Rudbeckia grown in SLS substrate had more NO_3 and Fe available in the substrate as N rate increased; however, N rate did not affect the uptake of N, P, K, Ca, Mg, S, Fe, Cu or B into the leaves of Rudbeckia (Tables 8 & 9 and data not shown). Foliar concentrations of Mn and Zn in Rudbeckia increased linearly as N rate increased (data not shown). Rudbeckia with 50 mg/L N or higher applied and grown in the SLS substrate had greater N, P, K, Ca, Mg, S, and Zn foliar concentrations than when grown in the control substrate.

Foliar content of nutrients was affected differently in each species. Looking again at the greater concentrations of NO_3, Ca, Mg, Mn, Zn, B and Na in the substrate solution of pennisetum with higher rates of N, N rate applied to the SLS substrate did not significantly affect the foliar content of N, P, Ca, Mg, S, Mn, Cu, and B (Table 10 and data not shown). In contrast, Pennisetum foliar content of K and Zn were affected, both responding quadratically to increasing rates of N applied to the SLS substrate. Pennisetum grown in the SLS substrate

generally resulted in foliar content similar to the control for N, P, Ca, Mg, Mn, and Zn with the 100 and 200 g N rate resulting in higher foliar content.

Foliar Ca, Mg, Fe, Zn, Cu, and B content of Musa grown in SLS substrate was significantly impacted with increasing rates of N (Table 10 and data not shown). Ca decreased linearly while B increased linearly and Zn responded quadratically to increasing N rates. Generally, Musa grown in SLS substrate had higher foliar N, P, Ca, Mg, S, Mn, Zn, Cu, and B content than when grown in the control substrate. However, K and Fe had significantly lower foliar content than when grown in the control substrate (Table 10 and data not shown).

The foliar content of Mg, Zn, and B in Rudbeckia grown in SLS substrate was affected by increasing rates of N, while the foliar N, P, K, Ca, S, Fe, Mn, and Cu contents were not impacted (Table 10 and data not shown). Foliar Mg and B content in Rudbeckia grown in SLS substrate decreased linearly as N rate increased while foliar Zn content increased linearly (Table 10). Rudbeckia grown in SLS substrate had similar foliar Fe, Mn, and Cu content when compared with the control substrate. Boron had significantly less foliar content in rudbeckia in the SLS substrate, and N, P, K, Ca, Mg, S, and Zn generally had greater or similar foliar content than when grown in the control substrate.

Conclusions

Minor differences in unavailable water content and bulk density occurred between the SLS substrate and the control substrate; however, these differences were likely not biologically relevant as both substrates supported plant growth. Growth was similar in the SLS and control substrates for all three species. Additionally, when grown in the SLS

substrate, 12.5 mg/L N was sufficient for growth. The SLS substrate maintained higher macro and micro nutrient levels than the control substrate throughout the 112 day experiment. N rate and species impacted the concentrations of macro and micro nutrients in the SLS substrate over time. For all three species, higher N rates increased NO_3-N even though ammonium nitrate was used as the nitrogen fertilizer. The SLS substrate increased the concentration of N, P, Ca, and Zn in Musa regardless of N rate. However, N applications greater than 200 and 50 mg/L for Pennisetum and Rudbeckia, respectively, were required to increase N, P, K, Ca, and Zn concentrations in these species. When evaluating nutrient content (actual mg of nutrient absorbed by the plant), the SLS substrate at all N rates resulted in either numerically or statistically higher N, P, K, Ca, and Zn than the control substrate for all three species. Higher N applied rates increased contents of N, P, Ca, Mg, S, Fe, Mn, Zn, Cu, and B but not growth, so are not worth the expense and potential environmental impact. Based on these data, Pennisetum, Musa, and Rudbeckia can be grown in a 9:1 PB:SLS substrate with only 12.5 mg/L N applied with each irrigation and no additional nutrients or lime added.

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Table 1. Swine lagoon sludge solid waste analysis.

Nutrient[z]	Concentration (ppm)[y]
Carbon	221,000
Nitrogen	28,500
Phosphorus	73,700
Potassium	4,930
Calcium	122,000
Magnesium	18,600
Sulfur	12,400
Iron	8,350
Manganese	975
Zinc	2,920
Copper	314
Boron	22.2
Sodium	2350
Other Measurements	
Carbon: Nitrogen	7.77: 1
pH	5.82
Electrical Conductivity	5.36 mS/cm[x]
Dry Matter	22%

[z]Nutrients included in waste analysis performed at North Carolina Department of Agriculture & Consumer Services, December 2014.

[y]Concentration of nutrients present in swine lagoon sludge solids (ppm= parts per million).

[x]mS/cm= millisiemens per centimeter.

Table 2. Effect of pine bark (PB) and PB substrate amended with swine lagoon solids (SLS) on total porosity (TP), air space (AS), container capacity (CC), available water (AW), unavailable water (UAW), and bulk density (BD).

Total Porosity[z] (TP)			
Sample time p=.0072		Substrate NS	
Sample time[y]	means	Substrate	means
Initial	85b[x]	PB[w]	85a
Final	86a	SLS[v]	86a
Air Space[u] (AS)			
Sample time NS		Substrate NS	
Sample time	means	Substrate	means
Initial	31a	PB	30a
Final	27a	SLS	28a
Container Capacity[t] (CC)			
Sample time p=0.019		Substrate NS	
Sample time	means	Substrate	means
Initial	55b	PB	56a
Final	60a	SLS	58a
Unavailable Water[s] (UAW)			
Sample time p=0.0035		Substrate NS	
Sample time	means	Substrate	means
Initial	29a	PB	27b
Final	28a	SLS	30a
Available Water[r] (AW)			
Sample time p=0.0264		Substrate NS	
Sample time	means	Substrate	means
Initial	26b	PB	29a
Final	32a	SLS	28a
Bulk Density[q] (BD) (g/cm^3)			
Sample time p=0.0004		Substrate p=0.0032	
Sample time	means	Substrate	means
Initial	0.26a	PB	0.25a
Final	0.21b	SLS	0.22b

[z]Based upon percent volume of a 7.6 cm core at 0 kPA.
[y]The substrates were sampled twice for physical analysis initially at potting (initial) and again at 12 weeks after planting (final). NS= Not significant, *P*-value given otherwise.

Table 2. Continued.
[x]Means within a column with different letters are significantly different from each other based on Tukey's HSD mean separation procedures ($p \geq 0.05$). N=4
[w]PB= pine bark substrate: 9:1 pine bark:mortar sand (v/v).
[v]SLS= swine lagoon solid substrate: 9:1 SLS:pine bark (v/v).
[u]AS = TP-CC.
[t]Measured as a percent volume of a 7.6 cm core at drainage.
[s]Based upon percent volume of a 2.5 cm core at 1500 kPA.
[r]AW = CC-UAW.
[q]BD is measured as the ration of dry solids to the bulk volume of the substrate.

Table 3. Impact of N rate on root and shoot dry weight (g) of Pennisetum, Musa, and Rudbeckia.

N rate[z]	Pennisetum		Musa		Rudbeckia	
mg/L	Shoot	Root	Shoot	Root	Shoot	Root
12.5 and SLS[y]	3.3	4	8	8.9	11.6	17.7
25 and SLS	4	5.7	8.2	8.4	4.4	10.3
50 and SLS	3.4	3.6	8.2	8.7	13.7	30.4
100 and SLS	3.1	2.9	7.3	7.1	14.3	15.8
200 and SLS	4.2	4.3	8	6.9	9.3	14.8
Control[x]	2.5	2.6	6.3	12.5	10.4	39.5
ANOVA[w]	NS	NS	NS	NS	NS	0.02
Linear[v]	NS	NS	NS	NS	NS	NS
Quadratic[u]	NS	NS	NS	NS	NS	NS
Linear Contrast[t]						
Control vs. 12.5	NS	NS	NS	0.009	NS	0.008
Control vs. 25	NS	0.03	0.04	0.004	NS	0.01
Control vs. 50	NS	NS	0.05	0.007	NS	NS
Control vs. 100	NS	NS	NS	0.0004	NS	0.005
Control vs. 200	NS	NS	NS	0.0003	NS	0.004

[z]N rate applied as liquid ammonium nitrate (34.9-0-0).
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Control substrate was a 9:1 pine bark:sand (v/v) with 20-10-20 applied as liquid to supply 100mg/L.
[w]Analysis of variance (ANOVA) effect of N rate within species NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[u]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[t]Linear contrast analysis comparing N rate treatment means to the control substrate. NS=not significant, *P*-value given otherwise.

Table 4. Effect of N rate on substrate solution pH and electrical conductivity (EC)

	Pennisetum		Musa		Rudbeckia	
N Rate (mg/L)[z]	pH	EC (µs/cm)	pH	EC (µs/cm)	pH	EC (µs/cm)
12.5 and SLS[y]	5.3	1.6	5.4	1.7	5.5	1.4
25 and SLS	5.4	1.4	5.4	1.9	5.4	1.6
50 and SLS	5.4	1.5	5.2	2.1	5.4	1.6
100 and SLS	5.3	1.8	5.2	2.2	5.3	1.9
200 and SLS	5.1	2.3	5.2	2.4	5.1	2.1
Control[x]	6.0	0.5	5.9	0.4	5.9	0.4
ANOVA[w]	<0.0001	<0.0001	0.002	0.0063	<0.0001	<0.0001
Linear[v]	<0.0001	<0.0001	NS	NS	<0.0001	0.0024
Quadratic[u]	NS	NS	NS	NS	NS	NS
Linear Contrast[t]						
Control vs. 12.5	<0.0001	<0.0001	0.0001	0.0009	<0.0001	<0.0001
Control vs. 25	<0.0001	<0.0001	0.0002	0.0002	<0.0001	<0.0001
Control vs. 50	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Control vs. 100	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Control vs. 200	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[z]N rate applied as liquid ammonium nitrate (34.9-0-0).
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Control substrate was a 9:1 pine bark:sand (v/v) with 20-10-20 applied as liquid to supply 100mg/L.
[w]Analysis of variance (ANOVA) effect of N rate within species NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[u]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[t]Linear contrast analysis comparing N rate treatment means to the control substrate. NS=not significant, *P*-value given otherwise.

Table 5. Effect of sample time on nutrient concentration in SLS substrate solution of urea, NH_4-N, NO_3-N, P, K, Mg, S, Fe, B, Cl, and Na of *Pennisetum alopecuroides*

Pennisetum	Sample Time			
Nutrient[z]	5-Mar-15	17-Mar-15	3-Apr-15	17-Apr-15
Urea	0.7a[y]	0.6a	0.5b	0.0b
NH_4-N	15.2a	1.6b	2.4b	0.6b
NO_3-N	220.0a	178.7b	133.4c	124.6c
P	294.3a	210.6b	136.7c	117.8c
K	110.3a	74.1b	44.9c	29.6d
Mg	207.8a	149.5b	92.8c	76.0c
S	88.4a	50.4b	33.7c	28.1c
Fe	0.0a	0.0ab	0.0b	0.0a
B	0.1a	1.0b	0.1c	0.1c
Cl	29.5a	22.4b	18.7c	19.2c
Na	46.6a	40.4b	38.9bc	34.9c

[z]Nutrient concentration in SLS substrate solution.
[y]Means within a column with different letters are significantly different from each other based on Tukey's HSD mean separation procedures ($p \geq 0.05$). N=4.

Table 6. Effect of N rate on nutrient concentration in SLS substrate solution of NO_3-N, P, K, and Mg of *Pennisetum alopecuroides*

Pennisetum	Nutrient			
N Rate (mg/L)[z]	NO_3-N	P	K	Mg
12.5 and SLS[y]	156.1	217.5	76.2	142.5
25 and SLS	129.5	176.4	60.1	114.6
50 and SLS	140.4	181.3	61.4	119.7
100 and SLS	171.4	171.7	64.6	130.3
200 and SLS	223.6	192.3	61.3	150.4
ANOVA[x]	<0.0001	0.0383	0.0363	0.0182
Linear[w]	<0.0001	NS	NS	NS
Quadratic[v]	NS	NS	NS	NS

[z]N rate applied as liquid ammonium nitrate (34.9-0-0).
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Analysis of variance (ANOVA) effect of N rate within species NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[w]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.

Table 7. Effect of N rate on nutrient concentration in SLS substrate solution of NO_3-N and Ca of *Musa velutina*

Musa	Sample Time		
Nutrient	NO_3-N		
N Rate (mg/L)[z]	5-Mar-15	17-Mar-15	3-Apr-15
12.5 and SLS[y]	165.5	134.1	33.0
25 and SLS	200.5	130.0	32.3
50 and SLS	230.5	140.0	64.4
100 and SLS	242.8	168.8	118.1
200 and SLS	211.0	251.5	183.8
Control[x]	2.5	10.3	12.2
ANOVA[w]	NS	0.0005	<0.0001
Linear[v]	NS	<0.0001	<0.0001
Quadratic[u]	0.0451	NS	NS
Linear contrast[t]			
Control vs 12.5	0.0019	<0.0001	NS
Control vs 25	0.0003	0.0001	NS
Control vs 50	<0.0001	<0.0001	0.0085
Control vs 100	<0.0001	<0.0001	<0.0001
Control vs 200	0.0002	<0.0001	<0.0001

Nutrient		Ca	
N Rate (mg/L)	5-Mar-15	17-Mar-15	3-Apr-15
12.5 and SLS	128.2	112.5	40.9
25 and SLS	156.5	114.3	34.3
50 and SLS	164.0	120.0	61.8
100 and SLS	170.5	118.8	96.4
200 and SLS	137.0	159.0	145.3
Control	9.9	5.1	4.9
ANOVA	NS	NS	0.0008
Linear	NS	0.0112	<0.0001
Quadratic	NS	NS	NS
Linear contrast			
Control vs 12.5	0.0004	<0.0001	NS
Control vs 25	<0.0001	<0.0001	NS
Control vs 50	<0.0001	<0.0001	0.0075
Control vs 100	<0.0001	<0.0001	0.0002
Control vs 200	0.0002	<0.0001	<0.0001

[z]N rate applied as liquid ammonium nitrate (34.9-0-0).

Table 7. Continued.

[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Control substrate was a 9:1 pine bark:sand (v/v) with 20-10-20 applied as liquid to supply 100mg/L.
[w]Analysis of variance (ANOVA) effect of N rate within species NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[u]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[t]Linear contrast analysis comparing N rate treatment means to the control substrate. NS=not significant, *P*-value given otherwise. N=4

Table 8. Effect of N rate on concentration of NO_3-N in SLS substrate solution over time

Nutrient N Rate (mg/L)[z]	NO_3-N			
	5-Mar-15	17-Mar-15	3-Apr-15	17-Apr-15
12.5 and SLS[y]	149.3	135.4	154.6	126.3
25 and SLS	236.5	162.8	104.4	100.8
50 and SLS	197.5	257.7	126.9	147.5
100 and SLS	216.8	222.8	160.5	216.8
200 and SLS	222.3	281.8	183.3	207.5
ANOVA[x]	0.0197	0.0274	NS	NS
Linear[w]	NS	0.0037	NS	0.0106
Quadratic[v]	NS	NS	NS	NS

[z]N rate applied as liquid ammonium nitrate (34.9-0-0).
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Analysis of variance (ANOVA) effect of N rate within species NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[w]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.

Table 9. Effect of N rate on foliar nutrient concentration of Pennisetum, Musa, and Rudbeckia

N Rate (mg/L)[z]	N (%)	P (%)	K (%)	Ca (%)	Zn (mg/L)
			Pennisetum		
12.5 and SLS[y]	9.2	3.1	10.9	1.7	709.2
25 and SLS	11.6	3.4	11.7	2.0	12.7
50 and SLS	9.5	2.9	9.3	1.9	1112.0
100 and SLS	13.2	3.1	10.8	1.9	1385.7
200 and SLS	18.4	5.2	14.7	3.0	1734.9
Control[x]	8.3	2.5	12.5	1.5	807.2
ANOVA[w]	NS	NS	NS	NS	NS
Linear[v]	0.0017	0.0049	NS	0.009	0.0052
Quadratic[u]	NS	0.0336	NS	NS	NS
Linear Contrast[t]					
Control vs. 12.5	NS	NS	NS	NS	NS
Control vs. 25	NS	NS	NS	NS	NS
Control vs. 50	NS	NS	NS	NS	NS
Control vs. 100	NS	NS	NS	NS	NS
Control vs. 200	0.0076	0.0035	NS	0.0059	0.0269
N Rate mg/L	N (%)	P (%)	K (%)	Ca (%)	Zn (mg/L)
			Musa		
12.5 and SLS	30.6	14.4	29.7	10.3	712.4
25 and SLS	33.9	17.2	34.7	11.3	1085.0
50 and SLS	32.4	15.2	29.9	11.3	1095.8
100 and SLS	30.2	13.2	28.4	9.3	1118.7
200 and SLS	33.1	14.3	34.9	9.7	1190.3
Control	19.7	4.6	35.0	5.3	275.9
ANOVA	NS	NS	NS	NS	0.0441
Linear	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS

Table 9. Continued.

Linear Contrast					
Control vs. 12.5	0.0114	0.0009	NS	0.0008	0.0071
Control vs. 25	0.002	<0.0001	NS	0.0001	<0.0001
Control vs. 50	0.0043	0.0005	NS	0.0001	<0.0001
Control vs. 100	0.0144	0.0025	NS	0.0039	<0.0001
Control vs. 200	0.003	0.001	NS	0.002	<0.0001
N Rate	N (%)	P (%)	K (%)	Ca (%)	Zn (mg/L)
mg/L			Rudbeckia		
12.5 and SLS	34.1	4.3	28.1	46.2	2399.3
25 and SLS	28.6	3.6	19.5	34.1	1865.0
50 and SLS	45.7	6.1	22.6	55.7	2816.3
100 and SLS	49.5	6.5	26.3	59.6	4439.6
200 and SLS	44.2	5.3	18.8	46.4	4174.6
Control	27.6	2.5	26.0	34.2	2118.7
ANOVA	NS	NS	NS	NS	0.0051
Linear	NS	NS	NS	NS	0.0026
Quadratic	NS	NS	NS	NS	NS
Linear Contrast					
Control vs. 12.5	NS	NS	NS	NS	NS
Control vs. 25	NS	NS	0.0094	Ns	NS
Control vs. 50	0.0158	0.0046	0.0335	0.0262	NS
Control vs. 100	0.0055	0.0017	NS	0.0066	0.0003
Control vs. 200	0.0299	0.0191	0.0084	NS	0.0015

[z]N rate applied as liquid ammonium nitrate (34.9-0-0).
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Control substrate was a 9:1 pine bark:sand (v/v) with 20-10-20 applied as liquid to supply 100mg/L.
[w]Analysis of variance (ANOVA) effect of N rate within species NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Linear regression analysis. NS=not significant, *P*-value given otherwise.

Table 9. Continued.

[u]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.

[t]Linear contrast analysis comparing N rate treatment means to the control substrate. NS=not significant, *P*-value given otherwise.

Table 10. Effect of N rate on foliar nutrient content of Pennisetum, Musa, and Rudbeckia

N Rate (mg/L)[z]	N (%)	P (%)	K (%)	Ca (%)	Zn (mg/L)
			Pennisetum		
12.5 and SLS[y]	2.8	0.9	3.3	0.5	218.3
25 and SLS	2.9	0.9	2.9	0.5	306.8
50 and SLS	2.8	0.9	2.8	0.6	323.0
100 and SLS	3.4	0.8	2.8	0.5	365.1
200 and SLS	3.5	1.0	2.8	0.6	328.2
Control[x]	2.6	0.8	3.8	0.5	244.7
ANOVA[w]	NS	NS	0.0175	NS	0.0324
Linear[v]	0.0047	NS	0.0473	NS	NS
Quadratic[u]	NS	NS	0.0439	NS	0.0065
Linear Contrast[t]					
Control vs. 12.5	NS	NS	NS	NS	NS
Control vs. 25	NS	NS	0.0144	NS	NS
Control vs. 50	NS	NS	0.0052	0.0188	NS
Control vs. 100	0.0147	NS	0.0172	NS	0.0153
Control vs. 200	0.0128	0.0448	0.0096	NS	NS
N Rate (mg/L)	N (%)	P (%)	K (%)	Ca (%)	Zn (mg/L)
			Musa		
12.5 and SLS	3.8	1.8	3.7	1.3	90.0
25 and SLS	4.2	2.1	4.3	1.4	129.7
50 and SLS	4.0	1.8	3.6	1.4	134.0
100 and SLS	4.1	1.8	4.0	1.3	154.3
200 and SLS	4.1	1.8	4.4	1.2	148.8
Control	3.1	0.7	5.6	0.8	43.2
ANOVA	NS	NS	NS	0.0297	0.002
Linear	NS	NS	NS	0.0203	0.0092
Quadratic	NS	NS	NS	NS	0.0079
Linear Contrast					
Control vs. 12.5	0.0021	<0.0001	0.0069	<0.0001	0.0011
Control vs. 25	<0.0001	<0.0001	0.0462	<0.0001	<0.0001
Control vs. 50	0.0002	<0.0001	0.0065	<0.0001	<0.0001
Control vs. 100	<0.0001	<0.0001	0.02	<0.0001	<0.0001
Control vs. 200	<0.0001	<0.0001	0.0739	<0.0001	<0.0001
N Rate	N (%)	P (%)	K (%)	Ca (%)	Zn (mg/L)

Table 10. Continued.

(mg/L)	Rudbeckia				
12.5 and SLS	2.9	0.4	2.4	4.0	206.0
25 and SLS	3.4	0.4	2.5	4.0	205.9
50 and SLS	3.4	0.4	1.7	4.0	202.6
100 and SLS	3.6	0.4	1.9	4.2	321.5
200 and SLS	3.9	0.5	1.7	4.1	377.3
Control	2.7	0.2	3.5	3.3	204.3
ANOVA	NS	NS	NS	NS	0.0089
Linear	0.0043	0.0124	0.0325	NS	0.0002
Quadratic	NS	NS	NS	NS	NS
Linear Contrast					
Control vs. 12.5	NS	0.0002	0.008	0.0414	NS
Control vs. 25	0.0351	0.0001	0.0207	0.0466	NS
Control vs. 50	0.0136	<0.0001	0.0006	NS	0.9
Control vs. 100	0.0018	<0.0001	0.0004	0.0144	0.0104
Control vs. 200	0.0004	<0.0001	0.0007	NS	0.0019

[z]N rate applied as liquid ammonium nitrate (34.9-0-0).
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Control substrate was a 9:1 pine bark:sand (v/v) with 20-10-20 applied as liquid to supply 100mg/L.
[w]Analysis of variance (ANOVA) effect of N rate within species NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[u]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[t]Linear contrast analysis comparing N rate treatment means to the control substrate. NS=not significant, *P*-value given otherwise.

Chapter Two

Making Profit from Sludge: Reducing Fertilizer Needs for Nursery Plant Production

(In the format appropriate for submission to the Journal of Environmental Horticulture)

Making Profit from Sludge: Reducing Fertilizer Needs for Nursery Plant Production

M.T. Williams[1], H.T. Kraus, and E.D. Riley

Department of Horticultural Science

North Carolina State University

Raleigh, NC 27695-7609

Abstract: A study was designed as a randomized complete block with six replications and a factorial arrangement of four nitrogen (N) rates and four species to evaluate the impacts on plant growth when grown in a substrate composed of pine bark (PB) amended with swine lagoon solids (SLS) (9:1 PB:SLS v/v) (n=24). An industry control substrate (9:1 PB:mortar sand v/v) amended with 1.8 $kg \cdot m^{-3}$ (3 $lbs \cdot yd^{-3}$) dolomitic lime and 0.89 $kg \cdot m^{-3}$ (1.5 $lbs \cdot yd^{-3}$) micronutrients was included for comparison (n=4). No lime or micronutrients were added to the SLS substrate. Only forsythia in SLS with 2 g N and gardenia in SLS with 0 g N applied were significantly larger (forsythia) and smaller (gardenia) than the control. Buddleia growth was greater in the control substrate than in the SLC substrate at all N rates. Rhaphiolepis growth was similar regardless of substrate and N rate. The SLS substrate maintained higher EC than the control at each sample time until July, 20 2015 where they were similar suggesting that slow release nitrogen application could be delayed as much as 31 days after potting in an SLS amended substrate. For the first sample times the amounts of NH_4-N and NO_3-N in the SLS substrate solution were greater than the control substrate. By the last two sample dates, July 20 and August 13, 2015, the control substrate had greater amounts of $_{NH4\text{-}N}$ than the SLS substrate solution. The final sample date Aug 13 had a greater amount of nitrate

in the control substrate solution than in the SLS substrate solution. These data support the hypothesis that application of the slow release 43-0-0 could be delayed until 31 days after potting.

Additional index words: manure, swine lagoon solids, substrate amendment, plant growth, substrate physical and chemical properties

Species used in this study: *Buddleia davidii* 'Potter's Purple', buddleia; *Forsythia* x *intermedia* 'Courdijau', forsythia; *Gardenia jasminoides* 'Radicans', gardenia; *Rhaphiolepis indica* 'Conia', rhaphiolepis

Significance to the Industry:

Swine lagoon solids (SLS) are a valuable amendment to pine bark (PB) substrates that supports the air and water needs for growth of woody species of ornamental plants as well as act as a fertilizer source reducing the need for inorganic fertilizer application. Forsythia, gardenia, and rhaphiolepis grew as well or better in the 9:1 PB:SLS as they did in the 9:1 PB:sand control substrate. Nitrogen fertilizer could be reduced by 43% when forsythia or gardenia are grown in the SLS substrate. No additional fertilizer of lime was needed for these species when grown with SLS. Buddleia, a high nutrient requiring plant, did not grow as well in the SLS substrate compared to the control substrate even though nutrients NO_3, K, Ca, Mg, Mn, Zn and Cu were higher in the SLS substrate.

Introduction

Pine bark (PB) has been the primary potting material of the nursery industry for many years (Warren et al., 2007) as it is as waste product from the lumber industry. With much of the timber industry moving overseas the availability of pine bark is reduced and so is the quality (Lu et al., 2006). Alternative amendments such as composted cotton stalks (Riley et al., 2011 and Warren et al., 2009), industrial minerals (Owen et al., 2007), vermicomposts (Atiyeh et al., 2000 and McGinnis et al., 2009), and turkey litter (Tyler et al., 1993a & b and Kraus et al., 2000) can be used to extend the pine bark supplies. The need to evaluate both the physical and chemical properties of an addition to pine bark is emphasized by Owen et al. (2007) and Tyler et al. (1993a). The authors also indicate the cost of amendments can be offset by using local wastes.

North Carolina is one of the top hog producers in the US, with approximately 16% of the state's farm cash receipts coming from hog production (USDA, 2015). Duplin County, NC has a population in excess of 2.2 million hogs producing untreated waste that rivals that of New York City (Food & Water Watch, 2015), which, when used as an amendment to pine bark, could contribute to a reduction of fertilizer use in the nursery and greenhouse industry. Swine lagoon waste has been researched as both an amendment (Choudhary et al., 1996 and Keener et al., 2001) and as a nutrient source (Duffera et al., 1999a & b and Read, et al., 2008) for bermuda turfgrass (*Cynodon dactylon*) (Burns et al. 1990) and agronomic crops: sweet corn (*Zea mays* L. var. silver queen), sorghum (*Sorghum bicolor* L. var. DK-54), and field bean (*Phaseolus vulgaris* L. var. blue lake) (Duffera et al., 1999b). Vermicomposted fresh swine waste has been shown to increase plant dry weight of *Hibiscus moscheutos* L. 'Luna Blush' as much as 58% in container grown plants (McGinnis et al., 2009). However, the use

of swine lagoon waste in nursery production of ornamental plants needs further analysis. Therefore the objective of the research was to evaluate the growth of several woody ornamental species when grown in a pine bark substrate amended with swine lagoon waste so that appropriate substrate air and water characteristics were achieved. Additionally, the impact of the swine lagoon waste on substrate pH and EC as well as the nutrient release rate and plant uptake of nutrients was evaluated for their impacts on plant growth.

Materials and Methods

A study was designed as a randomized complete block with six replications and a factorial arrangement of four nitrogen (N) rates and four species to evaluate the impacts on plant growth when grown in a substrate composed of pine bark (PB) amended with swine lagoon solids (SLS) (9:1 PB:SLS v/v) (pH 5.6) (n=24). An industry control substrate (9:1 PB:mortar sand v/v) (pH 5.8) amended with 1.8 $kg \cdot m^{-3}$ (3 $lbs \cdot yd^{-3}$) dolomitic lime and 0.89 $kg \cdot m^{-3}$ (1.5 $lbs \cdot yd^{-3}$) micronutrients (Parker Bark Company, Rose Hill, NC) was included for comparison (n=4). No lime or micronutrients were added to the SLS substrate.

Swine lagoon solids (SLS) were dredged from a lagoon in Garland, NC (Murphy Brown, LLC, Warsaw, NC) using a tiller attachment to cut the solids off the lagoon bottom and pumped to a holding tank where a polymer (PT1051, PolyTec Inc., Mooresville, NC) was added and thoroughly mixed with the solids. The solids and polymer mix were 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 and was pumped from the reservoir back into the lagoon. The waste/polymer mix in the bag was allowed to drain for two years before use. Once removed from the bag, the SLS were

spread on plastic, allowed to air dry in a plastic covered hoop house with heat and forced air for a week, and then ground to 2mm using a grist mill (Molino Corona, Landers, Mora & Cia, LTDA, Medellin, Colombia).

Waste samples were submitted to the NCDA&CS (North Carolina Department of Agriculture and Consumer Services, Agronomic Division Raleigh, NC) for analysis. 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) (AOAC 1990b; Campbell 1992). Inorganic-nitrogen (IN-N) fraction concentrations include nitrate-nitrogen plus nitrite-nitrogen (NO_3-N + NO_2-N and ammonium-nitrogen (NH3-N + NH4-N). NO_3-N is determined by nitrate-hydrazine reduction (Kempers 1988; Skalar Analytical 1995b) and NH_4-N is determined by modified Berthelot reaction (adapted from Krom 1980; Skalar Analytical 1995a) 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) are determined with inductively coupled plasma-optical emission spectrometry (ICP-OES) (Spectro Arcos EOP, Spectro Analytical: A Division of Ametek; Mahwah, NJ) (Donohue and Aho 1992; adapted USEPA 2001), after closed-vessel nitric acid (HNO_3) digestion in a microwave digestion system (MARS 6 Microwaves; CEM Corp.; Matthews, NC) (Campbell and Plank 1992) (Table 1).

On May 21, 2015 liners of *Buddleia davidii* 'Potter's Purple' Franch. (buddleia), *Forsythia* x *intermedia* 'Courdijau' Zab.(forsythia), *Gardenia jasminoides* 'Radicans' J. Ellis

(gardenia), and *Rhaphiolepis indica* 'Conia' Lindl. Ex Ker-Gawl. (rhaphiolepis) grown in 10.16 cm containers were potted into 3.8L (1 gal) (Classic 500, Nursery Supplies, Inc., Chambersburg, PA) containers filled with either the 9:1 PB:SLS or the control substrate. The plants were grown on a gravel covered pad at the NCSU Horticulture Field Lab (longitude: 35°47'29.57"N; latitude: 78°41'56.71"W; elevation: 136 m) Raleigh, NC. On June 4, 2015, 14 days after potting, controlled released fertilizer was top-dressed. Urea nitrogen (43-0-0) (Harrell's LLC, Lakeland, FL) was applied at the rates of 0, 1, 2, or 3g N/3.8L to the 9:1 PB:SLS substrate. A complete fertilizer (17-5-10) (Harrell's LLC, Lakeland, FL) was applied to the control substrate and supplied 3.5g N/3.8L. Cyclic irrigation was applied three times daily; irrigation water contained an average of 0.83mg·L^{-1} N, 0.21mg·L^{-1} P, and 3.44mg·L^{-1} K with a pH of 7.83.

Leaching fractions (LF = volume leached ÷ volume applied) were measured (June 23, July 16, July 30, 2015) and irrigation volume was adjusted to maintain a 0.2 LF for each substrate. Additionally, substrate solution was collected (June 4, June 18, June 30, July 20, August 11) from buddleia and gardenia using the pour-through nutrient extraction method (Wright, 1986). Substrate solution electrical conductivity (EC) and pH were measured using a combination EC/pH meter (HI 8424, Hannah Instruments, Ann Arbor, MI). Substrate solution samples collected on June 4, June 18, June 30, July 20, and August 11 were submitted to the NCDA&CS (North Carolina Department of Agriculture and Consumer Services, Agronomic Division Raleigh, NC) for inorganic nitrogen (IN-N), urea, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) analyses. The IN-N fraction concentrations include

nitrate + nitrite nitrogen (NO_3-N + NO_2-N) and ammonium nitrogen (NH_4-N). NO_3-N was determined on a homogenized sample (~20 mL) by nitrate-hydrazine reduction (Kempers, 1988; Skalar Analytical, 1995b) and NH_4-N was determined by a modified Berthelot reaction (adapted from Krom, 1980; Skalar Analytical, 1995a), with an auto-flow spectrophotometric analyzer (San++ Segmented Flow AutoAnalyzer, Skalar Instruments; Breda, The Netherlands). Total concentrations of P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, and B were determined with an inductively coupled plasma (ICP) spectrophotometer (USEPA, 2001) (Optima 3300 DV ICP emission spectrophotometer; Perkin Elmer Corporation; Shelton, CT).

Substrate physical properties were determined initially at potting (May 21, 2015) and at harvest (Aug 13, 2015) from fallow containers maintained in the same growing space and with the same irrigation as treatment plants after harvest. Total porosity (TP), airspace (AS), container capacity (CC), unavailable water (UAW), available water (AW), and bulk density (BD) analyses were conducted in the Horticultural Substrates Laboratory, Department of Horticultural Science, N.C. State Univ., Raleigh, NC. Three replications of each substrate were packed into 347.5 cm3 cylindrical aluminum 23 rings (7.6 cm dia, 7.6 cm ht) and were used to determine TP, AS, CC, and BD according to procedures outlined in Tyler et al. (1993).

Particle size data was collected and analyzed on both the SLS substrate and the control substrate at the time of initial potting (May 21, 2015) and at harvest (August 13, 2015). Samples of the substrates were oven dried at 105°C for not less than 24 hours. The samples were portioned into three 100 g subsamples and sorted on a Ro-Tap Sieve Shaker with six sieve sizes (6.3mm, 2mm, 0.71mm, 0.5mm, 0.25mm, and 0.11mm) and a solid pan.

The subsamples were then shaken through the sieves for 5 minutes each and then the contents of each sieve and the pan were weighed. Particle size was expressed as a percentage of the total weight of the sample.

After twelve weeks, shoots were removed and roots were washed free of substrate using a high pressure stream of water. Shoot and root dry weights (oven dried at 60°C for four days) were determined and used for growth comparisons. After dry weights were measured, shoot samples were submitted to the North Carolina Department of Agriculture and Consumer Services, Agronomic Division, Raleigh, North Carolina for grinding and tissue analyses of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, and Na. Foliar N concentration was determined by oxygen combustion gas chromatography with an elemental analyzer (NA 1500; CE Elantech Instruments, Lakewood, N.J.) (Campbell and Plank, 1992). Foliar P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn concentrations were determined with an inductively coupled plasma (ICP) spectrometer (Donohue and Aho, 1992) (Optima 3300 DV ICP Emission Spectrometer; Perkin Elmer Corp., Shelton, CT) following open-vessel nitric acid digestion in a microwave digestion system (CEM Corp., Matthews, NC) (Campbell and Plank, 1992). Foliar content was calculated as shoot dry weight x nutrient concentration.

All data were subjected to analysis of variance (ANOVA) and regression analyses where appropriate ($P \leq 0.05$). The industry control substrate was excluded from ANOVA and regression analyses to evaluate the species by N rate interaction and main effects of species and N rate and the responses to increased N rate in the SLS substrate. Single degree of freedom linear contrasts were used to compare N rates applied to the SLS substrate to the industry control. Tukey's honestly significant differences means separation procedures were

used to compare differences between species and the main effects of the SLS and industry control substrate.

Results and Discussion

The substrate by sample time interaction was not significant for all physical properties (data not shown). Based on data reported by Williams et al. (2015) a 9:1 PB:SLS substrate was chosen with the anticipation that the physical properties would be similar to the 9:1 PB:sand control substrate. In this project, while the SLS and control substrates did not differ in TP or AW, they did differ in AS, CC, UAW, and BD (Table 1). The control substrate had greater AS (32%) and BD (0.32g·cc^{3}) but lower CC (49%) and UAW (29%) than the SLS substrate (28, 58, 32%, and 0.27g·cc^{3} for AS, CC, UAW, and BD, respectively). Regardless of substrate, TP, AS, UAW, and BD changed over the 12 week (82 day) experiment. TP and AS increased between the initial measurement (72 and 25%, TP and AS, respectively) and the final measurement (90 and 35%, TP and AS, respectively). Unavailable water decreased between the initial measurement (33%) and the final measurement (28%). BD increased between the initial measurement (0.24) and the final measurement (0.35).

The substrate by sample time interaction was significant for the particle distribution in the 2, 0.5, 0.25, and 0.11 mm ranges (data not shown). The distribution of particles in the 2, 0.5, 0.25, and 0.11 mm ranges in the SLS and control substrates did not differ initially but did at the final sample time (82 days after potting) (data not shown). Particles 2mm in size were greater in the SLS substrate while particles in the 0.25 and 0.11mm ranges were greater in the control substrate at the conclusion of the experiment. In general the control substrate became less coarse (decomposed more) than the SLS substrate over time (data not shown).

The interaction between species and N rate was significant (P=0.008) for shoot dry weights of species grown in SLS; however, N rate affected the shoot dry weight of only two of the species, *Forsythia* and *Gardenia* (Table 2). For forsythia and gardenia there was a quadratic response to increasing N rate with 2 g N resulting in the maximum shoot growth; however, only forsythia in SLS with 2 g N and gardenia in SLS with 0 g N applied were significantly larger (forsythia) and smaller (gardenia) than the control. Buddleia growth was greater in the control substrate than in the SLS substrate at all N rates. Rhaphiolepis growth was similar regardless of substrate and N rate.

The species and N rate interaction was not significant for root growth and root growth was not impacted by N rate (data not shown). Additionally, root growth of each species was similar in the SLS and control substrates (data not shown).

The three way interaction species by nitrogen rate by sample time was not significant for pH or EC, nor were the two way interactions N rate by sample time, species by sample time, or species by N rate. Nitrogen rate affected pH of the SLS substrate and decreased linearly from 0 to 3 g of N (Table 3). The control substrate pH averaged 5.8 and ranged from 6.3 to 5.5 over the first and last sample times. Sample time significantly affected pH (p=<0.0001) and the maximum pH (6.0) was the final sample time (20 July 2015). Substrate pH remained within acceptable ranges in both substrates over the course of the study (Yeager et al., 2007).

Similarly to pH, sample time did significantly affected EC while in contrast to pH N rate did not. On June 4, 2015 the EC was highest and averaged 3.84µs/cm while on July 20, 2015 it was lower and averaged at 0.92µs/cm (Table 4). The SLS substrate maintained higher

EC than the control at each sample time until 20 July 2015 where they were similar. Soluble salts levels in the SLS substrate were higher than recommended (Yeager et al., 2007) for the first 31 days of the 82 day experiment. However, root growth was not negatively affected as there were no significant differences between root growth in SLS and control substrates. Soluble ion levels of the SLS substrate were greater than the control until July 20 suggesting that slow release nitrogen application could be delayed as much as 31 days after potting in an SLS amended substrate.

The interaction between N rate, sample time, and species and the species by N rate interaction were not significant for all concentration of nutrients in SLS substrate solution (data not shown). Phosphorus concentration in SLS substrate solution was affected by the interaction between species and sample time while none of the other elements were (data not shown). Urea and iron concentration in SLS substrate solution were both affected by the interaction between N rate and sample time, yet this interaction was not significant for the other nutrients (data not shown).

Urea in the SLS substrate solution increased over time with a peak on June 30 in the SLS substrate solution and then decreased at the final sample time ($p=0.0091$) (August 11) (Table 5). Even though a slow release urea fertilizer was applied, N rate did not have a profound effect on urea concentrations in the SLS substrate solution (Table 5). When N rate did impact urea in the substrate solution (on June 18, June 30, and August 11) the 2 g N rate resulted in the greatest urea concentration and was greater than the control. Otherwise, urea in the SLS substrate solution was statistically similar to the control substrate solution.

Substrate solution concentration of NH_4–N and NO_3–N were both affected by sample time (p=<0.0001) but not N rate (Table 5). Both NH_4–N and NO_3–N were reduced over the 82 days of the study while the concentration of NH_4-N and NO_3-N in the control substrate solution increased from the first sample time (June 4, 2015) to the last (August 11, 2015). For the first sample times the amounts of NH_4-N and NO^3-N in the SLS substrate solution were greater than the control substrate. By the last two sample dates, July 20 and August 13, 2015, the control substrate had greater amounts of NH_4 than the SLS substrate solution. The final sample date Aug 13 had a greater amount of nitrate in the control substrate solution than in the SLS substrate solution. These data support the hypothesis that application of the slow release 43-0-0 could be delayed until 31 days after potting.

The rate of N applied to the SLS substrate did not affect NH_4-N concentration but did affect affected the concentration of NO_3-N, Ca, Mg, and Zn (Table 6). The concentrations of NO_3-N and Ca in the SLS substrate solution increased linearly with increasing rates of N applied. The SLS substrate concentrations of NO_3-N, Ca, Mg, and Zn were significantly greater when compared to the control substrate solution.

The SLS substrate increased in amount of Fe in the substrate solution over time for each of the nitrogen rates (Table 7). The control substrate had greater concentrations of Fe than the SLS substrate until 11 August.

Although not affected by N rate, sample time affected the concentration of P (p=<0.0001), K (p=<0.0001), S (p=<0.0001), Mn (p=<0.0001), Cu (p=<0.0001), and B (p=<0.0001) in the SLS substrate solution by decreasing it over time. At the sample time on July 20 the concentrations of K, S, Cu, and B had decreased to be similar to the control

substrate, while Mn remained greater throughout the 82 day study (Table 8). For the nutrients (K, S, Mn, Cu, and B) that were only affected by sample time and not N rate, concentration was greater in the SLS substrate than the control throughout the 30 June sample date (except K). After 30 June, these nutrients were in higher concentration in the control substrate.

Rate of N applied to the SLS substrate affected the foliar concentration of N, K, Mg, S, and Mn (Table 9), but not P or Ca. There was a linear increase in buddleia foliar N and S concentrations with increasing N rate applied while foliar K decreased linearly. Concentrations of K in the leaves of buddleia were lower in the SLS substrate compared to the control substrate and were further decreased with the addition of nitrogen fertilizer. Buddleia grown in SLS with 2 and 3 g N applied had similar N and S concentrations to the control substrate while the 0 and 1 g N rates applied to SLS substrate resulted in lower N and S foliar concentrations.

In contrast to buddleia, N rate applied to the SLS substrate affected the foliar concentrations of N, K, Mg, S, and Mn in forsythia. Foliar concentrations of N, K, and S showed quadratic responses to increasing rates of N applied to the SLS substrate, while Mg and Mn had a linear increase with increasing N rates applied. Uptake of N, K, and S by forsythia was greatest in the SLS when 2 or 3 g N were applied. As with buddleia, concentration of K in the leaves of forsythia in the SLS substrate were lower than those of the control substrate and decreased with increase of N applied. Concentrations of foliar Mn in forsythia were lower in the SLS substrate compared to the control substrate and were similar regardless of rate of N applied.

N, K, Mg, S, and Mn foliar concentrations in gardenia were affected by rate of N applied to the SLS substrate. A quadratic response to increasing rates of N applied to the SLS substrate was found in N, K, and Mg while S and Mn had linear increase in gardenia foliar concentration in the SLS substrate. Gardenia grown in the SLS with 2 and 3 g N applied had similar N and S concentrations to the control substrate and the 3 g N applied to the SLS substrate had similar Mn foliar concentration.

While growth of rhaphiolepis was poor in both substrates and all N rates, N rate applied to SLS substrate affected N and Mn foliar concentrations while K, Mg, and S foliar concentrations were not affected. Concentration of N in the leaves of rhaphiolepis responded quadratically with increasing rates of nitrogen applied to the SLS substrate. Rhaphiolepis grown in SLS substrate with 1 and 2 g N had similar N concentrations to the control substrate, as did the 0, 1, and 3 g N for Mn foliar concentrations in SLS substrate.

The two way interaction of species by N rate was not significant for foliar P, Ca, Zn, and B concentrations, but the effect of nitrogen rate was significant (Table 10). The SLS substrate had lower foliar concentration of B when compared to the control substrate. There was a linear increase in Ca and Zn with increasing N rate application while foliar P decreased linearly. Concentration of P was greater in the SLS substrate compared to the control substrate and decreased linearly with the addition of N fertilizer. The 0 and 1 g N rates applied to the SLS substrate had similar Ca and Zn concentrations to the control substrate while the 2 and 3 g N rates applied to the SLS substrate had greater Ca and Zn foliar concentration.

Buddleia foliar contents of N, P, K, Mg, S, Mn, Zn, and Cu were not affected by rate of N applied to the SLS substrate (Table 10 and data not shown). In contrast, rate of N applied to the SLS substrate affected the foliar N, P, Mg, S, Mn, Zn, and Cu content of forsythia and gardenia but not the K foliar content. There was a quadratic response with increasing rates of N applied to the SLS substrate in N, P, K, S, Mn, Zn and Cu with the maximum values at 2 g N in forsythia. With gardenia there was a quadratic response with increasing N rates in N, P, S, Mn, and Zn while Mg decreased linearly and Cu increased linearly. Forsythia grown in SLS with 1, 2, and 3 g N rates applied to the SLS substrate had similar foliar Cu contents to the control substrate while the P foliar content was greater at all N rates than the control substrate. Gardenia grown in SLS with 2 and 3 g N had greater foliar contents of P, Mg, Mn, and Zn. The control substrate had greater foliar contents of S and Cu in the 1, 2, and 3 g N rates added to SLS substrate.

The rate of N applied to SLS substrate affected the foliar content of Mg in rhaphiolepis but not N, P, K, S, Mn, Zn, or Cu (Table 10 and data not shown). Mg responded quadratically to increasing rate of N application with the lowest content value in rhaphiolepis grown in 2 g N applied to the SLS substrate. The control substrate had similar foliar content to the N rates applied to the SLS substrate for N, P, K, Mg, S, Mn, Zn, and Cu.

Rate of N applied to SLS substrate did not impact foliar content of Ca in buddleia or rhaphiolepis, however forsythia and gardenia Ca contents were affected by N rate (Table 12). Forsythia and gardenia Ca foliar contents responded quadratically with increasing rates of N applied to the SLS substrate with the maximum values at 2 g N applied. Forsythia and

gardenia grown in 2 and 3 g N applied to the SLS substrate had greater Ca foliar contents compared to the control substrate.

The foliar content of Fe and B were not affected for buddleia grown in SLS substrate with N rates applied (Table 10). In contrast, N rate applied to SLS substrate affected the foliar content of Fe and B in forsythia and gardenia, and both showed quadratic responses to increasing N rates applied to the SLS substrate with the maximum values of both Fe and B occurring in 2 g N rate. Forsythia and gardenia grown in SLS with 2 and 3 g N had similar foliar Fe content compared to the control substrate while the 0 and 1 g N SLS had lower Fe content. Foliar B content in forsythia was greater at 2 g N SLS substrate compared to the control substrate while the 0 g N SLS substrate was lower than the control. With gardenia foliar content of B was similar compared to the control in the 1, 2, and 3 g N rates applied to SLS while the 0 g N SLS had lower foliar B content.

Conclusions

The 9:1 blend of SLS:PB resulted in a substrate with air and water holding properties that supported growth of three of the four woody plants with different requirements for available water (forsythia and gardenia have medium irrigation needs and rhaphiolepis has low irrigation needs) (Yeager et al., 2007). Forsythia and gardenia grew better in the SLS substrate than the control substrate and 43% less N fertilizer could be applied to achieve optimal growth of these species. Rhaphiolepis grew equally well in both substrates at all N rates. Buddleia grew better in the control substrate that in the SLS substrate possibly do to the higher UAW content of the SLS substrate and the high irrigation requirement of this species (Yeager et al., 2007). Electrical conductivity and nutrient levels of the SLS substrate

were higher than the control substrate for the first third of the experiment so it is not likely that fertility negatively affected growth of this high nutrient requiring plant early in the experiment (Yeager et al., 2007). However, SLS substrate nutrient levels decreased over time indicating that control release fertilizer application could be delayed and fertility of the SLS substrate extended to support growth of high fertility requiring species. This hypothesis is supported by the fact that N concentration of buddleia was higher with higher N rates applied to the SLS substrate. However, foliar K concentrations of buddleia were lower with higher N rates applied to the SLS substrate and N and K contents of buddleia were much higher in the control substrate. This would seem to indicate a root zone environment that decreased N and P uptake by buddleia when grown with SLS.

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Table 1. Swine lagoon sludge solid waste analysis.

Nutrient[z]	Concentration (ppm)[y]
Carbon	221,000
Nitrogen	28,500
Phosphorus	73,700
Potassium	4,930
Calcium	122,000
Magnesium	18,600
Sulfur	12,400
Iron	8,350
Manganese	975
Zinc	2,920
Copper	314
Boron	22.2
Sodium	2350
Other Measurements	
Carbon: Nitrogen	7.77: 1
pH	5.82
Electrical Conductivity	5.36 mS/cm[x]
Dry Matter	22%

[z]Nutrients included in waste analysis performed at North Carolina Department of Agriculture & Consumer Services, December 2014.

[y]Concentration of nutrients present in swine lagoon sludge solids (ppm= parts per million).

[x]mS/cm= millisiemens per centimeter.

Table 2. Effect of pine bark (PB) and PB substrate amended with ground swine lagoon solids (SLS) on total porosity (TP), air space (AS), container capacity (CC), available water (AW), unavailable water (UAW), and bulk density (BD).

TP[z] (% vol.)			
Sample Time p=0.0380		Substrate NS	
Sample Time	means	Substrate	means
Initial[y]	72b[x]	PB[w]	76a
Final	90a	SLS[v]	86a
AS[u]			
Sample Time p=0.0008		Substrate p=0.0300	
Sample Time	means	Substrate	means
Initial	25b	PB	32a
Final	35a	SLS	28b
CC[t]			
Sample Time NS		Substrate p=0.0112	
Sample Time	means	Substrate	means
Initial	52a	PB	49b
Final	55a	SLS	58a
UAW[s]			
Sample Time p=<0.001		Substrate p=0.0002	
Sample Time	means	Substrate	means
Initial	33a	PB	29b
Final	28b	SLS	33b
AW[r]			
Sample Time NS		Substrate NS	
Sample Time	means	Substrate	means
Initial	23a	PB	23a
Final	26a	SLS	26a
BD[q] (g/cm^3)			
Sample Time p=<0.0001		Substrate p=<0.0001	
Sample Time	means	Substrate	means
Initial	0.24b	PB	0.32a
Final	0.35a	SLS	0.27b

[z]Based upon percent volume of a 7.6 cm core at 0 kPA.
[y]The substrates were sampled twice for physical analysis initially at potting (initial) and again at 12 weeks after

Table 2. Continued.
planting (final). NS= Not significant, *P*-value given otherwise.
[x]Means within a column with different letters are significantly different from each other based on Tukey's HSD mean separation procedures ($p \geq 0.05$). N=6
[w]PB= pine bark substrate: 9:1 pine bark:mortar sand (v/v).
[v]SLS= swine lagoon solid substrate: 9:1 SLS:pine bark (v/v).
[u]AS = TP-CC.
[t]Measured as a percent volume of a 7.6 cm core at drainage.
[s]Based upon percent volume of a 2.5 cm core at 1500 kPA.
[r]AW = CC-UAW.
[q]BD is measured as the ration of dry solids to the bulk volume of the substrate.

Table 3: Impact of nitrogen rate on shoot dry weight (g) of Buddleia, Forsythia, Gardenia, and Rhaphiolepis

	Shoot dry weight			
Nitrogen Rate[z]	*Buddleia*	*Forsythia*	*Gardenia*	*Rhaphiolepis*
0 g N and SLS[y]	11.4	10.0	3.3	2.4
1 g N and SLS	18.5	20.1	6.2	2.5
2 g N and SLS	11.5	25.8	8.1	2.4
3 g N and SLS	23.7	19.5	7.5	2.5
Control[x]	43.1	15.1	6.2	2.7
ANOVA[w]	NS	0.0002	0.001	NS
Linear[v]	NS	0.00045	0.0002	NS
Quadratic[u]	NS	<0.0001	0.0105	NS
Linear Contrast[t]				
Control vs 0 g N	<0.0001	NS	0.0063	NS
Control vs 1 g N	0.001	NS	NS	NS
Control vs 2 g N	<0.0001	0.0004	NS	NS
Control vs 3 g N	0.0065	NS	NS	NS

[z]N rate applied as a topdress of slow release 43-0-0 per container.
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Control substrate was a 9:1 pine bark:sand (v/v) with 17-5-11 applied as a topdress to apply 3.5 g N/container.
[w]Analysis of variance (ANOVA) effect of N rate within species NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[u]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[t]Linear contrast analysis comparing N rate treatment means to the control substrate. NS=not significant, *P*-value given otherwise.

Table 4. Effect of nitrogen rates on 9:1 PB:SLS substrate

pH	
N Rate[z]	pH
0 g N and SLS[y]	5.8
1 g N and SLS	5.8
2 g N and SLS	5.7
3 g N and SLS	5.7
ANOVA[x]	0.0008
Linear[w]	0.0061
Quadratic[v]	NS

[z]N rate applied as a topdress of slow release 46-0-0 per container.
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Analysis of variance (ANOVA) effect of N rate averaged over species NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[w]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.

Table 5: Effect of varying nitrogen rates for pine bark (PB) amended with swine lagoon solid (SLS) on substrate solution electrical conductivity (EC)

	EC µs/cm			
N Rate[z]	4-Jun-15	19-Jun-15	30-Jun-15	20-Jul-15
SLS Substrate[y]	3.8a[v]	1.7a	1.3a	0.9a
Control[x]	0.2b	0.4b	0.5b	0.5b
ANOVA[w]	<0.0001	<0.0001	<0.0001	<0.0001

[z]N rate applied as a topdress of slow release 46-0-0 per container.
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Control substrate was a 9:1 pine bark:sand (v/v) with 17-5-11 applied as a topdress to apply 3.5 g N/container.
[w]Analysis of variance (ANOVA) effect sample time averaged over species and N rate. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Means within a column with different letters are significantly different from each other based on Tukey's HSD mean separation procedures ($p \geq 0.05$). N=6

Table 6: Effect of substrate, N rate, and sample date on nitrogen species.

N Rate[z]	4-Jun	18-Jun	30-Jun	20-Jul	11-Aug
			Urea		
0 g N and SLS[y]	0.4	0.2	0.5	0.3	0.3
1 g N and SLS	0.6	0.1	0.6	0.2	0.4
2 g N and SLS	0.5	2.7	4.3	0.4	0.7
3 g N and SLS	0.6	1.3	1.3	0.3	0.4
Control[x]	0.6	0.1	0.6	0.2	0.4
ANOVA[w]	NS	0.0024	0.0001	NS	0.0091
Linear[v]	NS	0.0306	NS	NS	NS
Quadratic[u]	NS	NS	0.0302	NS	0.0226
Linear Contrast[t]					
Control vs 0 g N	NS	NS	NS	NS	NS
Control vs 1 g N	NS	NS	NS	NS	NS
Control vs 2 g N	NS	0.0002	<0.0001	NS	0.0198
Control vs 3 g N	NS	NS	NS	NS	NS
			NH_4-N		
SLS	143.7a	28.7a	7.9a	4.0a	1.6a
Control	0.1b	1.3b	3.0b	4.2a	6.8a
			NO_3-N		
SLS	260.1a	85.0a	53.0a	39.0a	20.8a
Control	0.3b	9.6b	23.3b	30.7a	24.9a

[z]N rate applied as a topdress of slow release 43-0-0 per container.
[y]Swine lagoon solids (SLS) substrate
[x]Control substrate was an 9:1 pine bark sand (v/v) with 17-5-11 applied as a topdress to apply 3.5 g N/container
[w]Analysis of variance (ANOVA) effect of N rate averaged over species. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[u]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[t]Linear contrast analysis comparing N rate treatment means to the control substrate. NS=not significant, *P*-value given otherwise.

Table 7: Effect of substrate and nitrogen rate on NO_3-N, Ca, Mg, and Zn in substrate solution.

	Substrate Solution			
Nitrogen Rate[z]	NO_3-N	Ca	Mg	Zn
0 g N and SLS[y]	71.7	35.9	134.3	0.2
1 g N and SLS	83.0	39.4	144.2	0.2
2 g N and SLS	111.1	46.0	154.1	0.2
3 g N and SLS	102.6	42.5	158.4	0.2
Control[x]	17.7	13.8	10.9	0.1
ANOVA[w]	<0.0001	0.0012	0.0166	0.0089
Linear[v]	0.0335	0.0198	NS	NS
Quadratic[u]	NS	NS	NS	NS
Linear Contrast[t]				
Control vs 0 g N	0.0012	<0.0001	<0.0001	<0.0001
Control vs 1 g N	<0.0001	<0.0001	<0.0001	<0.0001
Control vs 2 g N	<0.0001	<0.0001	<0.0001	<0.0001
Control vs 3 g N	<0.0001	<0.0001	<0.0001	<0.0001

[z]N rate applied as a topdress of slow release 43-0-0 per pot.
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Control substrate was a 9:1 pine bark:sand (v/v) with 17-5-11 applied as a topdress to apply 3.5 g N/container.
[w]Analysis of variance (ANOVA) effect of N rate within species NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[u]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[t]Linear contrast analysis comparing N rate treatment means to the control substrate. NS=not significant, *P*-value given otherwise.

Table 8: Effect of substrate, nitrogen rate and sample date on iron in SLS substrate solution.

	Fe Leachate				
Nitrogen Rate[z]	4-Jun	18-Jun	30-Jun	20-Jul	11-Aug
0 g N and SLS[y]	0.01	0.02	0.03	0.04	0.05
1 g N and SLS	0.01	0.01	0.03	0.03	0.04
2 g N and SLS	0.01	0.01	0.01	0.02	0.02
3 g N and SLS	0.01	0.01	0.02	0.02	0.03
Control[x]	0.03	0.02	0.02	0.03	0.03
ANOVA[w]	NS	NS	<0.0001	<0.0001	<0.0001
Linear[v]	NS	NS	0.0002	<0.0001	<0.0001
Quadratic[u]	NS	NS	NS	0.0177	0.0254
Linear Contrast[t]					
Control vs 0 g N	<0.0001	0.0008	0.0021	NS	0.0022
Control vs 1 g N	<0.0001	<0.0001	NS	NS	NS
Control vs 2 g N	<0.0001	<0.0001	NS	0.0044	0.0096
Control vs 3 g N	<0.0001	<0.0001	NS	0.0118	NS

[z]N rate applied as a topdress of slow release 43-0-0 per container.
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Control substrate was a 9:1 pine bark:sand (v/v) with 17-5-11 applied as a topdress to apply 3.5 g N/container.
[w]Analysis of variance (ANOVA) effect of N rate averaged over species NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[u]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[t]Linear contrast analysis comparing N rate treatment means to the control substrate. NS=not significant, *P*-value given otherwise.

Table 9: Effect of varying nitrogen rates for pine bark (PB) amended with swine lagoon solid (SLS) on substrate solution concentration of K, S, Mn, Cu, and B.

	4-Jun	18-Jun	30-Jun	20-Jul	11-Aug
K					
SLS[z]	106.9a[y]	34.2a	18.5a	6.3b	3.2b
PB[x]	15.5b	17.5b	17.3a	17.8a	15.2a
S					
SLS	104.7a	35.7a	32.0a	18.8b	27.8a
PB	16.5b	28.4a	26.7b	26.2a	32.5a
Mn					
SLS	0.6a	0.4a	0.2a	0.1a	0.1a
PB	0.0b	0.0b	0.0b	0.0b	0.0b
Cu					
SLS	0.0a	0.0a	0.0a	0.0a	0.0a
PB	0.0b	0.0b	0.0b	0.0a	0.0b
B					
SLS	0.1a	0.1a	0.1a	0.1a	0.0a
PB	0.1b	0.0b	0.1b	0.1a	0.0a

[z]SLS= swine lagoon solids substrate- 9:1 SLS:pine bark (v/v).
[y]Means within a column with different letters are significantly different from each other based on Tukey's HSD mean separation procedures ($p \geq 0.05$). N=1
[x]PB= pine bark control substrate was a 9:1 pine bark:sand (v/v) with 17-5-11 applied as a topdress to apply 3.5 g N/container.

Table 10: Effect of varying nitrogen rates for pine bark (PB) amended with swine lagoon solid (SLS) on foliar concentration of nitrogen, potassium, magnesium, sulfur, and manganese in buddleia, forsythia, gardenia, and rhaphiolepis

Buddleia					
Nitrogen Rate[z]	N concn	K concn	Mg concn	S concn	Mn concn
0 g N and SLS[y]	1.4	0.6	0.6	0.2	0.0
1 g N and SLS	2.2	0.4	0.6	0.2	0.0
2 g N and SLS	2.9	0.4	0.5	0.2	0.0
3 g N and SLS	2.8	0.4	0.6	0.2	0.0
Control[x]	3.0	1.2	0.3	0.2	0.0
ANOVA[w]	0.0042	<0.0001	NS	0.0011	NS
Linear[v]	0.0002	0.0004	NS	<0.0001	NS
Quadratic[u]	NS	0.0168	NS	NS	NS
Linear Contrast[t]					
Control vs 0 g N	0.0002	<0.0001	<0.0001	<0.0001	<0.0001
Control vs 1 g N	0.0305	<0.0001	<0.0001	0.0034	<0.0001
Control vs 2 g N	NS	<0.0001	0.0003	NS	0.0007
Control vs 3 g N	NS	<0.0001	<0.0001	NS	0.0001
Forsythia					
Nitrogen Rate	N concn	K concn	Mg concn	S concn	Mn concn
0 g N and SLS	1.5	1.1	0.5	0.1	0.0
1 g N and SLS	2.0	0.6	0.6	0.1	0.0
2 g N and SLS	2.5	0.4	0.7	0.2	0.0
3 g N and SLS	2.4	0.5	0.8	0.6	0.0
Control	2.6	2.0	0.2	0.2	0.0
ANOVA	<0.0001	<0.0001	0.0107	<0.0001	0.0003
Linear	<0.0001	<0.00001	0.0005	<0.0001	NS
Quadratic	0.0014	<0.0001	NS	NS	NS
Linear Contrast					
Control vs 0 g N	<0.0001	<0.0001	0.002	<0.0001	<0.0001
Control vs 1 g N	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Control vs 2 g N	0.0019	<0.0001	<0.0001	NS	0.0012
Control vs 3 g N	0.0001	<0.0001	<0.0001	0.0015	<0.0001
Gardenia					
Nitrogen Rate	N concn	K concn	Mg concn	S concn	Mn concn
0 g N and SLS	2.1	1.5	0.7	0.2	0.0
1 g N and SLS	2.3	1.2	0.7	0.2	0.0
2 g N and SLS	3.1	0.9	0.5	0.2	0.0
3 g N and SLS	2.8	1.1	0.6	0.2	0.0

Table 10. Continued.

Control	3.0	2.0	0.4	0.3	0.0
ANOVA	<0.0001	<0.0001	0.0002	0.0024	0.001
Linear	0.0001	<0.0001	0	0	0.01
Quadratic	0.0498	<0.0001	0.0064	NS	NS
Linear Contrast					
Control vs 0 g N	<0.0001	<0.0001	<0.0001	<0.0001	NS
Control vs 1 g N	<0.0001	<0.0001	<0.0001	0.0001	1
Control vs 2 g N	NS	<0.0001	<0.0001	NS	0.0002
Control vs 3 g N	NS	<0.0001	<0.0001	NS	NS
		Rhaphiolepis			
Nitrogen Rate	N concn	K concn	Mg concn	S concn	Mn concn
0 g N and SLS	1.5	1.3	0.7	0.1	0.0
1 g N and SLS	1.7	1.3	0.5	0.1	0.0
2 g N and SLS	1.9	1.1	0.5	0.1	0.0
3 g N and SLS	1.6	1.2	0.6	0.1	0.0
Control	1.8	1.5	0.4	0.1	0.0
ANOVA	0.0369	NS	NS	NS	0.0223
Linear	NS	NS	NS	NS	NS
Quadratic	0.013	NS	0.033	NS	NS
Linear Contrast					
Control vs 0 g N	0.0128	0.1714	<0.0001	NS	NS
Control vs 1 g N	NS	0.0563	0.0128	NS	NS
Control vs 2 g N	NS	0.0052	0.0145	NS	0.0094
Control vs 3 g N	0.0422	0.0207	0.0041	0.0297	NS

[z]N rate applied as a topdress of slow release 43-0-0 per container.
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Control substrate was a 9:1 pine bark:sand (v/v) with 17-5-11 applied as a topdress to apply 3.5 g N/container.
[w]Analysis of variance (ANOVA) effect of N rate within species NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[u]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[t]Linear contrast analysis comparing N rate treatment means to the control substrate. NS=not significant, *P*-value given otherwise.

Table 11: Effect of varying nitrogen rates on pine bark (PB) amended with swine lagoon solid (SLS) on foliar concentration of phosphorus, calcium, zinc, copper, and boron.

	Foliar Concentration				
Nitrogen Rate[z]	P concn	Ca concn	Zn concn	Cu concn	B concn
0 g N and SLS[y]	0.4	0.6	0.0	0.0	0.0
1 g N and SLS	0.3	0.6	0.0	0.0	0.0
2 g N and SLS	0.3	0.8	0.0	0.0	0.0
3 g N and SLS	0.3	0.7	0.0	0.0	0.0
Control Substrate[x]	0.2	0.6	0.0	0.0	0.0
ANOVA[w]	0.0056	<0.0001	<0.0001	NS	<0.0001
Linear[v]	0.0506	0.0014	<0.0001	NS	<0.0001
Quadratic[u]	NS	NS	NS	NS	0.0019
Linear Contrast[t]					
Control vs 0 g N	<0.0001	NS	NS	0.0233	0.0327
Control vs 1 g N	<0.0001	NS	NS	0.0233	0.0327
Control vs 2 g N	<0.0001	<0.0001	<0.0001	0.0233	0.0001
Control vs 3 g N	<0.0001	<0.0001	<0.0001	0.0068	0.0026

[z]N rate applied as a topdress of slow release 43-0-0 per container.
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Control substrate was a 9:1 pine bark:sand (v/v) with 17-5-11 applied as a topdress to apply 3.5 g N/container.
[w]Analysis of variance (ANOVA) effect of N rate averaged over species.
NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Linear regression analysis. NS=not significant, *P*-value given otherwise.
Control excluded from analysis.
[u]Quadratic regression analysis. NS=not significant, *P*-value given otherwise.
Control excluded from analysis.
[t]Linear contrast analysis comparing N rate treatment means to the control substrate.
NS=not significant, *P*-value given otherwise.

Table 12: Effect of varying nitrogen rates applied to pine bark (PB) amended with swine lagoon solid (SLS) on foliar content of nitrogen, phosphorus, potassium, magnesium, sulfur, manganese, zinc, and copper in buddleia, forsythia, gardenia, and rhaphiolepis.

Buddleia				
Nitrogen Rate[z]	N mg	P mg	K mg	Zn mg
0 g N and SLS[y]	16.0	4.1	6.6	0.1
1 g N and SLS	34.2	7.0	7.7	0.1
2 g N and SLS	34.5	4.5	4.0	0.1
3 g N and SLS	60.5	8.6	8.6	0.1
Control[x]	127.3	8.4	53.6	0.2
ANOVA[w]	NS	NS	NS	NS
Linear[v]	0.0138	NS	NS	0.0369
Quadratic[u]	NS	NS	NS	NS
Linear Contrast[t]				
Control vs 0 g N	<0.0001	NS	<0.0001	0.0004
Control vs 1 g N	<0.0001	NS	<0.0001	0.0014
Control vs 2 g N	<0.0001	NS	<0.0001	0.0023
Control vs 3 g N	0.0005	NS	<0.0001	0.0432
Forsythia				
Nitrogen Rate	N mg	P mg	K mg	Zn mg
0 g N and SLS	14.6	5.5	11.3	0.1
1 g N and SLS	39.1	7.7	12.0	0.1
2 g N and SLS	65.1	11.2	11.1	0.2
3 g N and SLS	45.8	7.5	9.6	0.2
Control	43.4	3.1	29.0	0.1
ANOVA	<0.0001	0.0001	NS	0.0002
Linear	0.0005	0.0297	NS	0.003
Quadratic	0.0001	0.0003	NS	0.0197
Linear Contrast				
Control vs 0 g N	0.0005	0.0078	<0.0001	NS
Control vs 1 g N	NS	<0.0001	<0.0001	NS
Control vs 2 g N	0.0053	<0.0001	<0.0001	<0.0001
Control vs 3 g N	NS	<0.0001	<0.0001	NS
Gardenia				
Nitrogen Rate	N mg	P mg	K mg	Zn mg
0 g N and SLS	6.7	1.0	4.9	0.0
1 g N and SLS	14.4	1.7	7.2	0.1
2 g N and SLS	24.6	2.3	7.0	0.1
3 g N and SLS	20.8	2.1	7.9	0.1

Table 12. Continued.

Control	18.6	1.4	11.9	0.0
ANOVA	<0.0001	0.0004	NS	<0.0001
Linear	<0.0001	0.0003	0.0122	<0.0001
Quadratic	0.0081	0.0102	NS	0.0059
Linear Contrast				
Control vs 0 g N	0.0001	NS	<0.0001	0.072
Control vs 1 g N	NS	NS	0.0008	0.0344
Control vs 2 g N	0.0241	0.0004	0.0005	<0.0001
Control vs 3 g N	NS	0.0049	0.0034	0.0003
	Rhaphiolepis			
Nitrogen Rate	N mg	P mg	K mg	Zn mg
0 g N and SLS	3.6	0.9	3.2	0.0
1 g N and SLS	4.2	0.8	3.0	0.0
2 g N and SLS	4.5	0.8	2.6	0.0
3 g N and SLS	4.0	0.8	3.1	0.0
Control	4.9	0.5	4.1	0.0
ANOVA	NS	NS	NS	NS
Linear	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS
Linear Contrast				
Control vs. 0 g N	NS	NS	NS	NS
Control vs. 1 g N	NS	NS	NS	NS
Control vs. 2 g N	NS	NS	NS	NS
Control vs. 3 g N	NS	NS	NS	NS

[z]N rate applied as a topdress of slow release 43-0-0 per container.
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Control substrate was a 9:1 pine bark:sand (v/v) with 17-5-11 applied as a topdress to apply 3.5 g N/container.
[w]Analysis of variance (ANOVA) effect of N rate within species NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[u]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[t]Linear contrast analysis comparing N rate treatment means to the control substrate. NS=not significant, *P*-value given otherwise.

Table 13: Effect of varying nitrogen rates on pine bark (PB) amended with swine lagoon solid (SLS) on foliar content of calcium in buddleia, forsythia, gardenia, and rhaphiolepis.

	Foliar content of Ca			
Nitrogen Rate[z]	Buddleia	Forsythia	Gardenia	Rhaphiolepis
0 g N and SLS[y]	4.7	3.9	1.9	2.3
1 g N and SLS	8.4	8.1	4.4	2.3
2 g N and SLS	8.2	18.0	5.9	2.6
3 g N and SLS	14.6	10.7	5.6	2.8
Control[x]	16.4	4.9	3.7	2.6
ANOVA[w]	NS	<0.0001	0.0011	NS
Linear[v]	0.0286	0.0039	0.0001	NS
Quadratic[u]	NS	0.0034	0.01665	NS
Linear Contrast[t]				
Control vs 0	0.0067	NS	0.0261	NS
Control vs 1	0.0501	NS	NS	NS
Control vs 2	0.0449	<0.0001	0.0099	NS
Control vs 3	NS	0.0076	0.0273	NS

[z]N rate applied as a topdress of slow release 43-0-0 per pot.
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Control substrate was a 9:1 pine bark:sand (v/v) with 17-5-11 applied as a topdress to apply 3.5 g N/container.
[w]Analysis of variance (ANOVA) effect of N rate within species. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[u]Quadratic regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[t]Linear contrast analysis comparing N rate treatment means to the control substrate. NS=not significant, *P*-value given otherwise.

Table 14: Effect of varying nitrogen rates applied to pine bark (PB) amended with swine lagoon solid (SLS) on foliar content of iron in buddleia, forsythia, gardenia, and rhaphiolepis

Foliar content Fe and B		
Buddleia		
Nitrogen Rate[z]	Iron	Boron
0 g N and SLS[y]	0.1	0.0
1 g N and SLS	0.1	0.6
2 g N and SLS	0.1	0.0
3 g N and SLS	0.2	0.1
Control[x]	0.5	0.1
ANOVA[w]	NS	NS
Linear[v]	NS	NS
Quadratic[u]	NS	NS
Linear Contrast[t]		
Control vs 0 g N	<0.0001	0.0012
Control vs 1 g N	<0.0001	0.0081
Control vs 2 g N	<0.0001	0.0003
Control vs 3 g N	<0.0001	0.0124
Forsythia		
Nitrogen Rate	Iron	Boron
0 g N and SLS	0.1	0.0
1 g N and SLS	0.1	0.1
2 g N and SLS	0.1	0.1
3 g N and SLS	0.1	0.1
Control	0.1	0.1
ANOVA	0.0476	<0.0001
Linear	0.0487	0.0029
Quadratic	0.031	<0.0001
Linear Contrast		
Control vs 0 g N	0.0314	0.0011
Control vs 1 g N	NS	NS
Control vs 2 g N	NS	0.0182
Control vs 3 g N	NS	NS
Gardenia		
Table 13. Continued.	ron	Boron
0 g N and SLS	0.0	0.0
1 g N and SLS	0.1	0.0

2 g N and SLS	0.1	0.0
3 g N and SLS	0.1	0.0
Control	0.1	0.0
ANOVA	0.0102	0.0102
Linear	0.0017	0.0007
Quadratic	0.0438	NS
Linear Contrast		
Control vs 0 g N	0.001	0.0093
Control vs 1 g N	0.0425	NS
Control vs 2 g N	NS	NS
Control vs 3 g N	NS	NS
Rhaphiolepis		
Nitrogen Rate	Iron	Boron
0 g N and SLS	0.0	0.0
1 g N and SLS	0.0	0.0
2 g N and SLS	0.0	0.0
3 g N and SLS	0.0	0.0
Control	0.0	0.0
ANOVA	NS	NS
Linear	NS	NS
Quadratic	NS	NS
Linear Contrast		
Control vs 0 g N	0.022	NS
Control vs 1 g N	0.0267	NS
Control vs 2 g N	0.0188	NS
Control vs 3 g N	0.0253	NS

[z]N rate applied as a topdress of slow release 43-0-0 per container.
[y]Swine lagoon solids (SLS) substrate- 9:1 SLS:pine bark (v/v).
[x]Control substrate was a 9:1 pine bark:sand (v/v) with 17-5-11 applied as a topdress to apply 3.5 g N/container.
[w]Analysis of variance (ANOVA) effect of N rate within species NS=not significant, *P*-value given otherwise. Control excluded from analysis.
[v]Linear regression analysis. NS=not significant, *P*-value given otherwise. Control excluded from analysis.
Table 13. Continued.
[u]Quadratic regression analysis. NS=not significant,

P-value given otherwise. Control excluded from analysis.
[t]Linear contrast analysis comparing N rate treatment means to the control substrate. NS=not significant, *P*-value given otherwise.