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Chemical and Physical Properties of Potting Media Containing Varying Amounts of Composted Poultry Litter

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Abstract. *Composted poultry litter (CPL) was obtained from a commercial composting operation in South Carolina. The proprietary recipe included broiler breeder litter, cotton gin trash, and wood shavings. A common base mix for woody ornamentals of 8 parts pine bark and 1 part sand was compared with 3 other mixes that contained 20%, 40%, and 60% compost (v/v). The remaining fraction of these three mixes was the base mix (bark and sand). Samples of the bark and CPL were analyzed to determine the following mineral concentrations: nitrogen (organic and soluble), P_2O_5, K_2O, Ca, S, Mg, Mn, Cu, Zn, and Na. The chemical characteristics of the three compost-based potting mixes was calculated based on a mass basis. The aeration porosity, total porosity, water holding capacity and bulk density of the four mixes were measured using a chamber that was constructed to facilitate measurement of the physical properties of potting media. The results indicated increasing the percentage of compost in potting media caused the desired decrease in aeration porosity, and total porosity. However, volumetric water holding capacity was not significantly influenced by the addition of CPL. Including CPL in potting media created a substantial increase in valuable plant nutrients and minerals. The normalized evaporation rate from the four mixes was measured by placing three replicate pots containing equal volumes of each mix in a room with common temperature and convective conditions. The pots were brought to saturation and were allowed to dry for four days. It was determined that media composition did not affect the evaporation rate, but the addition of CPL increased the mass of water in a pot at all water contents included in the experiment. It was concluded that adding 20% to 40% CPL to a screened bark base mix would provide the majority of the improvements in fertilizer value, physical properties, and mass of water in a container for a growing plant.*

Keywords. Compost, Poultry Litter, Potting Media, Aeration Porosity, Total Porosity, Water Holding Capacity

Introduction

Success for any container grown, nursery crop, greatly depends on the chemical and physical properties of the potting media. An ideal media must be free of pests (i.e., weed seeds, insects, and pathogens), heavy enough to prevent the pot from tipping over, but light enough to allow ease-of-transport. The mix should retain sufficient water to reduce the need for frequent watering, but have enough porosity to allow for good drainage and to provide air for plant roots. Compost has been evaluated as an alternative to peat moss in pine bark media because it offers the advantages of supplying nutrients and improving the physical properties of the media (Robbins and Evans, 2005b). Disadvantages of including compost in the growing media include possible high salts and fine particle size (Robbins and Evans, 2005a).

Peat has been a valuable component of many potting mixes since it can be mixed with a variety of materials (i.e. pine bark, vermiculite, sand) to provide media with the desired porosity and consistency. However, peat is a non-renewable resource, and decreased availability has caused price increases in some regions of the USA (Herrera et. al, 2006). This has prompted many media manufacturers and growers to search for alternatives that will be more sustainable and cost-effective.

Screened pine bark is a common primary ingredient for soilless potting mixes in the Southeastern USA. Traditionally, the advantages of pine bark were good availability and low price. However, the price of screened pine bark is expected to increase as more bark is used as a source of boiler fuel in the forest products industry for home heating pellets. The primary disadvantages of pine bark are its high bioavailable carbon content and low pH. Bioavailable carbon can cause immobilization of soluble nitrogen in the container resulting in a reduction of nitrogen that can be taken up by the plant. Low pH (≈ 5) requires addition of lime, another media component that is increasing in price, to raise the pH to 6 or more for many common ornamentals.

One of the problems with modern livestock and poultry operations is the large amount of manure generated in concentrated areas (Marble et. al, 2010). Historically, land application to cropland has been the main form of manure utilization, but new federal and state regulations on animal farms has caused many in the animal industries to consider composting as an alterative manure treatment option. The resulting compost product could be used to enhance soil structure and provide nutrients for fruit and vegetable production, erosion control blankets, and container ornamental production (Chastain, et al., 2006).

Poultry litter is a good choice as a component for making compost. It is relatively dry and can be transported to the composting facility and mixes easily with other high-carbon ingredients such as wood waste, yard waste, and crop residues. Poultry litter also has a higher concentration of major and minor plant nutrients than other types of animal manures. This is a key advantage since previous work has shown that the nutrient content of the substrates used to make compost has a direct impact of the fertilizer value of the compost product (Chastain et al., 2006). Litter from table egg and broiler breeder farms have the additional benefit of being high in calcium due to the nutritional requirements for egg production. Recent analysis of litter obtained from broiler breeder and table egg farms in South Carolina have shown that litter of this type can have a calcium carbonate equivalency in the range of 10% to 15%. Since composting tends to concentrate nutrients, such as Ca, the liming value of the compost may be even greater.

Field experience and research studies have shown that compost can be a valuable addition to a potting mix resulting in improved plant growth (Herrera et al., 2007, Marble et al., 2010). However, very little information is available that relates amount of compost added to a potting mix to the chemical and physical properties of the mix. The chemical properties of interest include major plant nutrients (organic-N, soluble-N, P, K), minor plant nutrients (Ca, Mg, S, Zn, Cu, Mn, Fe, Al), sodium, carbon, organic matter and pH. The physical properties that are important in evaluating a potting media are the aeration porosity, water holding capacity, total porosity, and dry bulk density. The ideal amount of compost to add to potting mix would be the amount that adds the desired plant nutrients while providing the optimal aeration porosity and water holding capacity to maximize plant performance.

One of the key factors in production of plants in containers is the maintenance of adequate pot moisture. Some have speculated that potting media with large amounts of compost would reduce evaporation losses from the surface of the media (Chastain, et al., 2006). That is, the rate of evaporation from a pot would decrease as the fraction of compost in the potting mix increased. If such were the case, potting media with large amounts of compost would provide a savings in irrigation costs and would enhance a nurseryman's ability to manage the water content of the pots in a greenhouse or in a field.

Four potting media mixes were formulated that contained 0%, 20%, 40%, and 60% compost on a volume basis. The base mix (0% compost) was composed of 8 parts screened pine bark and 1 part sand. The compost used was made from a mixture of broiler breeder litter, wood waste and gin trash.

The objectives of this study were to (1) determine the impact of adding composted poultry litter, CPL, (0% - 60%) on the chemical and physical properties of a potting mix and (2) determine the affect of compost addition on evaporation rate from containers exposed to a common thermal and convective environment.

Methods

Several bags of pine bark were obtained from a potting media manufacturer located in Anderson, South Carolina. The pine bark had been screened to exclude particles greater than 6.35 mm (0.25 in), but it still contained more fine particles than desired. For most nursery container mixes 70% to 80% (by volume) of the particles should be in the range of 0.610 to 9.535 mm (0.024 to 0.375 in) (Robbins and Evans, 2005a). The pine bark was screened again with a 2.0 mm (0.0787 in) screen to yield material with particles that ranged from 2.0 to 6.35 mm (0.0787 to 0.25 in). The arithmetic mean particle size of the pine bark used was 4.18 mm (0.165 in).

Composted poultry litter was obtained from a commercial composting operation in Blackville, South Carolina. The proprietary compost recipe included broiler breeder litter, cotton gin trash, and wood shavings. Composting was carried out in open windrows in a field surrounded by large vegetated buffer areas. Water and aeration was provided by a tractor-drawn windrow turner equipped with a water tank. Once active composting was completed, as indicated by temperature measurements, the windrow was covered with a porous fabric and was allowed to cure. The finished product was bagged using an in-field bagging machine. Several bags of the finished compost product were transported to Clemson University to be used in the study.

Four potting media mixes were formulated that contained 0%, 20%, 40%, and 60% CPL. All mixtures were made on a volume basis. The base mix was based on a common container mix used for woody ornamentals. It was a mixture of 8 parts screened pine bark (2.0 to 6.35 mm) and 1 part screened and washed builder's sand. The only other ingredients that were not included, but would normally be added by a nurseryman, were lime for pH adjustment and a granular fertilizer. The other three potting mixes were made by mixing 1 part CPL with 4 parts base mix (20% compost), 2 parts CPL with 3 parts base mix (40% compost), and 3 parts CPL with 2 parts base mix (60% compost).

Chemical Properties of Media

The large amount of composted poultry litter was stored in three large plastic storage bins. Three well-mixed, samples of compost were taken from each storage bin to yield 9 replicate samples. The screened pine bark was stored in one large plastic bin and three well-mixed samples of pine bark were collected. The volume of each of the compost and pine bark samples was about 473 mL and each replicate sample was placed in a sealable plastic bag.

The samples of CPL (9) and pine bark (3) were analyzed by the Agricultural Services Laboratory at Clemson University to determine concentrations of: total nitrogen (total-N), total ammonia nitrogen (TAN = NH_4^+-N + NH_3-N), nitrate-N, total P (expressed as P_2O_5), total K (expressed as K_2O), calcium, magnesium, sulfur, zinc, copper, manganese, sodium, carbon, pH, and the organic content. Organic-N content was calculated as: Org-N = Total-N - TAN - NO_3-N (Moore, 2004).

Physical Properties of Media

The physical properties included the total solids, volatile solids, bulk density, aeration porosity, water holding capacity, and total porosity. The aeration porosity, water holding capacity, and total porosity were measured using a chamber that was designed for that purpose. Also, the initial, or antecedent, moisture content of the media was taken into account when determining the water holding capacity to improve precision.

Total solids (TS), volatile solids (VS), and fixed solids (FS) of the compost and pine bark were measured in the Agricultural, Chemical, and Biological Research Laboratory at Clemson University using standard oven-drying techniques (APHA, 1995). Each of three replicate samples was dried in an oven at 105ºC for 24 hours. Total solids content was determined after the sample was allowed to cool in desiccator. Fixed solids content (ash) was determined by incinerating the dried solids in a furnace at 550ºC for 24 hours, allowing the sample to cool, and determining the sample mass. Volatile solids were calculated as the difference between the total and fixed solids. The moisture content was calculated as 100 – TS (%).

Bulk Density

The density of the composted poultry litter, pine bark and each potting media mix was measured using a calibrated aluminum container (323 ± 1.71 mL). The density of the CPL, pine bark, and each of the four mixes was determined by filling the calibrated container with a well-mixed sample, measuring the mass of the sample, and dividing the sample mass by the container volume. Three replications were performed for each material. The dry bulk density (g dry matter / cm^3) was calculated as the wet bulk density (g sample / cm^3) divided by the dry matter fraction (g dry matter / g sample).

Aeration Porosity, Water-holding Capacity, and Total Porosity

The aeration porosity, water-holding capacity and total porosity of potting media is typically measured and reported on a wet volume basis. The total porosity is defined as the percentage of the media that is occupied by open pores on a volume basis at saturation. The defining relationship for the total porosity (TP, %) is (MAFF, 2010):

$$TP = [\text{Pore Volume}_{TOTAL} / \text{Media Volume}] \times 100. \quad (1)$$

Where,

Pore Volume = Water added to saturate media and fill pore volume (mL), and

Media Volume = Volume of solid media and pores (mL).

The aeration porosity is defined as the percentage of saturated media which is occupied by air after completely draining water from the media by gravity. The volume of the water drained is measured and represents the volume of the pores occupied with air at 100% water holding capacity. The aeration porosity (AP, %) was calculated as (MAFF, 2010):

$$AP = [V_{DRAINED} / \text{Media Volume}] \times 100. \quad (2)$$

Where,

$V_{DRAINED}$ = Volume of water drained from pore space after saturating the media and filling all pores with water (mL).

The water holding capacity is the percentage of the media and pore volume that is occupied by water at saturation. The suggested water holding capacity (WHC) equation given by MAFF (2010) was:

$$WHC = TP - AP. \quad (3)$$

The methodology and equation 1 and 2 do not account for the antecedent moisture content prior to adding water to reach saturation and fill the pore volume. The aeration porosity (Equation 2) measures the pore space that is open to air and can be filled to saturation. To account for the antecedent moisture the defining equation for the water holding capacity was rewritten as:

$$WHC = [V_{TW} / \text{Media Volume}] \times 100. \quad (4)$$

Where,

V_{TW} = Total water volume in media at saturation (mL).

The total water volume (V_{TW}) is the amount of water contained in the media plus the amount of water required to bring the media to saturation and fill the pore volume. The total water volume was calculated based on the antecedent moisture content and the volume required to reach saturation as:

$$V_{TW} = 1/\rho_w (MC_I / 100 \times M_{PM}) + V_{WR}. \quad (5)$$

Where,

ρ_w = Density of water = 1g/mL,

MC_I = Initial moisture content of media (wet basis),

M_{PM} = Mass of potting media before adding water (g), and

V_{WR} = Volume retained by media after draining (mL).

The volume of water retained was defined as the difference in the volume of water added to fill the total pore space and the volume of water drained. The water volume retained (V_{WR}) was calculated as:

$$V_{WR} = V_{ADDED} - V_{DRAINED}. \quad (6)$$

Where,

V_{ADDED} = Total volume of water added to media to fill pore volume (mL).

The total porosity was calculated as:

$$TP = AP + WHC. \quad (7)$$

Where,

AP = Aeration porosity (%) as defined in equation 2, and

WHC = Water holding capacity (%) as defined by equation .4

A test chamber was designed and constructed to facilitate the measurement of the aeration porosity, water holding capacity, and total porosity using equations 2, 4, and 7 (Figure 1). The chamber was constructed from a section of Plexiglas pipe with an inside diameter of 14.6 cm (5.75 in) and a height of 8.25 cm (3.25 in). The bottom was a round, 0.635 cm (0.25 in) thick piece of Plexiglas sheet that was chemically welded to the pipe to form a water-tight seal. Three 0.813 cm (0.32 in) holes were drilled in the bottom of the chamber and were fitted with rubber stoppers that were flush with the inside surface of the bottom of the chamber when fully inserted. A circular piece of plastic window screen (1.27 mm or 0.05 in openings) was placed in the bottom of the test chamber to retain the media while water was allowed to drain from the pore volume. The chamber was placed on a level metal rack that facilitated the collection of water drained from saturated potting media.

Figure 1. Test chamber used to determine the aeration porosity and water holding capacity of potting media.

The test chamber was calibrated to two volumes: 1364.706 mL and 1788.604 mL. These two volumes correspond to the volume of media contained in pots with a diameter of 15 to 16.5 cm m (6 to 6.5 in).

The test chamber was used to determine the aeration porosity and the water holding capacity of potting media using the following procedure.

1. The media to be tested was placed into a large plastic container and water was added to increase the moisture content. It was determined that if extremely dry media was used the pine bark would float and it would take a prohibitively long time to saturate the media. After water was added to the media a tightly fitting cover was used to minimize evaporation between replications.
2. A large sample of the moistened potting media was taken and the moisture content was measure using standard oven drying techniques (105ºC oven for 24 hr). This provided a measure of the initial or antecedent moisture content and was used in equation 5.
3. The test chamber was filled with media to the 1364.706 mL mark. This was the value used for media volume in equations 2 and 4. The chamber was dropped onto a hard surface from the height of three inches four times and additional media was added to re-fill the container to the 1364.706 mL mark. This was done to ensure equal compaction for all replications of all four potting mixes.
4. The test chamber full of media was placed on a level rack and a plastic container was placed below the rack.
5. Water was slowly added to the media using a graduated cylinder until the solids were completely saturated and the pore volume was full. When this had been achieved, no air bubbles were present in the media and the surface of the media glistened. The total volume of water added (V_{ADDED}) was recorded and was used in equation 6.
6. The three rubber stoppers were removed and water was allowed to drain from the pore space of the media until all dripping stopped (approximately 1 hr per replication). The total amount of water that drained from the test chamber was measured using a graduated cylinder and was recorded. The volume drained ($V_{DRAINED}$) was used in equations 2 and 6.

This procedure was followed for three replications of each of the four potting mixes as well as screened pine bark.

Evaporation Rate

An experiment was performed to observe the affect of the amount of CPL used in a potting mix (0%, 20%, 40%, and 60%) on the rate of water loss from a pot by evaporation over a period of four days. This was accomplished by bringing pots of the four media mixes to saturation and then observing the change in pot mass and water content with respect to time. The water content (g water / g dry matter) of the entire pot contents was determined for each mix at the beginning of the experiment and after allowing evaporation to occur for two and four days. All of the pots of media were randomly placed on a laboratory table in an air conditioned room provide a common thermal and convective environment for all pots (Figure 2).

Figure 2. Experimental setup for the evaporation loss experiment.

The nominal 15 cm (6 in) diameter pots selected for use in this experiment were made from plastic to eliminate loss of water through the sides of the pots. They also had only one hole in the bottom to facilitate bringing the contents of each pot to saturation and then allowing pore water to drain. A total of nine pots were used for each of the four potting mixes to give a total of 36 pots for the study.

The experiment was initiated (day 0) by filling all of the pots with the selected mix to a known volume using the same compaction procedure as used to determine the aeration porosity and water holding capacity. Rubber stoppers were used to plug the whole in the bottom of the pots and water was added to fill the pore space and to bring the pot to water holding capacity. After the pot was at full capacity, the pot was placed on a rack and the stopper was pulled to allow the pore water to completely drain. After draining, the mass of each pot was recorded. After all nine pots of a particular media were initiated three pots were selected and the entire contents were emptied onto a foil pan and the moisture content was determined using standard oven drying techniques. The average of these three measurements was used to determine the initial water content for each of the four mixes.

After allowing the remaining pots to air dry for one day the mass of all of the pots was measured and recorded (day 1). The same procedure was repeated after allowing these pots to air dry for another day. Then three pots of for each type of media were removed from the experiment and the water content was determined using the entire pot contents as described previously (day 2). The remaining pots were allowed to air dry two more days and the mass of each pot was measured on each day (day 3 and 4). On the last day of the experiment the remaining 12 pots were used to determine the final water content (3 per treatment).

This procedure provided three replications of the water content at saturation and after two and four days of drying. It also provided 15 data points on the change in pot-weight with respect to time to allow calculation of the evaporation with respect to time for each media mix.

Results and Discussion

The chemical properties of the two media ingredients, screened pine bark and CPC, determined the chemical properties of the four media mixes. The physical properties of the four media mixes were also related to the physical properties of the ingredients. The data were analyzed to determine if the addition of composted poultry litter significantly influenced the aeration porosity, water holding capacity, dry bulk density, nutrient content, and evaporation losses from each of the media mixes.

Chemical Properties of Media

The two major components of the four experimental potting mixes that contributed plant nutrient and minerals were pine bark and CLP. Three replicate samples were taken for pine bark and nine for composted poultry litter. The mean concentrations of the chemical constituents and solids of these two ingredients are shown in Table 1.

Table 1. Chemical composition of the two ingredients used to make the four potting mixes.

	Pine Bark [a]		**CPL [b]**	
	% Dry Basis	**% Wet Basis**	**% Dry Basis**	**% Wet Basis**
Moisture	--	56.38	--	25.56
Ammonium Nitrogen	0.00	0.00	0.00	0.00
Organic Nitrogen	0.33	0.13	1.08	0.80
Nitrate-Nitrogen	0.00	0.00	0.12	0.09
Total Nitrogen	0.33	0.13	1.08	0.80
Carbon	52.40	21.26	9.94	7.41
Phosphorus (P_2O_5)	0.12	0.05	2.45	1.84
Potassium (K_2O)	0.22	0.09	0.82	0.62
Calcium	0.33	0.14	4.35	3.26
Magnesium	0.11	0.04	0.36	0.27
Sulfur	0.05	0.02	0.20	0.15
Zinc	0.0037	0.0015	0.0229	0.0172
Copper	0.0012	0.0005	0.0176	0.0132
Manganese	0.0140	0.0057	0.0222	0.0167
Iron	0.2977	0.1208	0.6702	0.5018
Sodium	0.0234	0.0095	0.1530	0.1148
Aluminum	0.3803	0.1543	1.1943	0.8925
Organic Matter	92.57	37.56	13.67	10.20
C:N Ratio	159.67	-	9.24	-
pH:	5.10	5.10	7.33	7.33
Total Solids [a]	-	43.62	-	74.44
VS/TS [a]	93.30	-	55.30	-

[a]. Mean based on three replications.
[b] Mean based on nine replications.

The major and minor plant nutrient contents on a dry basis were much higher in CPL than pine bark. Composted poultry litter contained 227% more total nitrogen, 1941% more total phosphorus, and 273% more potassium than pine bark. The CPL also had a larger minor nutrient content then pine bark, which could possibly eliminate the need for addition of minor plant nutrients. The calcium content of CPL was 1,218% greater than pine bark which contributed to a higher pH. Pine bark had a high C:N ratio which could immobilize a portion of the soluble nitrogen in a pot needed to grow a plant. The high volatile solid fraction (VS/TS) indicated that pine had a low ash content and a high bioavailable carbon content.

Nutrient Content of Potting Mixes

The nutrient content of a potting mix is important to ensure proper growth of a plant. The nutrient content of the four potting mixes was calculated on a dry basis since the moisture contents differed greatly. The concentration of each constituent for each of the four potting mixes was calculated based on the following relationship:

$$[C_j]_{MIX} = \{ (([C_j]\,\rho_{DM}\,V)_{PB} + ([C_j]\,\rho_{DM}\,V)_{CPL}) \div ((\rho_{DM}\,V)_{PB} + (\rho_{DM}\,V)_{CPL}) \} \times 100. \quad (8)$$

Where,

$[C_j]_{MIX}$ = Concentration of constituent, C_j, on a dry basis (%),

ρ_{DM} = Dry bulk density (g/cm^3), and

V = Volume (cm^3).

$([C_j]\,\rho_{DM}\,V)_{PB}$ = Mass of Cj added to the potting mix from screened pine bark,

$([C_j]\,\rho_{DM}\,V)_{CPL}$ = Mass of Cj added to the potting mix from composted poultry litter,

$(\rho_{DM}\,V)_{PB}$ = Mass of pine bark added to potting mix, and

$(\rho_{DM}\,V)_{CPL}$ = Mass of composted poultry litter added to potting mix.

The results of the calculations are provided in Table 2.

The addition of CPL at varying levels, created a linear increase in the major and minor plant nutrients. Each 20% addition of CPL gave a 67% increase in total nitrogen, 427% increase in phosphorus, and 68% increase in potassium. The level which is the most beneficial is to be determined based on individual plant requirements.

The average pH of the potting mixes was also influenced by the addition of CPL. Each 20% addition of CPL provided an increase in pH of 9%. Therefore, using CPL for 20% or more of a potting mix would be expected to reduce lime requirements.

Comparison with Desirable Nutrient Levels

The desirable levels of major and minor nutrients for potting mixes were provided by the Southern Nursery Association (SNA, 2005) and Yeager et al. (2010). The units used were g/1000 ml. Therefore, the concentrations in Table 2 were converted and are compared with the desirable levels from the literature in Table 3.

Each mixture containing composted poultry litter met or exceeded the suggested major and minor nutrient requirements for potting mixes (Table 3). Addition of 20% to 40% CPL to the potting mix may eliminate the need for additional P, K, and minor nutrients. Depending on the needs of a particular type of plant the slow release organic-N provided by CPL may also be sufficient.

Table 2. Chemical composition of the four experimental potting mixes.

	Base Mix		20% Compost		40% Compost		60% Compost	
	% Dry Basis	% Wet Basis	% Dry Basis	% Wet Basis	% Dry Basis	% Wet Basis	% Dry Basis	% Wet Basis
Moisture	--	56.382	--	53.525	--	53.087	--	52.840
Ammonium Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Organic Nitrogen	0.29	0.16	0.45	0.25	0.61	0.34	0.76	0.43
Nitrate-Nitrogen	0.00	0.00	0.02	0.01	0.05	0.03	0.07	0.04
Total Nitrogen	0.29	0.16	0.47	0.27	0.65	0.37	0.83	0.47
Carbon	46.58	26.26	39.25	22.13	31.92	18.00	24.59	13.87
Phosphorus (P_2O_5)	0.11	0.06	0.58	0.32	1.04	0.59	1.51	0.85
Potassium (K_2O)	0.19	0.11	0.32	0.18	0.44	0.25	0.57	0.32
Calcium	0.30	0.17	1.11	0.62	1.92	1.08	2.73	1.54
Magnesium	0.10	0.05	0.15	0.08	0.20	0.11	0.25	0.14
Sulfur	0.04	0.02	0.07	0.04	0.10	0.06	0.14	0.08
Zinc	0.00	0.00	0.01	0.00	0.01	0.01	0.02	0.01
Copper	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01
Manganese	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01
Iron	0.26	0.15	0.35	0.19	0.43	0.24	0.51	0.29
Sodium	0.02	0.01	0.05	0.03	0.07	0.04	0.10	0.06
Aluminum	0.34	0.19	0.51	0.29	0.68	0.38	0.85	0.48
Organic Matter	82.28	46.39	68.56	38.65	54.84	30.92	41.11	23.18
C:N Ratio	160.62	-	83.51	-	49.11	-	29.63	-
pH:	-	5.10	-	5.55	-	5.99	-	6.44

Table 3. The desirable levels of nutrient compared with the mean amount available. Nutrient concentrations are on a volume basis.

Desirable Levels [a]		**Amount at Different Compost Levels**			
	Guide Levels	**BM AVG.**	**20% AVG.**	**40% AVG.**	**60% AVG.**
pH:	*4.50 to 6.50*	5.10	5.55	5.99	6.44
	g/1000ml [b]				
Nitrate-Nitrogen	0.050 to 0.100	0.000	0.089	0.203	0.342
Total Nitrogen	1.188 to 1.782	0.898	1.793	2.824	4.036
Phosphorus (P_2O_5)	0.037to 0.055	0.329	2.1859	4.5199	7.332
Potassium (K_2O)	0.036 to 0.060	0.599	1.215	1.927	2.765
Calcium	0.020 to 0.040	0.917	4.210	8.308	13.232
Magnesium	0.015 to 0.020	0.297	0.564	0.869	1.227
Zinc	0.0002	0.0101	0.0274	0.0482	0.0730
Copper	0.00002	0.0034	0.0167	0.0333	0.0532
Iron	0.00005	0.8153	1.3137	1.8484	2.4630

[a] Sources: Southern Nursery Association (SNA, 2005) and Yeager et al. (2010)
[b] $(g\ C_j / 1000\ ml)_{MIX} = ([C_j]_{MIX} \times \rho_{DM} \times 1000\ ml)$

Physical Properties of Media

Proper plant growth is affected by the physical properties of the potting media. These properties include water holding capacity, aeration porosity, total porosity, and bulk density. Equations 2, 4, and 7 were used to determine aeration porosity, water-holding capacity, and total porosity, for the screened pine bark and the four experimental potting mixes. The dry bulk density was calculated as the mass of dry media / volume of media.

A one-way analysis of variance (Steel and Torrie, 1980) was used to calculate a pooled variance for the screened pine bark and the four potting mixes. The least significant difference using the 95% level of probability was calculated from the pooled variance as: LSD = $t_{0.025,edf}\ (2\ S_P^2/r)^{0.5}$. Where, edf represents the error degrees of freedom (10), and r is the number of replications per treatment (3). The LSD values were used to test for differences between treatment means for each of the physical characteristics. The treatment means and statistical results are given in Table 4.

Surprisingly, addition of CPL did not influence the water holding capacity (WHC) on a percent volume basis. However, all of the mixes had a WHC within the desirable range of 45% to 65% (Robbins and Evans, 2005b).

Addition of CPL to a potting mix decreased aeration porosity (AP) and total porosity (TP) when compared to the base mix and the screened pine bark. The only two potting mixes that were not significantly different with respect to aeration and total porosity were the mixes containing 20% and 40% CPL. Acceptable ranges are 10% to 20% for aeration porosity, and 50% to 70% for total porosity (Robbins and Evans, 2005b). All of the potting mixes that have been amended with CPL had AP and TP within the desirable range but the base mix did not. However, the 40 percent CPL mixture had the most desirable aeration porosity being near the median of the desirable range.

A pot should be heavy enough to prevent tipping due to plant weight or wind. Addition of CPL resulted in an increase in the dry bulk density of potting media. Higher bulk density of the potting mix would be expected to increase pot weight and reduce tipping.

Table 4: Water-holding capacity, aeration porosity, total porosity, and dry bulk density of screened pine bark and the four potting mixes.

Media Type **ID Term**	**Pine Bark** **PB**	**Base Mix (8 PB: 1 Sand)** **BM**	**20% Compost** **C20**	**40% Compost** **C40**	**60% Compost** **C60**
Water Holding Capacity (%)	43.84	45.51	48.35	50.25	46.15
Differs From:	None	None	None	None	None
Aeration Porosity (%)	38.38	29.97	18.27	15.46	12.07
Differs From:	BM,C20,C40,C60	PB,C20,C40,C60	PB,BM,C60	PB,BM	PB,BM,C20,C40
Total Porosity (%)	82.22	75.48	66.62	65.71	58.22
Differs From:	BM,C20,C40,C60	PB,C20,C40,C60	PB,BM,C60	PB,BM,C60	PB,BM,C20,C40
Dry Bulk Density (g_{DM}/cm^3)	0.158	0.306	0.369	0.419	0.473
Differs From:	All	All	All	All	All

Evaporation Results

The ability of a potting media to hold water over an extended period of time is important to reduce the frequency of watering. It was hypothesized that adding CPL to a bark and sand potting mix would increase the mass of water available to a growing plant and may alter the rate of water loss from a pot by evaporation.

The loss of water by evaporation from media was observed in two ways. The first was by direct measurement of the water content (WC) over time and the second was by the change in pot mass over time as described previously (Methods).

The water content of an entire pot of media was measured on a dry matter, mass basis (g water/g dry media). Water content measurements were taken at water holding capacity (day 0), and after two and four days of evaporation. The mean results are shown in Table 5.

Table 5. Evaporation results obtained by analysis of entire pot contents (day 0, 2 and 4).

	Base Mix	**20% Compost**	**40% Compost**	**60% Compost**
Initial Conditions (day 0)				
Mass of DM (M_{DM}), g/pot [a]	302	365	414	467
Mass of Water, g/pot [b]	390	420	468	523
Total Mass, g/pot	692	785	882	990
WC(0), g w/g DM	1.29	1.15	1.13	1.12
Moisture, % wet basis [c]	56.3	53.5	53.1	52.8
After 2 Days				
Water Remaining, g/pot [b]	369	414	430	466
Total Evaporation, g/pot	21	6.0	38	57
Evaporation Loss, %	5.4	1.4	8.1	10.9
WC(2), g w/g DM	1.22	1.13	1.04	1.00
Moisture, % wet basis [c]	55.0	53.1	50.9	49.9
After 4 Days				
Water Remaining, g/pot [b]	316	355	407	413
Total Evaporation, g/pot	84	65	61	110
Evaporation Loss, %	21.5	15.5	13.0	21.0
WC(4), g w/g DM	1.05	0.97	0.98	0.88
Moisture, % wet basis [c]	51.1	49.3	49.6	46.9

[a] Mean based on all nine replicate pots (day 0, 2, and 4).
[b] Mean based on three replicate pots.
[c] Calculated on a wet, mass basis.

Addition of composted poultry litter to a potting mix had a significant affect on the mass of dry matter and water in a container at saturation (WHC). The mass of dry matter contained in a pot was increased by 21% to 55% compared to the base mix depending on the percentage of compost in the mix. At saturation, the mass of water in a pot was increased by 7.7% more than the base mix when the mix contained 20% CPL. Doubling the CPL percentage to 40% increased the mass of water held in the container to 20% more than the base mix which was a 2.6 fold increase over the 20% CPL mix. Increasing the CPL percentage by a factor of 1.5 from 40% to 60% CPL provided an increase in water mass by a factor of 1.7 (34% more water than the base mix). Therefore, addition of compost to a potting mix increased the mass of the potting mix as well as the mass of water held by the mix at saturation.

At water holding capacity the mass of water was greater than the mass of dry media in all cases. The saturation water content (WC(0)) decreased from 1.29 g of water per g dry matter (g w/g DM) for the base mix to 1.15 g w/ g DM for the 20% CPL mix. As the percentage of CPL was increased to 40% and 60% the saturation WC continued to decrease by a small amount.

Previous measurements of water holding capacity (Table 4) indicated that addition of CPL did not significantly increase the water holding capacity of a potting mix. However, the results at saturation shown in Table 5 indicate that addition of CPL provided an increase in mass of water held in a container when brought to saturation using a similar procedure. The difference is due to that fact that water holding capacity was calculated on a wet, volume basis whereas the evaporation study were carried out on a mass, dry basis since mass is conserved in a thermodynamic system and volume is not. The moisture content was also provided for the four mixes in Table 5 on a percent, wet mass basis. These values were much closer to the values for WHC shown in Table 4. However, they are all greater than the values in Table 4 because they are based on mass and not volume. In short, WHC on a volume basis provides a useful index for comparing the container volume that is occupied by water at saturation. However, water content must be expressed on a dry, mass basis if it is desired to accurately determine how much water is in a container as it dries. In addition, WC is a more accurate measure of the water available to plant roots.

The relatively small number of data points (3 replications per day) made it difficult to determine the rate of evaporation loss over time using direct measurements of WC. However, as the four experimental mixes continued to dry for 2 and 4 days the data provided in tables indicated that all mixes that contained CPL maintained a larger mass of water as compared to the base mix. After four days of drying the 20% compost mix contained 12% more water than the base mix whereas the 40% CPL and 60% CPL mixes contained about 30% more water than the base mix.

Over the four day evaporation experiment 15 pot mass measurements were made with respect to time for each of the 4 mixes. Preliminary analysis indicated that each data set was linear with a high degree of correlation. All of the data sets could be fit to the following equation:

$$M_{POT}(T) = M_{POT}(0) - \Delta M_{POT} \times T. \qquad (8)$$

Where,

$M_{POT}(T)$ = Mass in pot at time T, g/pot,

$M_{POT}(0)$ = Initial mass of pot at saturation (water + media), g/pot,

ΔM_{POT} = Change in pot mass with respect to T, g / T, and

T = Elapsed time, days.

While every effort was made to fill each pot with the same volume of potting mix, there still was a variation in the initial saturated pot mass, $M_{POT}(0)$, for each replication of each treatment. In order to eliminate this source of variation equation 8 was normalized by dividing through by initial pot mass ($M_{POT}(0)$) to give:

$$P(T) = 1 - \Phi T. \qquad (9)$$

Where,

P(T) = Normalized pot mass = $[M_{POT}(T) / M_{POT}(0)]$, and

Φ = Normalized slope = change in pot mass relative to the initial pot mass at saturation = $[\Delta M_{POT} / M_{POT}(0)]$, g / T / g.

All replications of data were normalized and fit to the linear relationship given in equation 9. The results are summarized in Figure 3. All of the regressions were based on 15 observations (3 per day) except for the base mix. One data set of the five observations (day 0, 1, 2, 3, 4) for the base mix was corrupted and was not included. As a result, the correlation for the base mix was based on 10 data points.

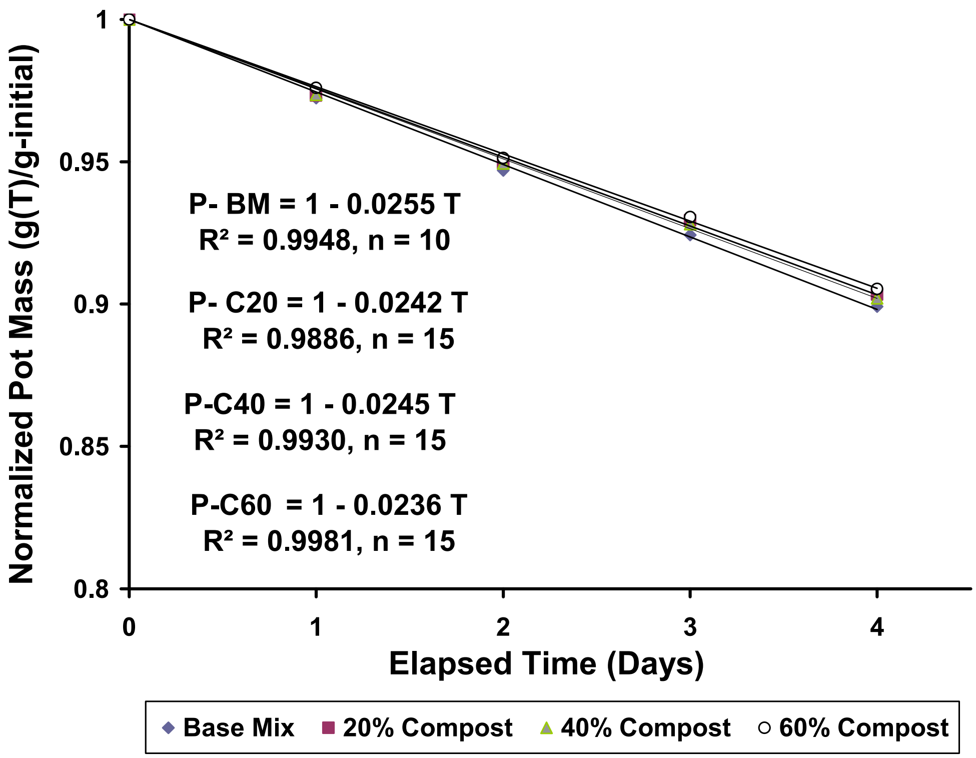

Figure 3. Correlations of normalized pot weights with respect to time.

The mass of the pots decreased in a linear manner for all four of the potting mixes as water evaporated from the pots. The correlation for each potting mix was high as indicated by coefficients of determination (R^2) that ranged from 0.9886 to 0.9981. The normalized slope, Φ, of each of the lines described the rate of evaporation from the pots. The magnitude of Φ appeared to decrease slightly as the percentage of CPL was increased. An ANOVA was performed for each regression in order to determine if the values of Φ were significantly different. The 95% confidence intervals were computed about each of the normalized slopes and are compared in Figure 4. Since all four values of Φ were contained within all four 95% confidence intervals it was concluded that they were not significantly different. Therefore, addition of composted poultry litter did not significantly alter the rate of evaporation from a container of potting media for this study. Furthermore, the grand mean normalized slope, $\Phi = -0.0245$, provided the best description of the change in pot mass with respect to time for all four of the potting mixes over the observed ranges of water content. If a greater amount of drying had occurred, then the rate of change in pot mass with respect to time would be expected to decrease as partially dried media added a diffusive resistance to mass transfer.

Equation 9 provided the relationship for the normalized change in pot mass with respect to time. The equation for the normalized evaporation rate, g water lost per g of initial pot mass, was found by subtracting one from equation 9 and substituting the grand mean value for Φ to yield:

$$\varepsilon(T) = -0.0245\,T. \qquad (10)$$

Where,

$\varepsilon(T)$ = Normalized evaporation = (P(T) -1), mass of water lost / $M_{POT}(0)$.

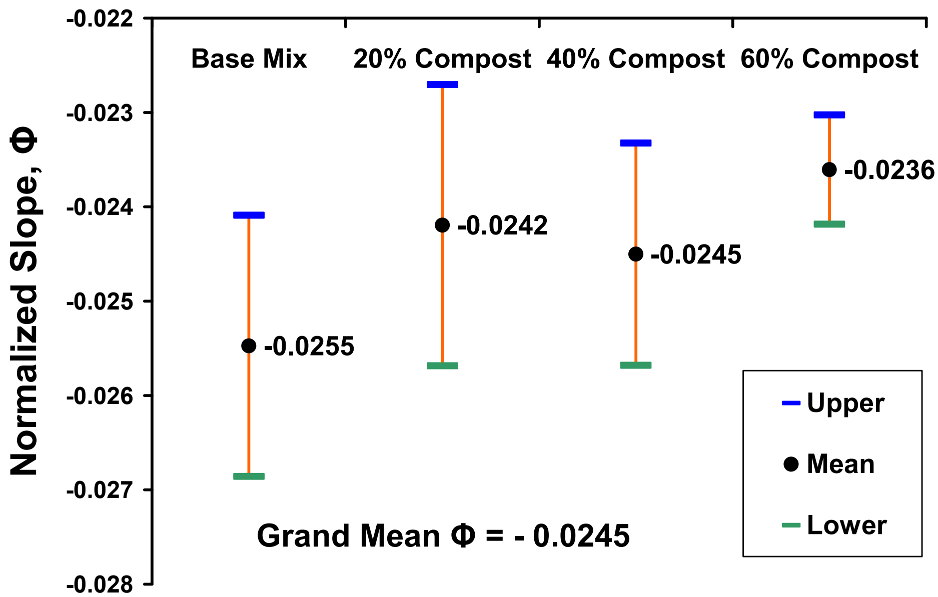

Figure 4. Statistical comparison of normalized slopes, Φ, for the four potting mixes. The upper and lower values around the means are 95% confidence intervals.

The evaporation rate in terms of mass of water lost per pot was simply $E(T) = \varepsilon(T) \times M_{POT}(0)$. Where, $M_{POT}(0)$ is the initial mass of water and dry matter for a particular potting mix. In terms of the grand mean value of Φ the equation for E(T) was written for the results of this experiment as:

$$E(T) = -0.0245\,T \times M_{POT}(0). \qquad (11)$$

Noting the sign convention that evaporation loss is negative allows the water content to be calculated from the correlation results as:

$$WC(T) = (Mw_{POT}(0) + E(T)) / M_{DM\text{-}POT} \qquad (12)$$

Where,

$WC(T)$ = Calculated water content, g w / g DM,

$Mw_{POT}(0)$ = Initial mass of water in pot (T=0) for a particular potting mix, g/pot, and

M_{DM-POT} = Mass of dry matter in pot for a particular potting mix, g/pot.

Equations 11 and 12 were used with the initial values given in Table 5 to calculate the mean water contents for the four potting mixes after 2 and 4 days of drying. The calculated values are compared with the measured means in Table 6. The calculated WC agreed with the measured values within 8%. The worst agreement was for the 20% CPL mix after 2 days of drying. Further inspection of the data indicates that one of the three replications for was lower than the others. Therefore, the value calculated based on the change in pot mass correlation and the initial water content appears to provide the more accurate value.

Table 6. Comparison of the measured water contents after two and four days of drying with those calculated using equations 11 and 12.

Day		**Base Mix** W (g w/g DM)	**20% Compost** W (g w/g DM)	**40% Compost** W (g w/g DM)	**60% Compost** W (g w/g DM)
0	Measured	1.29	1.15	1.13	1.12
2	Calculated	1.18	1.04	1.03	1.02
	Measured	1.22	1.13	1.04	1.00
	% Diff.	**3.46**	**7.55**	**1.38**	**-1.61**
4	Calculated	1.07	0.94	0.92	0.91
	Measured	1.05	0.97	0.98	0.88
	% Diff.	**-1.48**	**3.16**	**5.99**	**-3.66**

Conclusion

Measurements and experiments were conducted to determine the affects of adding composted poultry litter (0%, 20%, 40%, 60% compost) to a screened pine bark base mix on the chemical and physical properties of potting media and on evaporation rates from pots exposed to a common thermal and convective environment.

The key results and conclusions are summarized as follows.

1. The addition of composted poultry litter (CPL) from 20% to 60% of the mix provided a linear increase in the major and minor plant nutrients. Each 20% addition of CPL gave a 67% increase in total nitrogen, 427% increase in phosphorus, and 68% increase in potassium.
2. Comparison of the plant nutrients in CPL amended potting mixes with target values provided by the nursery industry indicated that mixes with 20% CPL would provide all of the P, K micro nutrients, and most of the N needed in most cases.
3. Adding CPL to a potting mix also increased the average pH. The mix with the lowest proportion of CPL, 20% CPL, provided a 9% increase in pH and would be expected to reduce lime requirements.
4. Addition of CPL to the screened bark base mix provided the desired reduction in aeration porosity. All of the CPL amended mixes had aeration porosities in the recommended range of 10% to 20%. The aeration porosity ranged from 12% for the

60% CPL mix to 18% for the 20% CPL mix. The base mix had an unacceptable aeration porosity of 30%.

5. Addition of CPL also provided the desired reduction in total porosity for all CPL amended mixes. The total porosity ranged from 58% for the 60% CPL mix to 67% for the 20% CPL mix. The target range is 50% to 70%. The base mix had an unacceptable total porosity of 75%.
6. Addition of CPL did not provide a statistically significant difference in the volumetric water holding capacity (WHC) of the potting mixes used in this study. The WHC of the four mixes in this study ranged from 46% to 50% which was well within industry recommendations.
7. Composted poultry litter had a higher dry bulk density than screen pine bark. Addition of CPL increased the bulk density and the total pot mass and should reduce pot tipping.
8. While the volumetric WHC was not impacted by the addition of CPL the actual mass of water contained in a pot was increased by 7.7% to 34% as the percentage of CPL was increased from 20% to 60%. Therefore, compost amended potting mixes would provide more water for plant roots.
9. The volumetric WHC provides a useful index for comparing the container volume that is occupied by water at saturation. However, water content must be expressed on a dry, mass basis if it is desired to accurately determine how much water is in a container as it dries.
10. The evaporation study indicated that the experimentally determined normalized rate of evaporation (Φ) was not influenced by potting media composition for the range of water contents (g water / g dry matter) included in the four-day experiment. The amount of water in a pot filled with media was directly proportional to the percentage of CPL in the media.

Results indicated that: potting mixes that contain 20% to 40% compost appear to be the most beneficial when considering the improvement in fertilizer value, physical properties, and water holding capacity on a mass basis. The actual amounts to be used in a particular case should be based on the nutrient content of the mix and the aeration porosity. Additional work is needed to evaluate the plant availability of major and minor nutrients.

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References

APHA, 1995. Standard Methods for the Examination of Water and Wastewater, 19th edition, eds: A.D. Eaton, L.S. Clesceri, and A.E. Greenberg, Washington, DC: American Public Health Association.

Chastain, J.P., C. Frase, and K. P. Moore. 2006. Composition of Animal Manure Compost and Utilization Implications. ASABE Paper No. 064054 St. Joseph, Mich.: ASABE.

Herrera, F., J.E. Castillo, A.F. Chica, and L. Bellido. 2007. Use of municipal solid waste compost (MSWC) as a growing medium in the nursery production of tomato plants. Bioresourse Technology 99(2008) 287-296.

MAFF. 2010. Importance of Aeration in Container Media. Abbotsford, BC: Ministry of Agriculture, Fisheries and Food. Available at: http://www.agf.gov.bc.ca. Accessed 15 August 2010.

Marble, S.C., C. Gilliam, J. Sibley, G Fain, H. Torbert, T. Gallagher, and J. Olive. 2010. Evaluation of Composted Poultry Litter as a Substrate Amendment for WholeTree, Clean Chip Residual, and Pinebark for Container Grown Woody Nursery Crops. Journal Environmental Horticulture. 28(2):107-116.

Moore, K.P. 2004. Compost Analysis Procedures. Clemson, SC: Agricultural Service Laboratory, Clemson University. Available at: http://www.clemson.edu/public/regulatory/ag_svc_lab/compost/compost_procedures/index.html. Accessed 25 August 2010.

Robbins, J. and M. Evans. 2005a. Growing Media for Container Production in a Greenhouse of Nursery Part I. Little Rock, AR. University of Arkansas Cooperative Extension Service. Available at: http://www.uaex.edu/Other_Areas/publications/PDF/FSA-6097.pdf. Accessed 15 August 2010).

Robbins, J. and M. Evans. 2005b. Growing Media for Container Production in a Greenhouse of Nursery Part I. Little Rock, AR. University of Arkansas Cooperative Extension Service. Available at: http://www.uaex.edu/Other_Areas/publications/PDF/FSA-6097.pdf. Accessed 15 August 2010).

SNA. 2005. Best Management Practices: Guide for Producing Nursery Crops. Southern Nursery Association. Atlanta, GA.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics: A Biometric Approach. 2nd ed. New York, NY: McGraw-Hill Book Company.

Yeager, T., J. Million, and C. Larsen. Bob Stamps. 2010. Florida Nursery Best Management Practices: Past Present, and Future. Gainesville, FL: Department of Environmental Horticulture, University of Florida.