MDARD 2015 Final Report

Project Title: Evaluation of compost type for the development of green roof substrates
Project Number: MDAHF #: 791N4300383
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Accomplishments during reporting period

Compost is often treated as a fungible material within the green roof community. Consequently, recommendations for the use of compost are generic and pay little consideration to the fact that composts are highly diverse. Multiple studies have shown that compost selection affects the physical and chemical properties of greenhouse substrates as well as the development of plants grown in those substrates. It stands to reason that variability in composts included in green roof substrates will result in differences between those substrates. Therefore, the objectives of this study were to determine how compost selection influences the physical and chemical properties of green roof substrates, how these properties influence growth and development, and how susceptible these substrates are to leaching of N and P which can be potential pollutants.

Six different composts varying in feedstock and production style were combined by volume with a commercial green roof mixture of expanded shale (Haydite A and B, Hydraulic Press Brick Co., Indianapolis, IN) and 2NS sand to create six substrates that varied only in their compost selection (Table 1). Substrate blends consisted of 24% haydite A (.074-2.38mm), 24% haydite B (2.38–9.51mm), 32% 2NS sand, and 20% of the given compost. Bulk density, total porosity, and volumetric water content at field capacity, and granulometric particle distribution were determined for each blended substrate.

Table 1. Description of Composts

Granger	Screened commercial compost produced in windrows from municipal yard waste (Granger LLC, Lansing MI)
Tuthill	Screened commercial compost produced in windrows from horse manure and municipal yard waste (Tuthill Farms and Composting, South Lyon MI)
Transplant	Unscreened compost produced in piles at the MSU Student Organic Farm (SOF) using straw, hay, and topsoil; for use in transplant mixtures.
Digestate	Produced in the same fashion as the Transplant blend with the addition of the liquid waste fraction of an on-campus anaerobic digester during the thermophilic composting phase.
FWH	Food Waste Hot (FWH). Screened compost produced in piles at the MSU SOF using pre-consumer food waste.
FWV	Food Waste Vermicompost (FWV). Screened vermicompost produced in a perpetual worm bed system at the MSU SOF using pre-consumer food waste.

In addition to quantifying substrate physical and chemical properties, plants were grown in the various substrates to determine their effect on plant performance. The study was conducted in the MSU Plant Science Greenhouses under natural photoperiod and irradiance levels using bulb crates measuring 56.2 x 35.6 cm that were filled to a depth of 10 cm and planted with three plant species that differed in metabolic strategy, nutrient demand, and drought tolerance: *Ocimum* *basilicum* (basil), *Sedum floriforum* (sedum), or *Carex eburnea* (bristleleaf sedge). Irrigation timing was determined by volumetric moisture content.

Plant growth was monitored every three weeks by measuring height and width in two directions to determine the approximate volume occupied by each plant. Growth of basil plants was measured until it was ready to be harvested. At that point it was harvested perpetually, fresh harvest weights were recorded, and top growth was removed to maintain the plant's height at approximately 20 cm. During three regularly spaced intervals (days 21, 93, and 165), runoff water was collected and analyzed for soluble ammonium, nitrate, and phosphorous quantity and concentrations. After 25 weeks plants were harvested, separated into roots and shoots, dried at 60 ºC for seven days, and weighed to determine plant biomass accumulation.

Statistical analyses was performed using SAS Version 9.3. Growth index was analyzed with a linear regression model. Biomass, fresh harvest weight, and water contaminant concentrations were analyzed using an ANOVA model with plant species as a blocking variable. Significant differences between substrate treatments were determined using multiple comparisons by LSD.

Physical and chemical properties of substrates. Compost selection influenced the commonly measured physical parameters used to evaluate substrates (Table 2). There were both increases and decreases of bulk density, total porosity, and saturated hydraulic conductivity of the substrate relative to the control. The exception to this was field capacity, which was greater in all of the compost treatments relative to the base substrate. The magnitude of differences between the base substrate and the compost treatments were also variable. One factor affecting stormwater management potential is saturated hydraulic conductivity, a measure of the rate at which water moves through a substrate where there was nearly ten times the difference between the FWW and Granger treatments. Bulk densities and air-filled porosities observed amongst the compost treatments were all within acceptable ranges for plant growth. However, there was a 13.6% difference in bulk density between the FWH and Digestate treatments, which has implications for transportation of these substrates. The transportation of substrates represents a significant portion of both the cost and embodied energy of a green roof, due largely to the fuel consumed.

Table 2. Physical Properties of Substrates Prepared with Different Composts

	FWH	FWW	Transpl	Digestate	Granger	Tuthill	Control
Porosity (% vol)	41.5 e	45.0 d	45.5 cd	50.3 a	48.5 ab	44.8 d	47.5 bc
Bulk Density ($g\cdot cm^{-3}$)	1.42 a	1.41 a	1.31 b	1.23 c	1.25 bc	1.42 a	1.32 b
Field Capacity ($ml\cdot cm^{-3}$)	0.175 bc	0.205 a	0.168 c	0.180 b	0.203 a	0.183 b	0.158 d
Saturated Hydraulic Conductivity($cm\cdot hr^{-1}$)	4.3 c	1.4 d	4.5 c	9.9 a	10.2 a	3.2 cd	7.3 b

Composts were mixed at 20% by volume with heat expanded shale and sand. FWV = "Food Waste Vermicompost"; FWH = "Food Waste Hot compost." Values in the same row sharing a letter were found to be statistically similar using Fischer's LSD at α=0.05.

The general distribution pattern of particle sizes in the substrates remained similar among the compost treatments and the control. This is not unexpected since the compost addition represented only a small change in the overall mass of each substrate. One notable difference was that the vermicompost treatment had a higher percentage of particles between 0.3 and 0.15 mm and a lower percentage of particles between 2.0 and 4.75 mm. The greater abundance of small particles in the vermicompost substrate is consistent with investigations into the effects of vermicomposting on mean weight diameters. All of the compost substrates fell within acceptable ranges for the German FLL (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau) granulometric and air-filled porosity requirements. Only the FWV and Granger substrates satisfied the FLL standard for field capacity (≥ 20%) and only the Digestate and Granger substrates satisfied the requirement for saturated hydraulic conductivity (≥ 6 cm·hr^{-1}). Of the six substrates tested, the Granger substrate was the only one that met all of the requirements set by the FLL for an extensive single-course green roof substrate.

Chemical analysis revealed that total and soluble nutrient concentrations as well as pH varied greatly among compost types (Table 3). Soluble nutrient concentrations were consistently greatest in the FWW compost. Among the nutrients analyzed, those in the FWV compost were between 3.5 (Ca) and 150 (NO_3) times greater than those of the lowest testing compost.

Table 3. Soluble Nutrient Analysis of Composts

	pH	EC (mmhos)	NO_3 (ppm)	NH_4 (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)
Granger	7.9	6.11	229	2.7	3.8	1350	660	131
Tuthill	7.6	3.75	204	2.6	5.2	462	420	125
Transplant	6	3.51	271	1.5	31	538	360	100
Digestate	6.3	7.03	416	244	56	1069	720	67
FWH	8.9	5.15	6	4.1	27.7	1386	660	56
FWW	6.5	12.89	904	6.5	123.5	2357	1500	247

FWV = "Food Waste Vermicompost"; FWH = "Food Waste Hot compost." Analysis performed by Michigan State University Soil and Plant Nutrient Laboratory.

Among the composts included in this study, there are two pairs that highlight the degree to which small differences in compost production can affect the physical and chemical properties of the finished composts and the green roof substrates in which they are included. The FWV and FWH composts were both produced using post-consumer food waste from a MSU dining hall. The FWV compost was processed using worms and the FWH compost was processed using a traditional hot composting technique with turned piles. The concentration of every measured soluble nutrient was considerably greater in the FWV compost and the pH of the FWV was slightly acidic while the pH of the FWH was basic. The saturated hydraulic conductivity of the substrate made from the FWH compost was three times greater than the substrate made from the FWV compost.

The Transplant and Digestate composts were even more similar to each other than the FWH and FWV composts. The feedstocks, environmental conditions, handling practices, and decomposition methods were identical. The two composts differed only by the addition of the liquid digestate of an anaerobic digester to the Digestate compost during the decomposition phase. The substrates made from these composts differed in every measured category. Based on the physical measurements, the Digestate substrate was most similar to the Granger substrate, despite the fact that the Granger compost was produced from a different feedstock, in a different location, with different post-production handling procedures.

Plant growth and development. Significant differences were observed in basil fresh harvest weight and dry shoot mass in bristleleaf sedge and sedum. One-way ANOVA also detected differences in sedum root masses, but not in bristleleaf sedge. Post-hoc pairwise comparisons revealed significant differences between the Transplant treatment, which had the lowest mean root mass, and the two treatments with the greatest mean root masses, FWV and FWH. There was nearly two fold difference in dry biomass production among compost treatments for all three species included in the study. Growth rates for basil varied by a factor of 2.6 and those of bristleleaf sedge by a factor of 1.5 (Table 4). These results suggest that compost selection can have a strong effect on the initial establishment of a green roof, both in terms of the size of plants and the area which they cover. Furthermore, compost selection could make the difference between having poor plant establishment, achieving desirable plant coverage, and producing a vegetative layer that is overly susceptible to drought stress.

Table 4. Effect of Compost Selection on Plant Growth Rates

Compost Type	Basil	Sedge	Sedum
FWW	3542.4 a	1975.1 ab	282.58 a
FWH	3955.3 a	2300.5 a	311.20 a
Transplant	1504.9 c	1949.2 ab	163.43 b
Digestate	3251.6 ab	2243.7 a	229.95 ab
Tuthill	1499.2 c	2017.9 ab	216.76 ab
Granger	1640.0 bc	1571.7 b	230.05 ab

Plant dimensions were taken every 2 weeks over a 98-day period. Values are reported as the change in plant volume ($cm^3 \cdot day^{-1}$) on a per tray basis. FWV = "Food Waste Vermicompost"; FWH = "Food Waste Hot compost." Values in the same row sharing a letter were found to be statistically similar using Fischer's LSD at α=0.05.

Water quality of runoff. There were significant differences in nitrate mass on day 21 within basil, bristleleaf sedge, and sedum, however no differences were observed at days 93 and 165. There were no significant differences in ammonium mass on any of the dates sampled. Significant differences in phosphorous mass were detected on all dates for all species except bristleleaf sedge on day 165. Initially among all treatments, nitrate mass ranged from 9.05 to 652 mg per tray, phosphorous from 0.61 to 8.99 mg, and ammonium from 0.41 to 1.04 mg. By day 165, the ranges had dropped from 0.06 to 1.71 mg for nitrate, from 0 to 0.52 mg for phosphorous, and from 0.02 to 0.15 mg for ammonium. The FWV treatments had substantially higher initial values than other compost treatments for both nitrate and phosphorous ions for all three species. Similar results were found for nitrate, ammonia, and phosphorus concentrations.

Initial nutrient concentrations within a given species varied from 311 to 645 ppm for nitrate and from 6.5 to 8.2 ppm for P. The interpretation of runoff water analyses is complicated by a lack of water quality standards specifically regulating green roof construction and maintenance. However, these numbers can be compared to established water quality standards. Published concentration limits for inorganic nitrogen and phosphorous include the US EPA Drinking Water Standards (≤ 5 ppm N, ≤ 5 ppm P), the US EPA Freshwater Standards for rivers and streams (≤ 2.18 ppm N, ≤ 0.076 ppm P), and the Michigan Department of Environmental Quality Groundwater Discharge Standards (≤ 10 ppm N).

Initial concentrations of nitrogen in all treatments exceeded all of the relevant limits except for US EPA Drinking Water. Only one treatment, basil growing in the Tuthill compost (8.23 ppm) was below the limit. By day 93, nitrate concentrations of several treatments had fallen within the acceptable ranges of multiple water standards and compliance increased significantly by day 165. All relevant standards were satisfied within sedum treatments by all but the vermicompost treatment. Within the bristleleaf sedge treatments, all treatments met groundwater discharge and drinking water standards and four of the six treatments were within acceptable ranges for the freshwater standard. Regarding phosphorus, all treatments exceeded the acceptable level for freshwater rivers and streams by at least an order of magnitude throughout the entire course of the study. However, all of the compost treatments, except the vermicompost treatment, were within the allotted range for groundwater discharge for all measured runoff events. The vermicompost treatments exceeded the groundwater standard initially, but were below the limit on days 93 and 165.

In this study there was a decreasing trend in nutrient concentrations relative to roof age, an observation that agrees with the results of multiple green roof runoff studies with respect to the age of the roofs. This trend is likely a result of younger roofs having a greater pool of soluble compounds from the substrate components that gradually reach a state of equilibrium after repeatedly being leeched by precipitation events. If this is the case, then the impact of compost selection on runoff water quality would be most pronounced during the establishment of the roof and would diminish with time.

Impacts

Compost is often handled as a generic material with little attention paid to its variability or quality. Information gained from this project provides scientific data regarding selection of compost to optimize substrate performance which has immediate applications in the green roof industry. Information gained will be presented at scientific and industry meetings; included in future ASTM standards; and in Green Roofs for Healthy Cities educational products and industry certification courses. Michigan is home to many compost producers, substrate suppliers, plant producers, and green roof companies that will benefit from our results. The potential impact for green roofs is outstanding considering that the potential market consists of all existing and future buildings and the people involved are the growers of nursery crops, substrate suppliers, and landscape contractors that will install and maintain these roofs.

Other funding or contributions related to project

Donations of various compost mixtures from Granger LLC, Lansing MI; Tuthill Farms and Composting, South Lyon MI; and the MSU Student Organic Farm.

Publications/ outreach activities related to project

Matlock, Jason. 2015. Evaluation of recycled materials and composts for use in green roof substrates. MS Thesis, Michigan State University, East Lansing.

Rowe, D.B. and J.M. Matlock. 2015. Compost selection influences green roof performance. Proc. of 13th North American Green Roof Conference: Cities Alive, New York, NY.

Matlock, J. and D.B. Rowe. Impact of compost selection on green roof substrate performance (Peer reviewed manuscript in preparation).