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Composting Animal Mortality Removed From Roads: A Pilot Study of Rotary Drum and Forced Aeration Compost Vessels

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16. Abstract:

The Virginia Department of Transportation (VDOT) removes an estimated 55,000 deer carcasses from its roadways each year at a cost of more than $4 million per year. Many VDOT maintenance facilities have a need for viable, environmentally compliant, and cost-effective carcass management strategies. Disposal challenges include a decreasing availability of conventional disposal methods, such as landfills, and a lack of viable burial areas. The purpose of this study was to evaluate two in-vessel composting systems to determine the utility of each as a carcass management option for VDOT. The systems were a rotary drum system and a forced aeration bin system (forced air system). Pilot projects were conducted to determine the utility of each system based on two factors: (1) whether the generated compost met a set of established composting criteria, including regulatory standards; and (2) whether the system performed well from an operational standpoint.

A rotary drum system was installed at a VDOT maintenance facility and monitored for 163 days. The generated compost met the established pathogen destruction criteria but was inconsistent with regard to meeting the temperature and moisture criteria. The operational performance of the system was also inconsistent. The problems encountered may be preventable in future installations, but the system requires further evaluation to determine its utility as a means of animal mortality management for VDOT. It is recommended that VDOT install a smaller rotary drum system at a selected maintenance facility and evaluate its performance when the lessons learned described in this study are applied.

A forced air system was installed at another VDOT maintenance facility and monitored for 274 days. The generated compost met all established compost criteria (i.e., temperature, compost maturity, and pathogen destruction), and the system performed well from an operational standpoint. This system is a useful means of animal mortality management for VDOT. It is recommended that VDOT install several additional forced air system units at maintenance areas interested in this method of composting.

When the savings in disposal fees and travel costs from composting mortalities in a compost vessel rather than disposing of them at a facility are taken into account, the initial investment in a compost vessel would be offset in less than 5 years for maintenance facilities with particularly long drives to a disposal facility (25 to 40 miles). This study will be followed by an in-depth study to evaluate the economics and logistics of in-vessel composting to complete the feasibility analysis of this method of animal mortality management for VDOT. A composting guidance document will also be prepared to support the implementation of animal mortality composting at VDOT maintenance facilities.

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FINAL REPORT

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ABSTRACT

The Virginia Department of Transportation (VDOT) removes an estimated 55,000 deer carcasses from its roadways each year at a cost of more than $4 million per year. Many VDOT maintenance facilities have a need for viable, environmentally compliant, and cost-effective carcass management strategies. Disposal challenges include a decreasing availability of conventional disposal methods, such as landfills, and a lack of viable burial areas. The purpose of this study was to evaluate two in-vessel composting systems to determine the utility of each as a carcass management option for VDOT. The systems were a rotary drum system and a forced aeration bin system (forced air system). Pilot projects were conducted to determine the utility of each system based on two factors: (1) whether the generated compost met a set of established composting criteria, including regulatory standards; and (2) whether the system performed well from an operational standpoint.

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When the savings in disposal fees and travel costs from composting mortalities in a compost vessel rather than disposing of them at a facility are taken into account, the initial investment in a compost vessel would be offset in less than 5 years for maintenance facilities with particularly long drives to a disposal facility (25 to 40 miles). This study will be followed by an in-depth study to evaluate the economics and logistics of in-vessel composting to complete the feasibility analysis of this method of animal mortality management for VDOT. A composting guidance document will also be prepared to support the implementation of animal mortality composting at VDOT maintenance facilities.

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INTRODUCTION

The Virginia Department of Transportation (VDOT) removes an estimated 55,000 deer carcasses from its roadways each year (Donaldson and Lafon, 2008). Disposal challenges facing VDOT include a decreasing availability of (or increasing restrictions on) conventional disposal methods such as landfills and a decreasing availability of viable burial areas. Composting has been identified as a potentially beneficial and efficient alternative animal mortality management option for VDOT (Donaldson and Moruza, 2010). Although composting livestock mortalities is a relatively common practice in the United States and worldwide (Arroyo-Rodriguez, 2009), composting animals removed from roads is less common among transportation agencies (Maryland State Highway Administration, 2005) and constitutes a needed area of research. Studies by Donaldson and Moruza (2010) and Donaldson et al. (2012) of the Virginia Center for Transportation Innovation and Research (VCTIR) found that static windrow composting can be a cost-effective and environmentally sound form of carcass management and can therefore serve as a valuable alternative for some VDOT maintenance facilities. Given the space requirements for composting large numbers of animals in windrows (described by Donaldson and Moruza [2010]), compost vessels may be more suitable options for maintenance facilities on smaller properties or in closer proximity to populated areas.

Vessels used for animal mortality composting vary widely in design and operation. A conventional method of in-vessel animal mortality composting comprises a bin with three sides, with one side open for access to loading, unloading, and turning the material. This type of bin composting requires that the material be turned periodically; the resulting introduction of air benefits the aerobic microbes responsible for decomposition and facilitates the composting process. This method has been described as successful by some departments of transportation (DOTs) such as the Ohio DOT (Arroyo-Rodriguez, 2009), but Donaldson and Moruza (2010) found that the capacity of the bins was insufficient in areas with large or increasing volumes of deer mortality to meet the disposal needs.

To increase aeration and speed the decomposition of the material, some in-vessel systems are designed to rotate (e.g., rotary drums) and others incorporate forced aeration pipes at the bottom of the containers. These systems are used to compost livestock mortality in some areas

(Kalbasi et al., 2006; Reuter et al., 2010), but they have not been discussed in the literature as a means of composting animal road mortalities. The management of animal mortality for DOTs can have unique challenges, including unpredictable mortality volumes and regulatory requirements for pathogen destruction and control of leachate (i.e., the water that percolates through and exits the compost). If in-vessel systems are determined effective and useful for a DOT, they can have environmental and cost benefits over the conventional disposal methods of landfill and burial (Donaldson and Moruza, 2010).

Because the Virginia Solid Waste Management Regulations (VSWMR) (Virginia Register of Regulations, 2011) include most animal mortalities as a Category IV solid waste, the composting of animals killed by vehicles must comply with the siting, construction, and testing requirements for solid waste composting. The Virginia Department of Environmental Quality is responsible for enforcing the VSWMR and authorizing composting permits. These regulations are largely intended to prevent the spread of pathogens and other contaminants and to prevent compost leachate from entering surface or groundwater. Some compost vessels, including those evaluated in this study, are designed to prevent leachate from entering the environment. Although leachate control is therefore less of a regulatory concern with regard to in-vessel composters, compost operators must nonetheless sample and test compost to demonstrate that it complies with attained finished compost standards (Virginia Register of Regulations, 2011). For operations producing less than 320 tons of compost per a 365-day period, compost must be tested a minimum of once per year for compost stability, parasites (i.e., helminth ova), bacterial pathogens (i.e., fecal coliform or *Salmonella* species), and metals. To be considered suitable for application, compost must also be tested to determine whether it is mature, stable, or “finished.” Because compost temperatures above ambient indicate that active composting is occurring, one method of determining whether compost is finished is a temperature decline to near ambient conditions following a period of high temperatures (120 °F+). Another method of determining compost maturity is a Solvita Compost Maturity Test (Virginia Register of Regulations, 2011), as described later in this report.

PURPOSE AND SCOPE

The purpose of this study was to evaluate two types of in-vessel composting systems to determine the utility of each as a means of animal mortality management for VDOT. The systems evaluated were a rotary drum system and a forced aeration bin system (hereinafter forced air system). Pilot projects were conducted to determine the utility of each system based on two factors: (1) whether the generated compost met a set of established composting criteria, including regulatory standards, and (2) whether the system performed well from an operational standpoint.

A rotary drum system was installed at a VDOT maintenance facility and monitored for 163 days, until the system was placed out of operation. A forced air system was installed at another VDOT maintenance facility and monitored for 274 days, until the end of the study period.

METHODS

The following tasks were carried out for each of the two systems to achieve the study objectives:

1. Assist the VDOT district or area headquarters (AHQ) staff with installation and operational logistics.

2. Collect composting data, and compare them with composting criteria, which were primarily established from composting regulations and vessel operating guidelines.

3. Document the performance of the system throughout the monitoring period, including mechanical and operational issues documented by operators and researchers.

4. Use the results of Tasks 2 and 3 to assess the system in terms of meeting composting criteria and performing well from an operational standpoint.

Installation and Operation

The VDOT AHQ selected for the study met the site conditions specified by the VSWMR (namely, 50-ft setback requirements from the property boundary and from regularly flowing streams and a 200-ft setback requirement from a residential property or public facility) (Virginia Register of Regulations, 2011). The Virginia Department of Environmental Quality was contacted for approval of this composting pilot study and was provided with site descriptions and detailed information about site and the compost vessels.

VDOT district and AHQ staff who would be involved in the operation of the systems were trained by representatives of the manufacturers of the systems. Training included operational aspects of the system and the steps required for successful composting.

Rotary Drum System

The rotary drum system was placed at the VDOT Salem District's Hanging Rock AHQ in Salem, Virginia (Figure 1). The Salem District requested the largest drum model to accommodate the large volume of animal mortality managed by the surrounding maintenance facilities. Six AHQ in three counties (Craig, Botetourt, and Roanoke) used the rotary drum system in the pilot project. These AHQ previously disposed of their animal mortalities at a landfill transfer station in Christiansburg, a round trip of up to approximately 150 miles.

The rotary drum acquired is the largest model constructed by the manufacturer; it is 66 ft in length and is constructed of noncorrosive polyethylene. The drum is insulated with polyethylene foam to enhance structural integrity and allow for composting in hot and cold weather. The drum has a volume of approximately 1,100 ft^3 and a daily capacity of 1,100 lb. It runs on electricity (220 V) and is equipped with a timer and a motor that allows for automatic rotation to mix and aerate the material. A typical rotation schedule is 4 times per operating day.

Figure 1. Rotary Drum System. There is a loading platform above the first door, and a second door is located near the center of the drum.

The drum also includes wireless temperature sensors (located inside the drum near each of two doors) and an aeration system. The aeration system comprises a blower that forces air into the drum to enhance aerobic decomposition and help maintain proper moisture levels. According to the vendor, leachate is not typically generated from the composting process (B. Irwin, personal communication).

To compost animal mortalities, carcasses and the cover material (i.e., processed woody material) should be loaded in equal volume through the first door (47 in by 33 in) located toward the front end of the vessel. A second door is near the center of the drum and is intended for "rebulking," or adding additional cover material as needed. Cover materials loaded into the drum should be as dry as possible; the vendor recommended against the use of freshly processed or "green" woodchips. Each rotation of the drum pushes the material 26 in toward the end of the drum, where it exits through an opening and falls onto the pavement below. Finished compost emerges 10 to 14 days after the material is loaded into the first door. Remaining bones, if any, can be reloaded into the unit. The vendor maintains that the final volume of finished compost is approximately one-third of the volume of the material that was loaded into the drum (B. Irwin, personal communication).

Standard maintenance requirements include greasing the bearings once a year and adding oil to a gear box that rotates the vessel. The drum has a 10-year warranty and an estimated life of 25 years (B. Irwin, personal communication).

Forced Air System

The forced air system was placed in VDOT's Lynchburg District's Bethel AHQ in Halifax County (Figure 2). Staff of all three AHQ in Halifax County brought their mortalities to this site for composting. Although the forced air system manufactured by the vendor is typically composed of three-sided concrete bins, the vendor agreed to fabricate a less permanent structure so the system could be used on a trial basis if necessary.

The aeration system comprises three customized steel open-top rolloff containers placed on a concrete pad 35 ft by 50 ft. Each container measures 8 ft by 16 ft by 6 ft and has a capacity of 10,000 lb (28 yd^3). Tin roofs were constructed above each container to block precipitation. Four stainless steel aeration tubes line the bottom of each container to provide consistent and even air distribution throughout the container. A semi-watertight steel door provides access for loading and unloading the material. A regenerative air blower and timer are attached to the back wall of one of the containers; a flexible hose is connected from the blower to the other containers. The timer is set to activate the air blower every 1 hour for 15 minutes; the forced air enhances the decomposition process by providing oxygen to the aerobic microorganisms responsible for decomposition. The front end of the container includes a 16-in drainage trench for the collection and conveyance of leachate from the floor to a leachate holding tank, where a biological treatment tube provides continual leachate aeration and treatment. An electric sewage pump mounted in the holding tank allows the operator to pump the leachate from the holding

Figure 2. Forced Air System and Its Components. Forced air system (*top left*); rolloff container with stainless steel aeration tubes (*top right*); air hole on side of aeration tube (*bottom left*); and leachate hose used to wet compost with leachate pumped from collection tank (*bottom right*).

tank through a hose back onto the compost material in the containers (Figure 2). Spraying the leachate onto the material returns the microorganisms responsible for material decomposition and maintains a moist environment that is essential for their survival. The vendor recommended wetting the compost with this leachate approximately 3 times per week (K. Warren, personal communication).

A skid steer with a bucket attachment is used to load mortalities and cover material, starting in the back of the container and working toward the front door. The vendor-recommended cover material to start the system is a 1:1 mix of poultry litter (which contains microorganisms that facilitate the composting process) and sawdust, although wood shavings or woodchips can also be used (K. Warren, personal communication). The three containers are used sequentially; once one container is full and has been composting a sufficient length of time for tissue breakdown, that compost can be used as the cover material in another container. Installation for the conventional aerated concrete containers typically includes the construction of an additional area for storing compost once it has been removed from a container in order to provide space for new mortalities. This storage site serves as a place for compost either to "finish" or to be drawn from for use as cover material for new mortalities. The temporary rolloff container system installed for this pilot project did not include a storage site.

Standard maintenance requirements include checking for clogged air holes each time the container is emptied and activating the air blowers to free any trapped material. The temporary rolloff containers have an estimated life of 7 years. The conventional concrete aeration bin system has an estimated life of 30 years (K. Warren, personal communication).

Data Collection and Tests Conducted

Data Collected and Compost Criteria Established

Compost data for each system were collected and compared with compost criteria to determine whether conditions for effective composting were achieved. Table 1 lists the data collected for each compost system and the criteria established; a notation is included for each criterion that explains the rationale for its use. Data collection methods differed slightly by compost system. Criteria included particular ranges or limits for compost temperature, moisture (for the rotary drum only), compost maturity (for the forced air system only), and pathogen density or presence. VDOT staff working with each compost unit were provided with a log book to record daily operational details, such as the date and number of mortality that was added, the species loaded, and the compost temperature (see the Appendix).

Temperature and Moisture

For the rotary drum, compost temperatures were recorded by two built-in temperature sensors and were documented in the log book on weekdays between 7:00 A.M. and 8:00 A.M. and between 3:00 P.M. and 3:30 P.M. Because the effectiveness of composting with the rotary drum is largely dependent on the moisture of the material, the moisture content of the compost was also recorded at the time of temperature recording. Although federal compost regulations

Table 1. Compost Data Collection and Compost Criteria

Compost Parameter	Data Recording or Collection Method and *Data Collector*	Data Collection Frequency		Compost Criteria
		Rotary Drum System	Forced Air System	
Date, number, and species of mortality added; compost temperature	Log book; *VDOT operators*	Mortality loading events	Mortality loading events	NA
Compost temperature	Temperature sensors (on rotary drum only); *VDOT operators*	Twice per weekday, 7-8 A.M. and 3-3:30 P.M.	NA	A.M. and P.M. temperatures remain minimum of 127 °F for 5 days or minimum of 131 °F for 3 days[a]
	Temperature data loggers (forced air system only); *researchers*	NA: Impractical for use in rotary drum given continuously moving nature of material	Every 60 min for 35 to 240 days, varied by cover material	Each 60-min temperature reading remains minimum of 127 °F for 5 days or minimum of 131 °F for 3 days[a]
Moisture content of compost	Moisture probe; *VDOT operators*	Twice per weekday	NA	40% to 60%[b]
Compost maturity index	Solvita compost maturity tester; *researchers*	NA: Solvita tester not acquired during period of drum operation	Samples of compost material of varying ages	Compost older than 6 months should have maturity index of 6 or more (on scale of 1-8)[c]
Pathogen concentration or density (i.e., helminth ova, *Salmonella*, and/or *E. coli*)	Compost sample collection; *researchers*	Collected samples of compost that exited drum on Days 73 and 179 of monitoring period	Samples of compost material from container at 14, 28, and 42 days of age	Below maximum threshold specified in Virginia regulations[d]
Metals concentrations		NA		

VDOT = Virginia Department of Transportation; NA = not applicable.
[a]Based on U.S. Environmental Protection Agency (2003) compost criteria for ensuring the destruction of indicator pathogens such as *Salmonella* and *E. coli*.
[b]Vendor-recommended moisture content to achieve optimum compost quality and performance of rotary drum (B. Irwin, personal communication).
[c]Criteria based on vendor's experience with and expectation for the forced air system (K. Warren, personal communication); no published standards available.
[d]Virginia Solid Waste Management Regulations (Virginia Register of Regulations, 2011).

require that temperatures consistently remain a minimum of 127 °F for 5 days or a minimum of 131 °F for 3 days to ensure pathogen destruction, it was not possible to monitor temperature continuously (with a device such as a data logger) given the continuously moving nature of the material. If 1 day's morning and afternoon temperature readings (documented 7 to 8 hours apart) recorded by the internal rotary drum sensors met the regulatory thresholds, it was assumed that these thresholds were met for the entire day. To read the moisture content, a moisture probe was inserted through the second door of the drum and placed in the center of the material.

For the forced air system, operators documented the probe's temperature reading in the log book after a loading event. Operators inserted the probe 2 ft deep into the compost and approximately 3 ft from the container wall. Researchers also recorded compost temperatures with temperature data loggers (HOBO Temperature Logger U23-004, Onset Computer Corporation). Data loggers were placed in the center of the uppermost layer, approximately 12 in deep and between two carcasses. A temperature logger was also placed 2 ft from the forced air containers to record ambient temperatures.

Compost Maturity

One of the indicators used to determine whether compost is mature and therefore suitable for application is a compost temperature decline to near ambient conditions (Virginia Register of Regulations, 2011). This testing option proved difficult for this pilot project because of limited options to store compost while continuously monitoring its temperature. Once compost exited the rotary drum, it was removed and disposed of to provide space for newly emerging compost; areas to store this compost for continual temperature monitoring purposes were unavailable at the maintenance facility.

With the forced air system, once the material composted for several weeks in the container, it was removed to provide space for new mortalities and used as a cover material for new mortalities in an adjacent container. Monitoring compost temperature long enough to note a temperature decline was limited to one pile of compost removed from a forced air system container after 31 days and set aside for 8 months for monitoring purposes. This compost was stored in a windrow formation on the ground near the containers. Because continual temperature monitoring was limited to this compost pile, another method of maturity testing was conducted on the compost generated from the forced air system. The Solvita Compost Maturity Test (Woods End Laboratories, Inc., Mount Vernon, Maine) is a widely recognized and validated test for compost stability (Brinton et al., 2012; Steger et al., 2007) and is one of the compost testing options listed in the VSWMR (Virginia Register of Regulations, 2011). The equipment measures carbon dioxide (CO_2) and ammonia (NH_3) emissions from compost to create a Compost Maturity Index. The index ranges from 1 to 8. A low index (1-5) indicates that the compost is actively degrading and therefore not yet suitable for most applications, and a high index (6-8) indicates that the compost is aged and ready for application (Woods End Laboratories, Inc., 2012). The rotary drum was no longer in operation when the Solvita tester was acquired.

The researchers established compost maturity criteria based on the vendor's expectation (K. Warren personal communication) that the forced air system should produce finished compost in less than 6 months, which is considerably faster than that produced by static windrow composting (whereby a passively aerated compost pile remains undisturbed for the duration of the composting process). A recent study (Donaldson et al., 2012) of static windrow deer mortality composting found that the compost was mature 10 to 11 months after windrow construction. Specifically, temperatures of two experimental windrows containing deer were statistically the same as temperatures of the control pile without deer 10 and 11 months after windrow construction. No other literature on animal mortality composting (windrow or vessel) was found that measured the time required to achieve finished compost. The criterion therefore established with regard to compost maturity was that compost from the forced air system that is older than 6 months should have a maturity index of 6 or more. Maturity tests were conducted on compost from the forced air system on samples ranging from 1, 2½, 3, and 8 months of age.

Because the compost in the forced air containers was routinely removed by 3 months of age for use as cover material for new mortalities in another container, compost between 4 and 7 months of age was unavailable for sampling. Samples of compost that were 3 months of age and younger were available for collection and testing before the compost was removed for use as cover material in another container. Testing more mature compost was limited to the pile of 8-month-old compost set aside for monitoring purposes. For all Solvita testing conducted, composite samples were obtained by removing three samples of material, each from a varying depth ranging from 6 in to 24 in below the surface and approximately 4 ft from the edge, and combining the samples into containers included in the Solvita testing kit. The researchers tested the compost in accordance with the manual supplied in the testing kit (Woods End Laboratories, Inc., 2012).

Pathogens and Metals

Tests for pathogens and metals were based on those specified in the VSWMR, and the results were compared with regulatory limits (Virginia Register of Regulations, 2011). For each sampling event for the rotary drum and the forced air system, composite compost samples were obtained by removing three samples of material. Samples from the rotary drum were collected from the compost immediately after it exited the rotary drum (after fully cycling through the drum). Samples from the forced air container were collected from varying depths in the container contents in order to have a representative sample of at least one layer of material. Sample depths ranged from 6 in to 24 in below the surface, approximately 4 ft from the container edge. All samples were combined into a quart-sized freezer bag, packed on ice, and shipped overnight to a laboratory operated by the Virginia Department of Agriculture and Consumer Services. Compost samples were analyzed for the presence of parasites (i.e., helminth ova) and bacterial pathogens (i.e., fecal coliform or *Salmonella* species). All results were reported per dry weight and compared with Virginia composting regulations (Virginia Register of Regulations, 2011).

Compost samples from only the forced air system were analyzed for metals in order to verify the findings in the literature that high concentrations of metals are not typical in organic material composting (Cole, 1994; Peigne and Girardin, 2004; Warman and Termeer, 1996). Compost samples were packed on ice and shipped overnight to Schneider Laboratories, Inc. Metals tested included arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc. Sample results were compared with Virginia composting regulations (Virginia Register of Regulations, 2011).

Additional Tests of Forced Air System

Additional tests were conducted to test the effectiveness of the forced air system at handling the variety of mortality volumes and cover materials available throughout VDOT maintenance facilities. Although the forced air system allowed for experimentation with cover materials, it was apparent from the vendor training that the rotary drum is sensitive to moisture levels and would thereby give little room for experimentation with the cover materials used. For the forced air system, the cover materials used included (1) a poultry litter and sawdust mix; (2) compost material removed from another container, often mixed with woodchips or sawdust; and

(3) woodchips only (collected and chipped within 3 months prior to use). The vendor maintained that the use of young compost material (as young as 6 weeks) removed from another container could expedite the degradation of new mortalities, as it is high in temperature and contains a high concentration of microorganisms. Using the methods previously described, the researchers monitored the temperature and determined the maturity of the compost comprising varying cover materials. The data loggers remained until the material composted was relocated to another container for use as cover material. For the first two materials (i.e., the litter/sawdust mix and the compost), the loggers remained for 35 and 92 days, respectively, before the material was moved into another container. Temperature loggers remained in the material composed of woodchips for longer (240 days). As described previously, after the woodchips compost remained in the container for 31 days, the material was removed from the container to provide space for new mortalities. The material was piled on the ground into a windrow formation so that the material could continue to be monitored until the end of the study.

Another test was conducted in an effort to test the effectiveness of the forced air system in handling a large number of mortalities at one time. The monitoring period did not include the late fall deer breeding season (commonly referred to as the “rut”), when more deer movement corresponds to an annual peak of deer-vehicle collisions and associated high volumes of deer mortality (Virginia Department of Game and Inland Fisheries, 2006). A “rut simulation” was therefore conducted to determine whether loading a relatively high volume of mortality at one time would affect the performance of the forced air system. For the rut simulation, 60 animals (approximately 90%, or 54, deer and 10% a variety of smaller species) were loaded into one of the three containers, with the compost from an adjacent full container used as the cover material between mortality layers. A temperature data logger was placed in the center of this material, where it remained for 240 days.

Compost Vessel Performance and Observations

Mechanical and operational aspects of the compost vessel were documented (at no specific intervals) throughout the operating period. VDOT staff directly involved with loading and operating the compost vessels were communicated with regularly. Discussions included the general condition of the compost (i.e., whether tissues or bones remained), whether an offensive odor was detected, problems encountered, and the operators’ overall assessment of the compost vessel.

Suitability of Compost Vessel for VDOT

Information gained from the previous tasks was used to determine the suitability of each system as an animal mortality management option for VDOT. Overall ratings of the compost system in terms of meeting each of the established compost criteria and a determination of whether the system performed well were generalized to “always, sometimes, seldom, or never.” Although the ratings with regard to meeting the compost criteria were based on quantitative data, the performance rating was largely based on a qualitative assessment, using a combination of the system’s physical operating performance and the subjective judgments of the primary VDOT operators.

RESULTS AND DISCUSSION

Rotary Drum System

Operation

Following installation of the rotary drum system, the vendor held a training session for VDOT operators. The training included various aspects of instruction on the operation and maintenance of the rotary drum. Given the anticipated volume of animal mortality to be composted, the vendor instructed the operators to set the rotation schedule to four times per day for weekdays and one turn per day for weekends (when no loading events occurred). Following a period of low compost temperatures, the vendor recommended setting the number of rotations to three per day for weekdays and two per day for weekends (B. Irwin, personal communication).

The first cover material used in the rotary drum was store-bought kiln-dried woodchips. Because of the high cost of this material, the operators reverted to wood shavings acquired from a local furniture manufacturer at no cost to VDOT. For loads of more than two deer (or a rough equivalent volume of other species), the vendor encouraged the operators to separate the load into two sessions: morning and afternoon (B. Irwin, personal communication). Because VDOT's end use options for compost were not yet established and granted regulatory approval, compost that exited the drum was taken to a landfill. Each loading event was conducted by two operators and took approximately 20 to 30 minutes. One operator operated the front loader, and the other guided the mortality and cover material from the bucket into the drum.

The rotary drum was in use (discontinuously) over a period of 5½ months (163 days), from June 8 through November 19, 2010. During that period, the drum was operational (i.e., actively rotating and composting mortalities) for 143 days. The drum was not in use for two 10-day periods as a result of mechanical problems and difficulties meeting temperature and moisture criteria, as explained further later.

Data Collection

Log Book Records

The rotary drum was monitored throughout the 163-day period of its use. A total of 306 animal mortalities were composted, 209 (68%) of which were deer (Table 2). Other species included 2 or more of each the following: groundhog, dog, cat, turtle, raccoon, fox, and rabbit.

Table 2. Animal Mortalities Recorded in Log Book for Rotary Drum

Month	Deer	Other	Total
June (8-30)	56	30	86
July[a]	6	0	6
August	37	31	68
September[a]	31	23	54
October	60	14	74
November (1-19)	19	0	19
Total	209	97	306

[a]Operation discontinued for 10 days because of mechanical problems.

One cow and 1 bear were also composted. A single loading event ranged from 1 to 9 deer with up to 4 smaller species.

Temperature and Moisture

Figure 3 illustrates the maximum daily compost temperature and the moisture content recorded by two fixed thermometers and a moisture probe. Morning and afternoon temperatures were recorded on weekdays during the drum's operating period; the absence of temperature data indicates periods the drum was temporarily out of operation or days the operators were unable to document temperature because of competing priorities. Moisture content was not measured the first 2 weeks of operation because of a delayed acquisition of the temperature probe. Although the dark band above 127 °F in Figure 3 reflects the minimum temperature specified in federal composting regulations (U.S. Environmental Protection Agency, 2003), *Salmonella* and *E. coli* are unlikely to survive in compost with temperatures as low as 122 °F that are sustained over a period of several days to 2 weeks (Schwarz et al., 2006). The criteria established for the study, however, were based on the current federal composting regulations.

As described previously, if a day's morning and afternoon temperatures met the minimum regulatory standards, the researchers assumed that temperatures met these standards for the entire day. Of the 94 days that temperatures were recorded over the drum's span of operation, the morning and afternoon temperatures were above 127 °F on 56 days (60%). More important, the maintenance of these temperatures for a sufficient duration to achieve pathogen

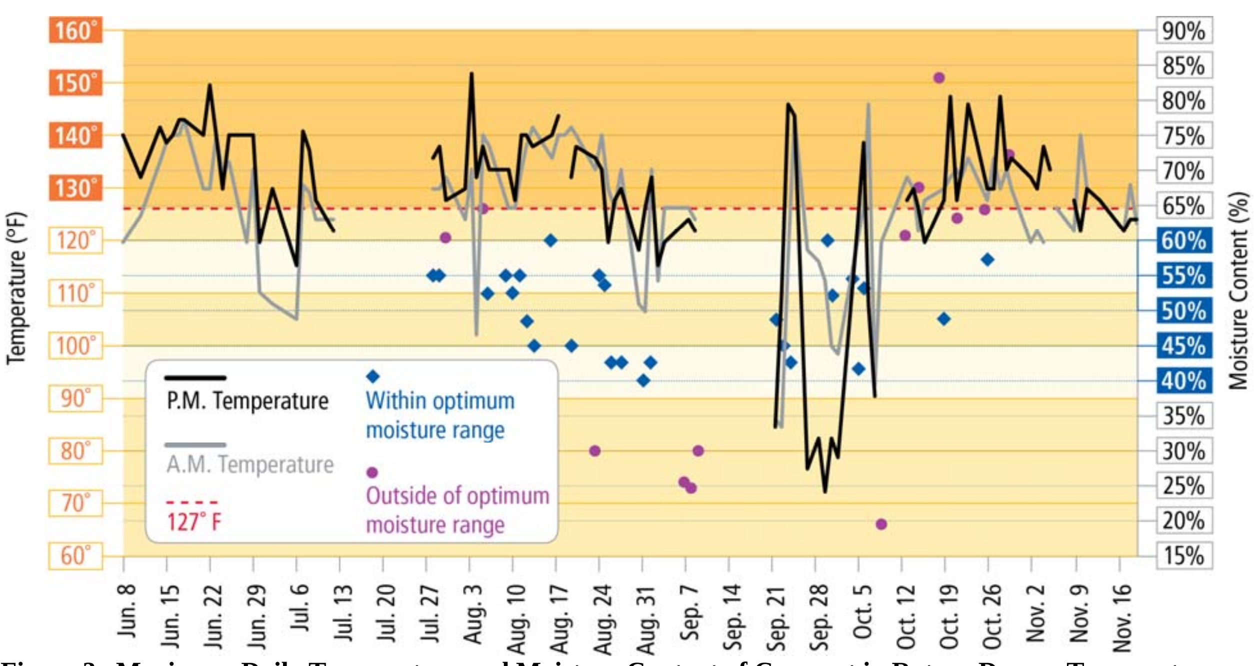

Figure 3. Maximum Daily Temperature and Moisture Content of Compost in Rotary Drum. Temperatures within the dark band meet the federal minimum composting temperature requirement (U.S. Environmental Protection Agency, 2003). The absence of temperature data indicates periods of up to 10 days that the unit was not in operation.

temperature readings were within a consecutive 5- or 3-day grouping that remained above 127 °F or 131 °F, respectively. Moisture content was within the optimal range (40% to 60%) for 26 of the 39 readings (64%).

Pathogen Tests

Table 3 includes the results of pathogen analyses of samples of compost that exited the drum after a full cycle (i.e., 10 to 14 days). The first test was conducted on August 19 (Table 3, Sample A) after temperatures consistently remained above 127 °F. The second test was conducted on October 5 (Table 3, Sample B) following low but increasing temperatures (Figure 3). For both analyses of compost samples, no *Salmonella* or roundworm (i.e., helminth) ova were detected, and fecal coliform concentrations were well below the maximum concentration specified by the VSWMR (Virginia Register of Regulations, 2011).

Table 3. Pathogen Concentrations in Samples of Compost That Exited Rotary Drum

Pathogen	Sample A	Sample B	Regulatory Standards[a]
Salmonella or Fecal coliform (as *E. coli*)	None 33 MPN/g	None 34 MPN/g	*Salmonella*: Less than 3 MPN per 4 grams of total solids (dry weight basis) or Fecal coliform: Median of all samples shall be less than 1000 MPN per gram of total solids (dry weight basis)
Helminth ova (as Ascarid)	None	None	Less than 1 ovum per 4 grams of total solids (dry weight basis)

MPN = Most Probable Number.
[a]Virginia Solid Waste Management Regulations (Virginia Register of Regulations, 2011).

Performance

The compost that exited the drum had an appearance similar to that of the cover material added at the time the mortalities were loaded (kiln-dried woodchips or wood shavings), and the mortality appeared fully broken down with few remaining bones. Although the odor level was not regularly documented in the log book by the operators, a primary operator maintained that the odor level was typically minimal except when drum temperatures remained low, at which point the primary operator noticed occasional periods of moderate to strong odor.

The unit was stopped on two occasions during the monitoring period, each for a period of 10 days, as a result of mechanical problems, consistently low compost temperatures (i.e., <127 °F), and/or a consistently high moisture content (>60%). After an attempt to restart the drum and achieve high temperatures failed in early December, the drum was taken out of operation permanently at this location. Table 4 describes the problems encountered and the lessons learned. Because compost conditions can affect the operational performance of the drum, difficulties achieving optimum temperature and moisture levels are also included in Table 4.

Table 4. Problems Encountered and Lessons Learned During Rotary Drum Monitoring Period

Problem Encountered	No. of Occasions	Solution	Lesson Learned
Operational/Performance			
Difficult to load animals carefully from loading bucket through drum loading door.	Several	Built platform (see Figure 1) above drum for workers to guide mortality safely from loading bucket through drum door.	Prepare structure and equipment requirements prior to beginning operation.
Drum rotation settings adjusted incorrectly by operators.	1	Readjusted settings.	Lock settings box and designate a trained operator to control settings and oversee loading events.
Drum expanded and contracted with drastic temperature changes inside drum, resulting in broken equipment (i.e., chain that controls rotation and equipment associated with blower hose).	3	Repaired equipment with assistance from vendor.	Maintain as consistent an internal drum temperature as possible.
Leachate accumulated in blower hose.	Most operating days	Regularly emptied liquid from blower hose.	Empty liquid from blower hose as needed. Add more cover material with each loading event to avoid excess moisture accumulation.
Material in drum did not move toward exit, resulting in clogged motor fan and blower hose.	1	Cleaned out drum.	High moisture content slows movement of material. Add dry cover material to decrease moisture content.
Drum could not accommodate all mortalities picked up in areas designated for rotary drum.	Numerous	Disposed of extra mortalities at landfill.	Designate an area (pad or container) to store mortalities with cover material until they can be loaded in drum. To increase driving efficiency and prevent exceeding drum's capacity, consider use of smaller drums in more areas, particularly areas with high mortality volumes.
Difficult to achieve high compost temperatures when re-starting drum in cold ambient temperatures.	1	Discontinued drum operation.	Avoid re-starting drum in freezing temperatures or with frozen mortalities. Consider temporarily reverting to landfill disposal each winter when mortalities are low or keeping drum under shelter with less exposure to freezing conditions.
Compost			
Low temperatures (<127 °F)	38 of 94 days (40%)	Decreased mortality volume loaded at once.	For loads greater than 2 deer or equivalent mortality volume, split day's load into 2 events.
High moisture content (>60%)	13 of 39 days (33%)	Added more wood shavings. Consistently recorded volume of cover material added with mortalities.	Add cover material before loading mortality when moisture content is high and/or temperatures are low. Use at least 1full loading bucket per mortality load or as much cover material as space in drum allows.

[a]The number of occasions was not consistently documented for all problems encountered.

As described in Table 4, one of the mechanical difficulties (i.e., the material not moving toward the exit) was associated with high moisture content. Moisture became problematic when high temperatures were not achieved and sustained. This was often a result of high mortality loading volumes and/or low cover material loading volumes. After a period of low temperatures and high moisture, restoring proper temperature and moisture took up to 1 week.

After the first 6 weeks of operation, staff of the Salem District and the researchers held a conference call with the rotary drum vendors to seek solutions to the problems encountered (namely, temperatures below 127 °F and moisture content above 60%). In response, the vendors reiterated the importance of separating the day's load into two loading events, adding cover material to the drum before adding the mortality, and using only trained operators to oversee loading events. Sufficient temperature and moisture content were sporadically achieved over the following months of operation. Throughout the operating period, compost temperatures above 131 °F were maintained for 3 or more consecutive days on 10 occasions. Of these occasions, temperatures were above this threshold for an average of 5½ consecutive days before they dropped. The use of the rotary drum was permanently discontinued after an attempt to restart the unit in freezing temperatures failed.

District staff and the researchers discussed measures that would have maximized the efficiency of the carcass management process at this location. Originally, the rotary drum was intended to compost animal road mortalities from the three surrounding counties in the Salem District, but on several occasions after the drum's daily capacity was met, operators had to take the remaining day's load to the landfill. One operator recommended placing smaller drums throughout areas of high animal mortality volumes to increase driving efficiency and help prevent exceeding a drum's capacity. A smaller drum used by fewer maintenance facilities would also likely have decreased the severity of some of the problems encountered. It was also suggested by a member of the Salem District staff that having two smaller drums at *one* maintenance facility might be beneficial, as this would allow for (1) any unfinished material (i.e., remaining bones) to be processed in the other drum, and (2) composting to continue if temporary problems were encountered with just one of the drums. In addition, decreasing the number of large loading events would help maintain optimum compost moisture levels; excess mortalities could be stored on site between layers of cover material. To avoid difficulties starting the drum in freezing ambient temperatures, a member of the Salem District staff suggested storing the drum indoors or otherwise sheltering it from freezing temperatures. Conversely, as suggested by a member of the Salem District staff, operators could consider temporarily discontinuing the drum's operation each winter when mortalities were low and restarting the drum in the spring (J. Butler, personal communication).

Overall Assessment of Rotary Drum

As reflected in Table 5, the rotary drum did not consistently perform well from an operational standpoint. However, the pathogen concentration or density criterion was consistently met (100%) and the moisture criterion was met for the majority of the readings (64%). The temperature criterion (whereby high temperatures were sustained for a sufficient duration to destroy pathogens) (Virginia Register of Regulations, 2011) was met 43% of the days temperature was recorded. Despite the difficulties encountered, it was concluded among the

Table 5. Summary of Rotary Drum Compost and Performance Assessment

Question	Assessment			
	Always	**Sometimes**	**Seldom**	**Never**
Were compost criteria met?				
Compost temperature		X		
Pathogen destruction	X			
Moisture content		X		
Did the system perform well?		X		

primary operators and researchers that the problems could be prevented and/or corrected by applying the lessons learned (Table 4).

The drum performed optimally when the recommended capacity was not exceeded. Given the regular peaks in deer mortality volume each fall and the capacity limitations of the rotary drum, the plan and approach for the use of a drum are particularly important. Although the vendor maintained that the drum's recommended capacity can occasionally be exceeded, doing so requires decreasing the loading volume for several days until sufficient temperatures are attained. For successful drum operation, it would be necessary for operators to be mindful of the drum's capacity limit and designate a separate storage area for mortality to be layered between cover material and/or prepare for an alternate means of disposal once the capacity of the drum or storage area was reached. Maintaining precise log book records is also critical to meeting compost criteria and resolving problems encountered. In addition, as noted in Table 4, the use of smaller drums placed in strategic areas would likely decrease driving time and help minimize exceeding a drum's capacity.

Compared with the forced air system, the primary benefits of the rotary drum include the following:

- its speed in mortality composting (10 to 14 days, not including reloading any remaining bones)
- its smaller footprint, particularly if a smaller drum were acquired
- the availability of smaller capacity rotating drums and their lower cost (approximately one-half the cost of a forced air system)
- its suitability for maintenance facilities with lower mortality volumes (i.e., a forced air system provides more space than necessary for facilities that receive relatively low mortality volumes).

Given these potential advantages and the mixed results of the overall assessment (Table 5), the utility of the rotary drum as a mortality management option for VDOT is inconclusive. Plans are underway to modify the existing drum into a smaller unit with approximately one-half the capacity for use by a single maintenance facility. The drum's operators plan to incorporate the lessons learned from this study, and the drum will continue to be monitored and evaluated to determine its effectiveness.

Forced Air System

Operation

The vendor of the forced air system trained the eight AHQ operators on proper operation and maintenance. The vendor instructed the operators to load the mortality in one container at a time until the container was full. Mortalities were to be placed in a container with the use of a skid steer and enveloped with the cover material on the day they were removed from the road. The vendor-recommended layering method included the following: 12 in of sawdust on the floor, followed by deer (or other animal mortality) placed back to back, followed by a 6-in layer of cover material. Layering was to continue with mortalities placed between the cover material, ensuring that mortalities were fully surrounded and that cover material separated the mortality and the container walls (K. Warren, personal communication).

The first loading event in the forced air containers occurred on February 1, 2012. The AHQ supervisor trained the AHQ operators on how to load mortalities and cover material. Approximately 3 times per week, the contents of each container were watered for 5 to 6 minutes with leachate pumped from the collection tank. Large numbers of mortalities (e.g., 10 deer) took one operator approximately 1 hour to layer in a container and surround with cover material. The system remains in operation at the Bethel AHQ.

Data Collection

Log Book Records

The forced air system was monitored for 9 months (274 days), from February 1 through October 31, 2012. Log book records indicate that a total of 366 animal mortalities were composted. Of these, 251 (69%) were deer (Table 6). However, a primary operator suspected additional mortalities were loaded and not recorded in the log book. Other than deer, species loaded in the containers included at least 2 of each of the following: groundhog, dog, cat, turtle, raccoon, fox, rabbit, skunk, coyote, vulture, opossum, muskrat, and otter. Two mules were also loaded in the containers. According to log book records, one container held up to 53 deer and 40 smaller species.

Table 6. Animal Mortalities Recorded in Log Book for Forced Air System

Month	Deer	Other	Total
February	21	16	37
March[a]	106	41	147
April	20	6	26
May	12	8	20
June	15	10	25
July	20	22	42
August	11	6	17
September	12	4	16
October	34	2	36
Total	251	115	366

[a]Includes mortalities loaded for rut simulation.

Temperature

Figure 4 illustrates the compost temperatures recorded by a temperature logger every 60 minutes for 35 to 240 days (depending on the cover material). Temperatures of compost with cover material consisting of the litter/sawdust mix and the woodchips were recorded for 35 and 92 days, respectively, until the material was moved for use as the cover material in another container. The contents of the container used for the rut simulation were monitored for 240 days (nearly 8 months); this material was relocated to the ground (in the form of a windrow) 31 days after the last carcass was added to the container in March so that monitoring of the temperature could be continued until its decline to near ambient conditions. As mentioned previously, installation of the conventional aerated concrete containers (as opposed to the rolloff containers used for this pilot project) includes the construction of an additional non-aerated area for storing compost once it has been removed from a container; this compost can either "finish" until it is suitable for application or be drawn from for use as cover material for new mortalities. Storing the rut simulation material in a non-aerated fashion simulated the storage of material in a designated storage area that is a standard component of the forced air system.

Sufficient temperatures for pathogen destruction (i.e., 127 °F for 5 days or 131 °F for 3 days) were maintained for all cover materials (the litter/sawdust mix, the compost material removed from another container, and the woodchips). Temperatures typically remained between 140 °F and 160 °F for several weeks. Temperatures fell below 127 °F temporarily as follows:

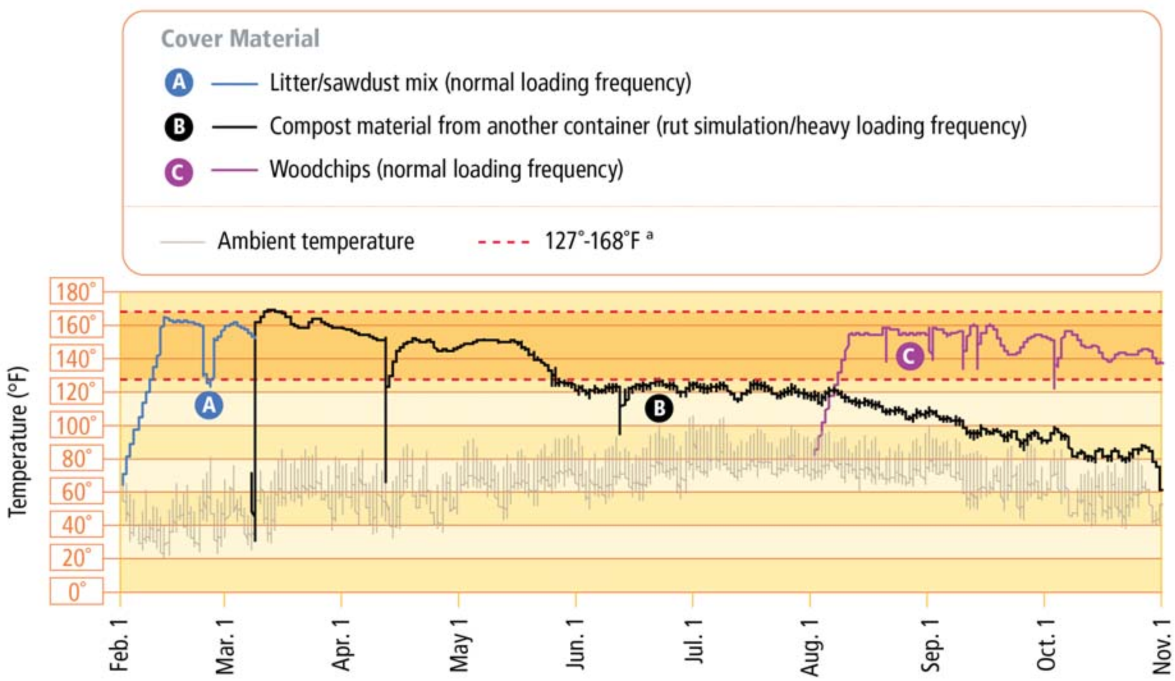

Figure 4. Compost Temperatures Recorded Hourly by Data Logger in Material Composted in Forced Air System. April 10, the rut simulation compost was relocated from the container to the ground, resulting in a temporary steep temperature drop. Steep temporary temperature drops of other compost material resulted from watering compost with leachate. [a]Temperatures above this range (i.e., above 168 °F) destroy beneficial microorganisms (J. Bonhotal, personal communication).

either (1) the first several days after a loading event, (2) during the movement of the rut simulation material from one location to another, or (3) immediately following watering the material with leachate.

The temperature rose steadily after a mortality loading event. It took approximately 7 days for the temperature of new compost (composed of the litter/sawdust mix or the woodchips) to rise above 127 °F. Because the rut simulation cover material consisted of active compost material removed from another container, the temperature rose above 127 °F in only 26 hours. As indicated in Figure 4, the temperature of the rut simulation material temporarily dropped when the material was relocated from the container to the ground in a windrow, but it quickly increased to levels that indicated the material continued to compost. After a 2½-month period of temperatures greater than 130 °F, the temperature of this material began a gradual descent toward ambient in mid-May, indicating an end of the active composting process. Although the rut simulation material was relocated and stored on the ground to provide space for new mortalities, leaving the material in the aerated container for longer than 31 days may have sped up the composting process and led to an earlier temperature decline.

Compost Stability

The criteria established for compost stability were met (i.e., a maturity index of 6 more for compost older than 6 months). Table 7 lists the results of the Solvita compost maturity tests conducted with equipment that measures CO_2 and NH_3 emissions from compost samples. The tests were conducted on compost samples (of four different ages) collected at the end of the study period (October 31, 2012). The Solvita Maturity Index ranges from 1 through 8. An index of 1 typically describes new compost with a very high rate of decomposition, and an index of 8 describes highly matured (and possibly over-aged) compost. An index of 6 or above is commonly recognized as suitable maturity for official uses (Woods End Laboratories, Inc., 2012).

Table 7. Results of Solvita Compost Maturity Tests

Age of Compost (months)	Cover Material	Description	Status of Composting Process Based on CO_2 and NH_3 Readings[a]	Solvita Maturity Index[a] and Associated Condition of Compost
1	Sawdust and compost	Composted continuously in container	Compost high in nitrogen (a low carbon:nitrogen ratio)	5, compost is moving past active phase of decomposition
2½	Woodchips and compost	Composted continuously in container	Mature compost	7, suitable maturity for official uses
3[b]	Woodchips	Composted continuously in container	Completing curing stage, nearly matured	6, suitable maturity for official
8[b]	Woodchips and compost (rut simulation)	Removed from container after 1 month, in windrow form for almost 7 months	Mature compost	6, suitable maturity for official uses

[a] Woods End Laboratories, Inc. (2012).
[b] This compost was tested on October 31, 2012, and was also monitored with a temperature data logger (see Figure 4).

Because container contents were routinely removed between 6 weeks and 3 months of age for use as cover material for new mortalities, the oldest material available for testing was the 8-month-old rut simulation material that was stored on site in a windrow after composting in the forced air container for 31 days. Testing compost between 3 and 8 months of age was therefore not possible. Relatively young compost (2½ and 3 months old) that remained in the containers had a relatively high maturity index of 7 and 6, respectively (Table 7). Based on the CO_2 and NH_3 readings, the compost consisting of woodchips and compost mix for a cover material matured slightly faster than that consisting of woodchips only.

It is important to evaluate the compost maturity indices in context with compost temperatures on the date of compost testing (October 31; Figure 4). The declining temperatures of the oldest (8 months) compost corresponded with its high maturity index (see the rut simulation temperatures in Figure 4). However, there was a disparity between the maturity index of the 3-month-old woodchips compost that signified nearly matured compost (Table 7) and its high temperature reading that is normally indicative of actively degrading material (see temperatures of woodchips in Figure 4). Despite its fairly high maturity index of 6 (with a classification as "suitable maturity for official uses"), the woodchip compost temperatures were in the upper 130 °F range. Given these results, a recommended approach for material as young as 2 to 3 months is either to continue to aerate the material in the container until the temperatures decline or if space is needed in the container, to use the compost as a cover material for new mortalities or relocate and store the material until its temperature decreases. Regardless of the disparity between the temperature reading and the maturity index in this instance, the NH_3 and CO_2 readings of the compost that was 2½ months old and older indicated a well-balanced carbon:nitrogen ratio and ideal curing conditions (Woods End Laboratories, Inc., 2012).

Pathogen and Metals Tests

Criteria for pathogen and metal concentrations were met for each compost sample tested. Table 8 includes the results of analyses of 2-, 4-, and 6-week-old compost samples removed from the forced air containers and a control sample of cover material (poultry litter / wood shavings mix) stored outside the containers. *Salmonella* or roundworm (i.e., helminth) ova were not detected in any sample, and fecal coliform concentrations were well below the maximum concentration specified in the VSWMR (Virginia Register of Regulations, 2011).

Although metals concentrations were well within regulatory standards (Virginia Register of Regulations, 2011) in all samples, small concentrations of copper and zinc were detected (Table 8) in the cover material (comprising a mix of poultry litter and wood shavings). Copper and zinc concentrations were also slightly elevated in samples of compost (comprising the cover material and mortalities), although to a lesser extent. The metals present in animal manures are largely derived from the feeds (Nicholson et al., 1999; Sims and Wolf, 1994). In a study that analyzed 183 livestock feeds and 85 manure samples collected from commercial farms and analyzed for heavy metals' concentrations, copper and zinc levels were elevated in poultry feeds and elevated (to a lesser degree) in poultry manure (Nicholson et al., 1999).

Table 8. Pathogen and Metal Concentrations in Samples of Compost and Samples of Cover Material (Poultry Litter / Wood Shavings Mix) From Forced Air System

Constituent	Compost Age			Cover Material	Regulatory Standards[a]
	14 Days	28 Days	42 Days		
Pathogen					
Salmonella or Fecal coliform (as *E. coli*)	None 33 MPN/g	None < 6.4 MPN/g	None <6.1 MPN/g	None < 5.9 MPN/g	*Salmonella*: Less than 3 MPN per 4 grams of total solids (dry weight basis) or Fecal coliform: Median of all samples shall be less than 1000 MPN per gram of total solids (dry weight basis)
Helminth ova (as Ascarid)	None	None	None	None	Less than 1 ovum per 4 grams of total solids (dry weight basis)
Metal[b]					
Arsenic					Less than 41 mg/l
Cadmium					21 mg/l
Copper	0.27 mg/l	0.48 mg/l	0.23 mg/l	0.64 mg/l	Shall not exceed 1500 mg/l
Lead					Shall not exceed 300 mg/l
Mercury					Shall not exceed 17 mg/l
Molybdenum					Shall not exceed 54 mg/l
Nickel					Shall not exceed 420 mg/l
Selenium					Shall not exceed 28 mg/l
Zinc	0.43 mg/l	0.58 mg/l	0.53 mg/l	0.57 mg/l	Shall not exceed 2,800 mg/l

MPN = Most Probable Number.
[a]Virginia Solid Waste Management Regulations (Virginia Register of Regulations, 2011).
[b]Blank cells indicate metals concentrations below the laboratory's minimum reporting limit (<0.10 mg/l).

Performance and Observations

The compost (at varying stages of maturity) had a similar appearance to the cover material added at the time the mortalities were loaded (litter/sawdust mix or woodchips). The mortality appeared predominantly broken down within 4 weeks and fully broken down (with no tissue and few small [less than 6 in] bones remaining) after 6 weeks.

The forced air system consistently performed well from an operational standpoint, with few problems encountered throughout the monitoring period (Table 9). Operators greatly preferred this method of animal mortality management over their previous method of landfill disposal.

Odor was typically mild regardless of the cover material, with an exception in the first 2 weeks of woodchip use when periods of strong odor were documented. Throughout the monitoring period, log book records specified odor as “heavy” on 8 occasions (12%), “moderate” on 10 occasions (15%), and “mild” on 47 occasions (72%). The odor was minimized when the top layer of woodchips was covered with finer cover material (i.e., sawdust or compost from another bin). The addition of sawdust may have also helped speed the composting process. Cover material with smaller particle sizes (and associated greater surface area) encourages microbial activity and increases the rate of decomposition (Cornell Waste Management Institute, 1996).

Table 9. Problems Encountered, Solutions, and Lessons Learned During Forced Air System Monitoring Period

Problems Encountered	Number of Occasions	Solution	Lesson Learned
Operational/Performance			
Difficult to find state-approved vendor for poultry litter	NA	Discontinued use of litter and experimented with other cover materials	Litter is not necessary as an addition to cover material. Unfinished compost can be used to start system and as a cover material for regular use.
Temporary strong odor after first use of woodchips as cover material	8	Covered top layer with sawdust to minimize spaces where air could escape	When using woodchips as primary cover material, keep a finer cover material, such as sawdust or wood shavings, on site.
More space needed for compost to finish outside container	1	Moved material to temporary location	Consider constructing an additional container for storage or a pad to contain material.
Small areas of rust along container interior	NA	Planned to install concrete bins once the temporary containers fail	NA: These temporary containers were known to have a shorter life span. Vendor manufactures concrete containers with longer life span.
Compost			
Burnt compost material found on base of container after temperatures above 169 °F	1	Added more leachate to decrease temperatures	Add water (leachate pumped from tank) or decrease air settings when temperatures are greater than 165 °F.

NA = not applicable.

Overall Assessment of Forced Air System

Compost criteria for the forced air system were met, and the VDOT operators of the forced air system were very satisfied with its performance (see Table 10). The few operational issues were minor and quickly overcome. Important benefits of this system were its ability to accommodate fluctuations in animal mortality volume and to handle very large loads of mortality at once. The composting process with this system took longer than with the rotary drum (months rather than weeks), but this is not a limitation with proper planning with regard to the number of maintenance facilities designated to use the system. The system at the Bethel AHQ easily accommodated the mortalities received from the three AHQ that used it, although the AHQ superintendent plans to add an additional storage area for cover material and finished compost.

Because of the system's success, the Bethel AHQ plans to replace the temporary rolloff containers with a concrete container forced air system. Plans for installation of this system are underway for several VDOT maintenance facilities.

Table 10. Summary of Forced Air System Compost and Performance Assessment

Question	Assessment			
	Always	Sometimes	Seldom	Never
Were compost criteria met (for the range of cover materials used)?				
Compost temperature	X			
Pathogen destruction	X			
Solvita maturity index	X			
Did the system perform well?	X			

CONCLUSIONS

- *Based on the results of this study, it is inconclusive as to whether the rotary drum is a useful means of animal mortality management for VDOT; the drum requires further evaluation with the application of the lessons learned described in this report.* The rotary drum has several potential advantages (i.e., composts mortalities in 10 to 14 days, can have a small footprint, and is well suited for facilities with low mortality volumes). The rotary drum met the established pathogen destruction criteria, but it was inconsistent with regard to meeting the temperature and moisture criteria and performing well from an operational standpoint. Some of the problems encountered included difficulties with (1) maintaining proper temperatures and moisture content, (2) managing high mortality volumes, and (3) achieving high temperatures when restarting the drum in cold temperatures.

  Overcoming the problems encountered during this study would require the following, at a minimum:

  — remaining within capacity thresholds
  — the use of a dry cover material (e.g., carbon source)
  — careful oversight and operation by trained operators
  — detailed operational guidance.

- *Based on the results of this study, the forced air system has been shown to be a useful means of composting animal mortality for VDOT.* The compost met all established compost criteria (i.e., temperature, compost maturity, and pathogen destruction), and the system performed well from an operational standpoint.

RECOMMENDATIONS

1. *In light of the operational problems encountered with the large rotary drum used by six AHQ in this study, VCTIR's Research Implementation Coordinator should coordinate installation of a smaller rotary drum at a different selected maintenance facility and evaluate its performance when the lessons learned described in this report are applied.*

2. *VCTIR's Research Implementation Coordinator should coordinate the installation of additional forced air system units at VDOT maintenance areas interested in in-vessel composting for animal mortality management.* Additional pilot installations at maintenance facilities in different areas of the state will provide valuable operational information beyond that available from this study's single installation.

3. *VCTIR should evaluate the economics and logistics of the forced air system in a subsequent study to complete the feasibility analysis of this method of animal mortality management.* One element of this evaluation should include time required to achieve finished compost from initial mortality loading into the vessel. Another element should include the optimal sizing and spacing of units to meet maintenance facility mortality management needs.

4. *VCTIR should create guidelines for in-vessel composting that incorporate information obtained from this and subsequent studies.* The minimum elements of the guidelines should include detailed instructions on windrow composting; detailed instructions on forced air composting; and a list of compost end use options. This would increase the prospects for successful implementation of animal mortality composting for VDOT.

COSTS AND BENEFITS ASSESSMENT

The forced air system had a total cost (including equipment and site work) of approximately $100,000. Depending on the location of the vessel, the cover material used to envelop the mortalities can be acquired at no charge or for a relatively small fee. The sawdust used for the forced air system costs approximately $300 per truck load, or an average of $100 per month. The large rotary drum was comparable in cost to the forced air system (approximately $100,000). A smaller drum costs approximately 50% less. Wood shavings using in the drum were acquired at no charge from a local furniture manufacturer.

To estimate the true costs of composting mortalities compared with taking them to a disposal facility, however, the savings in disposal fees and travel costs (i.e., labor and fuel) incurred from driving to a disposal facility must also be taken into account. Although the cost benefits realized from a VDOT maintenance facility replacing the disposal facility form of carcass management with composting vary depending on factors such as driving time to the nearest disposal facility, disposal fees, and number of mortalities managed, strategically located vessels can increase the cost efficiency of the carcass disposal process. This is primarily a result of the decreased labor associated with compost vessels. Labor represents the largest expense incurred from carcass removal and disposal, and employee time conducting carcass management activities is primarily spent in the vehicle (Donaldson and Moruza, 2010). Maintenance facilities with staff who travel the greatest distances off-route to reach a disposal facility would therefore reap the most savings (or require the fewest years to offset equipment costs) if they were to switch to a management option located at their own maintenance facility or a maintenance facility that took appreciably less travel time to reach than the disposal facility. This time savings in labor could be reallocated to other maintenance tasks.

A tool created in a previous VDOT composting study (Donaldson and Moruza, 2010) can be used to derive estimates of the number of years it would take to offset the costs of a compost vessel. For maintenance facilities with particularly long drives to a disposal facility (25 to 40 miles), the initial investment in a compost vessel would be offset in less than 5 years (Donaldson and Moruza, 2010). It would take longer to offset the costs of a compost vessel for maintenance facilities with shorter drives to the disposal facility (such as those in Halifax County), but the investment would still be easily offset within its 25- to 30-year lifetime (Donaldson and Moruza, 2010).

Another important benefit of composting is the ability to compost animals the day they are removed from the road. For example, the transfer station in Halifax County closed daily at 2 P.M. and was not open on weekends. This was not only an inconvenience for the maintenance facility, but it also increased the labor involved returning to a maintenance facility to store the mortalities before driving to the transfer station during its operating hours.

A composting guidance document will be prepared to support the implementation of animal mortality composting at a VDOT maintenance facility. The guidance will include detailed procedures for windrow and vessel composting and recommended end use options for finished compost. A study will also be conducted that will include an economic analysis of composting animal mortalities with the forced air system. Detailed costs associated with forced air composting, such as the initial investment, labor, and equipment and materials, will be analyzed to determine the net costs or benefits of replacing a maintenance facility's current method of animal mortality management with composting.

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APPENDIX

COMPOST LOG, BETHEL AHQ FORCED AERATION SYSTEM

Date	Time	Bin #	Number of Carcasses Added	Temp(F)*	Odor	Notes

*Temperature probe should be inserted near center of pile