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Composting Animal Carcasses Removed From Roads: An Analysis of Pathogen Destruction and Leachate Constituents in Deer Mortality Static Windrow Composting

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Deer mortality static compost windrows were monitored for 1 year under conditions typical of a VDOT area maintenance headquarters facility. Windrows were analyzed for pathogen destruction and the degree to which underlying soil filtered leachate contaminants. In response to high windrow temperatures, indicator pathogens *E. coli*, *Salmonella* were reduced by 99.99% the first sampling day (Day 7) and ascarids were deemed non-viable by Day 77. Soil filtration of leachate was effective in reducing concentrations of ammonia, chloride, and total organic carbon. Nitrate, a contaminant of particular regulatory concern, had an estimated mass contaminant loss of 1.9 lb/acre, compared to the 8 to 45 lb/acre estimated loss from fertilizer application on agronomic crops in Virginia.

Results from this study indicate that with properly constructed static compost windrows, (1) high temperatures destroy indicator pathogens; (2) the natural filtration of leachate through soil reduces deer mortality contaminant concentrations; and (3) the low volume of leachate from windrows results in nominal losses of nitrate and other contaminants. The study recommends that VDOT consider sharing these results with the Virginia Department of Environmental Quality to discuss options for a statewide composting program. This could provide VDOT with an additional carcass management option.

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ABSTRACT

More than 48,700 deer-vehicle collisions occurred in Virginia from 2010 through 2011, the fifth highest number in all U.S. states. The Virginia Department of Transportation (VDOT) is responsible for the removal and disposal of animal carcasses along the state road system. The predominant methods currently used (landfill and burial) have several costly disadvantages, including long travel distances to landfills, increasing landfill restrictions, and lack of viable burial areas. Other states have found static compost windrows to be an easy and cost-effective carcass management technique.

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Results from this study indicate that with properly constructed static compost windrows, (1) high temperatures destroy indicator pathogens; (2) the natural filtration of leachate through soil reduces deer mortality contaminant concentrations; and (3) the low volume of leachate from windrows results in nominal losses of nitrate and other contaminants. The study recommends that VDOT consider sharing these results with the Virginia Department of Environmental Quality to discuss options for a statewide composting program. This could provide VDOT with an additional carcass management option.

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INTRODUCTION

Background

More than 48,700 deer-vehicle collisions occurred in Virginia from 2010 through 2011, the fifth highest number of all U.S. states (M. Miles, personal communication). Removing animal carcasses from the road and properly disposing of them is an important service on Virginia roadways. The Virginia Department of Transportation (VDOT) is responsible for the removal and disposal of carcasses along the state road system and has spent an annual average of $4.1 million on carcass removal and disposal in the past five fiscal years (2007-2011).

A study by the Virginia Center for Transportation Innovation and Research (VCTIR) found that VDOT maintenance personnel have a high level of interest in adopting better methods for disposing of carcasses (Donaldson and Moruza, 2009). According to a survey of staff from

88 VDOT maintenance areas, 71% saw a need for or a benefit from having additional carcass management options, particularly those that could reduce costs and/or labor. Common shortcomings cited with regard to the predominant methods currently used by VDOT (landfill and burial) included long travel distances to landfills, landfill restrictions, and lack of viable burial areas. A national survey conducted by the Maryland State Highway Administration (2005) indicated that other states faced similar challenges with their predominant forms of carcass management. Of 23 state agency respondents, 78% used a combination of landfill and burial. Recurrent comments by respondents included a need for viable, environmentally compliant, and cost-effective alternatives to their current forms of carcass management.

The VCTIR study (Donaldson and Moruza, 2009) included a preliminary investigation of carcass management methods that could be located onsite (i.e., at a VDOT maintenance facility) and found that static compost windrows can be an applicable alternative management technique for transportation agencies. Static compost windrows are passively aerated static piles and, as such, do not require the materials turning needed with the more traditional covered bin composting method (Figure 1). Given the space requirements for windrow construction (as detailed by Donaldson and Moruza [2009]), windrow composting is not feasible for all VDOT maintenance areas. For those with adequate space for windrows, particularly maintenance areas with costly contracts for disposal and/or limited access to landfills or burial areas, this method can serve as a needed option for carcass management. Windrow composting is used by the New York State Department of Transportation (DOT) and the Montana DOT and has recently been adopted by the West Virginia DOT and the Kentucky Transportation Cabinet.

Figure 1. Static Compost Windrows. Photograph used with the permission of the Cornell Waste Management Institute.

Composting Regulations

The U.S. Environmental Protection Agency (U.S. EPA) promotes composting and the use of compost in state and local roadside applications (Composting Council Research and Education Foundation [CCREF] and the United States Composting Council [USCC], 2008). A report from a project funded by the U.S. EPA describes the benefits of implementing composting programs within a state DOT. Composting not only provides an alternative waste management strategy to occupying valuable landfill space but can also reduce the production of greenhouse gases.

Composting organic materials rather than disposing of them in a landfill decreases the volume of organic by-products, which are known sources of methane production. In addition, the use of compost itself can sequester carbon within the soil (CCREF and USCC, 2008).

Under the Virginia Solid Waste Management Regulations (VSWMR) (9 VAC 20-81-310), most animal carcasses are considered a Category IV solid waste. Composting animals killed by vehicles must, therefore, comply with the siting, construction, and testing requirements for solid waste composting (VSWMR, 2011). Several requirements in these regulations are intended to prevent leachate from composting operations from entering groundwater. In this study, *leachate* is defined as the product of precipitation that has percolated through the compost and contains extracted or dissolved material from the compost (Bonhotal and Schwarz, 2009; Krogmann and Woyczechowski, 2000). According to VSWMR for compost windrows (considered a Type B compost facility), all receiving, mixing, composting, curing, screening, and storing operations require one of the following:

- an asphalt or concrete area that drains directly to a wastewater storage, treatment, or disposal facility

- an asphalt, or concrete, and diked or bermed area to prevent entry of run-on or escape of run-off, leachate, or other liquids, and a sump with either a gravity discharge or an adequately sized pump located at the low point of the hard-surfaced area to convey liquids to a wastewater treatment, disposal, or holding facility, discharged under a [Virginia Pollutant Discharge Elimination System] permit issued pursuant to the State Water Control Board regulation 9 VAC 25-31 or recirculated within the composting process (a lime-stabilized area with a minimum thickness of 6 in and a laboratory-tested permeability of 1×10^{-7} cm/sec may be substituted for the asphalt or concrete)

- a 12-in compacted gravel pad underlain by a continuous high-density polyethylene liner of a minimum 60-mil thickness and equipped with leachate collection above the liner and leak detection below the liner.

Further, VSWMR requires tests for finished compost, including tests for metals, compost stability, and pathogens. The regulations specify that products will continue to be considered solid wastes until the testing indicates that they have attained the standards specified in the regulation. The Virginia Department of Environmental Quality (DEQ) is responsible for enforcing these regulations and authorizing composting permits.

VSWMR composting requirements for the construction of an impermeable surface and capture of leachate are largely intended to prevent leachate from migrating from the pile and entering groundwater. The impacts of organic compounds are known to be reduced by degradation in the soil (Buscot, 2010; Richard and Chadsey, 1990), yet little is known regarding the degree to which soil filtration affects contaminants found in animal mortality composting. If composting results in nominal losses of leachate contaminants and/or if soil filtration of contaminants sufficiently reduces the risk of groundwater pollution, this could be an important consideration in regulatory decisions affecting VDOT animal mortality composting.

PURPOSE AND SCOPE

The purpose of this study was to determine the extent of pathogen destruction and contaminant loss from the process of deer mortality static windrow composting. The objectives of the study were:

1. Determine the temperatures achieved in static compost windrows (hereinafter "windrows").

2. Determine the extent to which pathogens are reduced through thermal destruction in windrows.

3. Determine the volume of leachate leaving windrows.

4. Determine the extent to which leachate contaminants from windrows are mitigated by infiltration through underlying soil.

5. Calculate the mass loads of the monitored leachate contaminants.

6. Document whether odor was detectable, whether there was evidence of scavengers entering the windrows, whether runoff was visible leaving the windrows, and whether any tissue or bones remained when windrows were dismantled.

7. Provide a regulatory context for the results of the study.

The scope of the study was limited to two windrows and one control pile that were constructed at a VDOT maintenance area and monitored for approximately 1 year. Although the scope of this study was limited to windrow composting, a study of composting vessels is being conducted by VCTIR determine their utility as an additional option.

METHODS

Seven tasks were conducted to achieve the study objectives over the course of 18 months.

1. Conduct a literature review.

2. Construct windrow and control pile plots.

3. Prepare pathogens for placement in windrows and the control pile.

4. Construct the windrows and control pile and place monitoring instruments.

5. Monitor the windrows and analyze the data.

6. Document observations made throughout the study period regarding whether odor was detectable, whether there was evidence of scavengers entering the windrows, whether runoff was visible leaving the windrows, and whether any tissue or bones remained when windrows were dismantled.

7. Provide a regulatory context for the results of the study.

Literature Review

The literature was reviewed for (1) regulatory standards relevant to composting; (2) information on the pathogens listed in regulatory standards; and (3) leachate contaminants relevant to animal mortality composting.

Literature and information were gathered from the websites of the U.S. EPA, Cornell Waste Management Institute (CWMI), DEQ, the Virginia General Assembly, and USCC. Literature sources and regulatory information were also obtained from animal mortality composting experts and DEQ waste management and water quality staff. Federal and Virginia regulatory standards were reviewed for those most applicable to leachate pollution.

Construction of Windrow and Control Pile Plots

Three plots for compost windrows were constructed at a VDOT storage lot in Covesville, Virginia, on June 28, 2010. Plots were constructed on top of a 4-in layer of “crusher run” crushed and compacted aggregate. Within this surface, the aggregate sizes decrease and the fines mix with the native soil as they extend deeper into the soil profile. Although the properties of this material were not compared with and may differ from those of native soil types, this material comprises a common surface at VDOT maintenance areas and storage facilities. As such, it represents a common surface for potential future composting sites on VDOT property and was, therefore, chosen as the surface on which to construct the treatment plots for this study.

Given that the impacts of organic compounds are reduced by degradation in the soil (Richard and Chadsey, 1990), plots were constructed to determine the degree of this reduction in leachate contaminants from deer mortality windrows. Plot designs allowed for comparisons between the concentrations of contaminants from a windrow constructed on bare ground (where leachate filters through soil) and those from a windrow constructed on an impermeable surface (with no filtration effects). In the context of this study, “filtering” refers not only to the capturing of solid particles but also the adsorption or absorption of contaminants by the soil and/or biodegration of contaminants (Buscot, 2010). These two treatments were compared to a control plot containing only woodchips.

Plot 1

Plot 1 consisted of a marked section 8 by 12 ft instrumented with two lysimeters to collect leachate that percolates through the windrow and the underlying soil. The design and placement of the lysimeters were adapted from turf grass irrigation research at Virginia Tech (Evanylo et al., 2007). The lysimeters were constructed from polyvinyl chloride (PVC) pipe fashioned into a trough by cutting lengthwise pieces 10 ft long and 6 in in diameter. The lysimeters were centered in the plot and situated parallel to and 2 ft apart from each other, 10 in below the soil surface (Figure 2). The lysimeters were placed at a 3% slope to enable the leachate collected in them to drain by gravity to the lower end of the plots. The troughs were permanently capped at the upper end and plumbed at the lower end with a drainage ball-valve that could be easily opened for water sample collection (Figure 3). Once the lysimeters were in place, they were filled with aggregate (0.5 in diameter) and topped with native soil from the site. They were then covered with landscaping cloth that was secured to the pipes with cable ties. The trenches were backfilled with 3 in of native soil and topped with the original 4-in layer of crushed aggregate. Any leachate traveling from the windrow would, therefore, travel through 10 in of this mixed media before draining toward the lower end of the plots.

Figure 2. Plot 1: Lysimeters filled with aggregate *(left)*, covered with landscaping cloth, and positioned 10 in beneath the soil surface *(right)*.

Figure 3. Plot 1: Drainage valves at lower end of lysimeters.

Plot 2

Plot 2 was designed to demonstrate a worst case scenario with no filtering of leachate through the soil beneath the windrow. The plot was constructed from treated wooden beams measuring 4 by 4 in shaped into a rectangle measuring 8 by 12 ft. Two layers of heavy 6 mil plastic were placed in the plot and nailed to the beams to create a curb for containing leachate within the plot. To secure the plastic further, sections of treated wooden beams measuring 2 by 2 in were nailed on top of the wood beneath the plastic such that the plastic was sandwiched between the beams. The plot was built on a 3% slope, and the lower corner of the plot was instrumented with a 6-in-diameter PVC elbow (with a 45 degree angle) positioned below ground (Figure 4) such that leachate from the windrow would gravitate into the PVC elbow. One end of the elbow was positioned flush with the ground surface within the plot and covered with landscaping cloth. The other end extended below ground in an open hole just beyond the border of the plot and, similar to Plot 1, was plumbed with a drainage ball-valve that could be easily opened for water sample collection.

Figure 4. Plot 2: Impervious base *(left)* with drain for leachate collection at lower corner of plot *(right)*. Drainage valve not shown on PVC elbow. Plot 2 and Plot 3 were constructed identically.

Plot 3

Plot 3 was constructed with the same design as used with Plot 2. Plot 3 contained only woodchips and served as the control for the study.

Pathogen Preparation

Virginia compost regulations indicate that compost is not considered "finished" until compost samples are tested for particular pathogens and found not to exceed given concentrations. These pathogens include (1) helminth ova (a parasitic worm; to be considered representative of all parasites) and (2) the bacterial pathogen *Salmonella* (to be considered representative of all bacterial pathogens capable of regrowth) or the bacterial pathogen fecal coliform (Virginia Register of Regulations, 2011).

In order to study the destruction of these pathogens in the experimental windrows and control pile, it was necessary to ensure their presence. Pathogens were obtained from the Virginia-Maryland Regional College of Veterinary Medicine (VMRCVM) Center for Molecular Medicine and Infectious Diseases. Pathogens provided included live eggs from a parasitic roundworm classified as ascarids (*Toxocara cati*), nalidixic acid-resistant *Salmonella enteric* Serovar *Typhimurium*, and a subgroup of fecal coliform (*Escherichia coli* [*E. coli*] strain V517).

Suspensions of these pathogens were contained in durable 250-ml Erlenmeyer PETG storage flasks. *E. coli* and *Salmonella* were similarly prepared as 50-mL suspensions of 1×10^{10} cells/ml in Amies transport cell-preserving medium. This medium provides for long-term maintenance of cultures without supporting their continued growth. Ascarid eggs were isolated from feline fecal samples (collected from animal shelters) and brought to a total egg count of approximately 1×10^{5} eggs. The eggs were placed in a 250-ml flask and suspended in aqueous media with 2% sulfuric acid to prevent bacterial contamination. Each of the three groups of pathogens and their media was divided into four flasks, one to be placed in each of the two experimental windrows, one to be placed in a control pile, and one kept at room temperature to serve as a laboratory control.

The flasks were prepared for placement in windrows and the control pile by fitting them with 5 ft of sterile, durable laboratory tubing. The tubing was selected to fit 20-ml slip-tip syringes, which were to be used to draw flask samples from the outside the windrows. To prevent contamination of the flask contents, the flask end of the tubing was sealed to the flask cap by commercial sealant and the sampling end was sealed by heat (with a lighter) and clamped.

This design (i.e., tubing that extends from inside the flask to outside the windrow) eliminates the need to disturb the windrows by removing and replacing flasks during sampling events, which could affect windrow temperature and possibly contaminate the samples. The containment of pathogens in flasks allows for a determination of the effects of time and temperature on pathogen survival while minimizing additional uncontrolled variables that have also been shown to be capable of pathogen inactivation (Fuchs, 2010).

Windrow Construction and Instrument Placement

Windrows were constructed on each plot on September 14, 2010, using the static pile techniques recommended by CWMI (Bonhotal et al., 2007; CWMI, 2007). This technique involves enveloping the carcasses of road-killed deer in woodchips and allowing those windrows to sit undisturbed. Woodchips for windrow construction were obtained from VDOT chipping machines; chips had been collected within the previous 4 months during VDOT road maintenance activities. When used as a compost material, the absorbent and bulky quality of woodchips helps maintain proper moisture levels and oxygen flow, and their high carbon content balances the high nitrogen content of animal carcasses (Fuchs, 2010; J. Bonhotal, unpublished data).

Two experimental windrows (Windrow 1 and Windrow 2) and a control pile were constructed on Plot 1, Plot 2, and Plot 3, respectively. Immediately prior to construction, woodchips were mixed with the use of a front loader to achieve consistency in age and moisture among the windrows. The experimental windrows and the control pile each had an initial peak height of 6 ft and base dimensions of 8 by 12 ft. For Windrows 1 and 2, 24 in of woodchips were placed as the base layer to absorb leachate. Two deer, collected within 2 days prior to windrow construction, were placed back to back in the center of the bed. The deer were covered with approximately 9 in of chips. Three flasks containing pathogens (*E. coli*, *Salmonella*, and ascarid eggs) were placed upright and adjacent to one another on top of this layer of woodchips. The tubing on each flask extended from the interior and bottom of each flask to the outside of the windrow for sampling access. Care was taken to prevent moving the flasks or burying the sampling ends of the tubing during the remainder of windrow construction. A temperature data logger (HOBO® Temperature Logger U23-004, Onset Computer Corporation), programmed to record core temperatures every 45 minutes, was placed adjacent to the flasks. The flasks and data logger were then covered with an additional 9-in layer of woodchips (resulting in a middle layer thickness of 18 in). Two more deer were centered and placed back to back and covered with a final 24-in layer of chips (Figure 5A and B). The control was constructed entirely of woodchips (without deer), with the same dimensions as Windrows 1 and 2. Flasks and a data logger were placed in the same central location of the windrow as in Windrows 1 and 2 (Figure 5C).

An ambient temperature data logger (HOBO® U12 Temperature Data Logger U12-015, Onset Computer Corporation) and a rain gauge (HOBO® Data Logging Rain Gauge Data Logger RG3, Onset Computer Corporation) were placed onsite and programmed to collect data every 45 minutes.

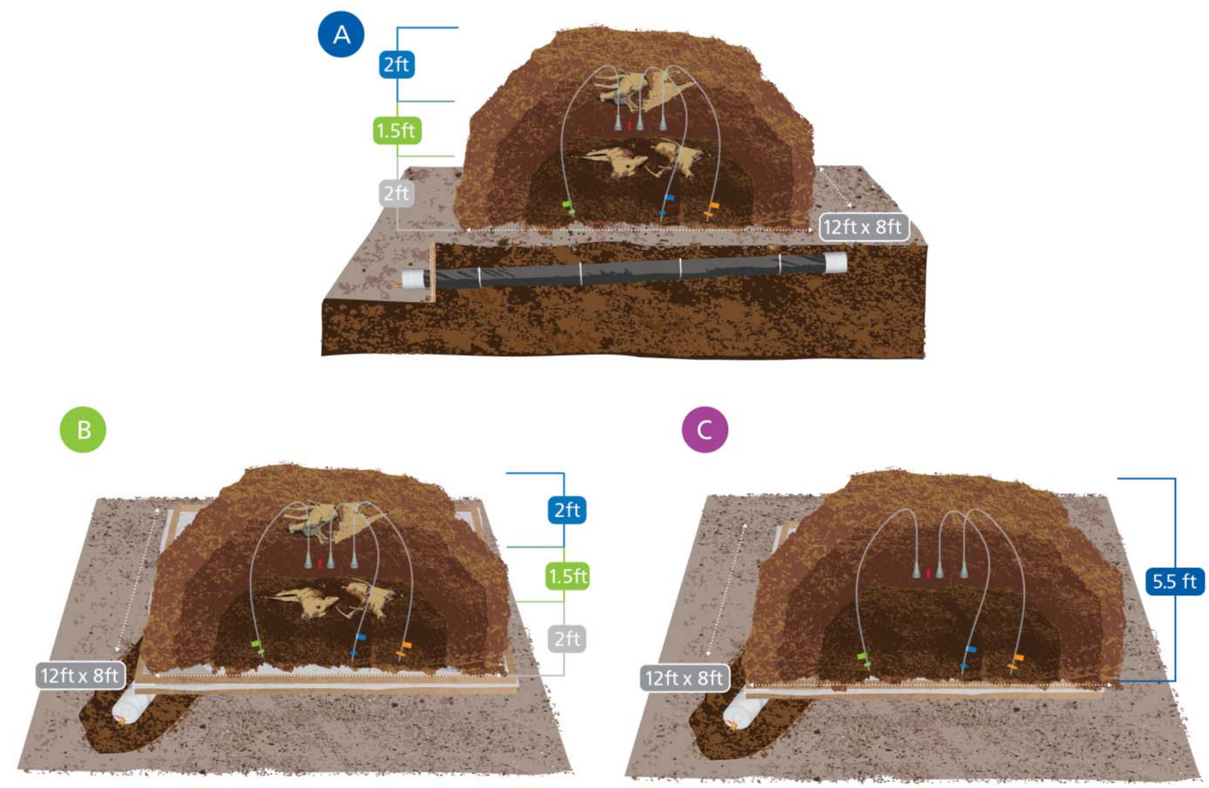


Figure 5. Illustrations of Plot Design, Windrow Construction, and Placement of Flasks Containing Pathogens: Windrow 1 (A), Windrow 2 (B), and control pile (C). A data logger was placed between the pathogen flasks in all three piles.

Monitoring and Data Analyses

The windrows and the control pile were monitored for approximately 1 year, from September 14, 2010, to September 7, 2011. Aside from four compost sampling events, windrows were left undisturbed over the course of the study. Monitoring included temperature measurements, analyses of pathogens (in flasks within windrows and in samples of the compost material), leachate volume, and leachate contaminants. Contaminant mass loads were then calculated based on leachate volume measurements and contaminant concentrations.

Temperature Measurements

The data loggers placed in the windrows and control pile during their construction were removed at the end of the 1-year monitoring period, and the data were downloaded to a laptop computer. Data from the ambient temperature data logger and the rain gauge were periodically downloaded to a laptop computer. Windrow temperatures were analyzed with regard to federal composting requirements regarding time and temperature pathogen destruction. Temperatures were also analyzed with respect to the length of time taken for windrow temperatures to approach control pile and ambient temperatures.

Analyses of Pathogens

Pathogens in Flasks Within Windrows and Control Pile

Flasks were sampled over the course of the study to determine the number of days at which pathogens were reduced and destroyed. Samples were taken the day prior to windrow and control pile construction (Day 0) and at the end of the following time periods: Week 1, Week 2, Week 3, Week 7, Week 10, Week 24, and Week 48. Samples were taken aseptically by snipping the heat-sealed end of the tubing and removing the clamp from each tube. A 20-cc syringe was inserted in the tubing and used to draw approximately 1 ml of stock from the bottom of each vial. After sampling, each tube was resealed with a lighter and clamped. Samples were placed in 1.5-ml microtubes, labeled, placed on ice, and sent overnight to VMRCVM for analysis.

At VMRCVM, *E. coli* and *Salmonella* samples were plated on MacConkey agar and TSA + 10 µg/ml nalidixic acid, respectively, to measure colony forming units (cfus) per milliliter. Ascarid samples were microscopically examined for percentage of eggs intact and life cycle stage (larvated versus unlarvated). Data for all pathogens were log-transformed, and the means of the pathogens from the experimental windrow flasks were compared to those from the control pile and laboratory control flasks using the two-tailed Student's t-test. *P*-values less than 0.05 were considered significant.

Pathogens in Compost Samples

To determine whether compost was "finished" in accordance with the VSWMR, samples of the compost were collected from each windrow and the control pile at Months 3, 6, 9, and 12 and tested for the presence of the pathogens listed in the regulations (Virginia Register of Regulations, 2011). With the data collector using a new set of sterile gloves for each sampling event and windrow, three samples from each windrow and the control pile were collected as close to the center of the pile as possible, that is, 3 ft above the base of the pile (between the bottom and top layers of carcasses for Windrows 1 and 2) and approximately 1 ft apart. Because the objective was to test samples representative of the entire pile rather than different sections of each pile, the three samples from each windrow and the control pile were combined into a single quart-sized freezer bag. The samples were packed on ice and shipped overnight to a laboratory operated by the Virginia Department of Agriculture and Consumer Services. All results were reported per dry weight and compared with Virginia composting regulations (Virginia Register of Regulations, 2011).

Leachate Volume

After each precipitation event over the course of the 1-year study, leachate from each windrow was collected from the drainage valve and its volume was determined. It is important to note that only leachate, not runoff, was collected from the windrows and control pile. Whereas leachate percolates through the compost, runoff water comes from the windrow sides and does not contact the interior contents of the windrow (Krogmann and Woyczechowski, 2000). Because windrows were constructed such that the sloped sides extended just beyond the 8 by 12 ft borders, runoff was shed exterior to the plots and only the rainfall that percolated through the windrow (leachate) was captured within the plots. Precipitation measurements recorded by the onsite rainfall gauge were used to calculate the volume of precipitation landing within an 8 by 12 ft plot. Because Windrow 2 and the control pile were constructed on an impermeable surface such that all leachate could be collected and measured, it was possible to determine the proportion of rainfall that left the pile as leachate as opposed to that shed as runoff, absorbed by the two piles, and/or evaporated from the piles.

Leachate Contaminants

The construction of the control pile (containing no carcasses) allowed for a comparison of the quantity and quality of leachate originating from the cover material (woodchips) and that from the carcasses. Contaminants chosen for analyses were based on those included in Virginia groundwater standards (Virginia Register of Regulations, 2011) *and* that are known leachate constituents according to animal mortality composting studies (Bonhotal and Shwartz, unpublished data; Glanville et al., 2009; Martins, 1992; Peigne and Girardin, 2004). These include ammonia-nitrogen (NH_3-N), nitrate-nitrogen (NO_3-N), total organic carbon (TOC), and chloride (Cl). Although VSWMR requires testing for a series of heavy metals, such tests were determined irrelevant for this study. Heavy metal concentrations are not expected in animal mortality composting and have even been shown to be minimal in compost comprising yard trimmings, manure, and sewage sludge (Cole, 1994; Peigne and Girardin, 2004; Warman and Termeer, 1996).

Leachate samples were collected within 12 hours following a precipitation event that was 0.5 in or greater over the 1-year study period. This ensured that at least two of the three windrows produced sufficient leachate volumes for laboratory analyses. Samples were collected by opening the ball-valve drains from each plot and releasing samples directly into sterile containers provided by the laboratory. Samples were received by the laboratory within 24 hours of collection. NO_3-N and Cl were analyzed using U.S. EPA Method 300.0 (Pfaff, 1993), and NH_3-N was analyzed using U.S. EPA Method 350.1 (O'Dell, 1993). TOC was analyzed using the U.S. EPA-approved persulfate-ultraviolet method (Standard Method 5310 C; American Public Health Association, 1992). Results were reported in milligrams per liter and compared with federal and state water standards.

Cumulative concentrations of each contaminant were analyzed using monotone spline regression to determine differences among experimental and control piles. Differences were reported at a significance level of 0.05 (a 95th percentile confidence level). The spline regression is a piecewise polynomial regression with a continuity constraint between "pieces" in the value range of explanatory variables. It was chosen for the analysis because it is extremely flexible in its curve shape to fit the study data. The monotone constraint was imposed on the spline specification to reflect the characteristics of cumulative concentrations (i.e., cumulative concentrations should be monotonic in their changes over time). All statistical analyses were performed in SAS 9.2.

Calculation of Contaminant Mass Loads

Using leachate volume measurements and contaminant concentrations, contaminant mass loads were determined for each contaminant analyzed in this study, with the following calculation:

Contaminant mass load (mass/yr) = Mean contaminant concentration (mass/volume)
x Annual leachate volume (volume/yr).

Contaminant mass load data were compared with contaminant losses from fertilization practices of typical agronomic crops in Virginia.

Documentation of Observations Regarding Odor, Presence of Scavengers, Runoff, and Remaining Tissue or Bones

Observations made throughout the study period regarding whether odor was detectable, whether there was evidence of scavengers entering the windrows, whether runoff was visible leaving the windrows, and whether any tissue or bones remained when windrows were dismantled were documented.

Provision of Regulatory Context for Study Results

Because compost windrows must comply with the requirements set forth in VSWMR (2011), a regulatory context for the results of the study was established. This was accomplished by comparing the study findings with regulatory standards and typical contaminant losses from comparable practices in Virginia (i.e., cow mortality windrows).

RESULTS AND DISCUSSION

Literature Review

Regulatory Standards Relevant to Composting

Table 1 lists contaminants and compost parameters analyzed in this study and the most applicable regulatory standards for each. These standards include (1) national primary (enforceable) (U.S. EPA, 2011a) and secondary (non-enforceable) drinking water standards (U.S. EPA, 2011b); (2) Virginia groundwater standards and criteria (Virginia Register of Regulations, 2004); and (3) Virginia composting regulations (Virginia Register of Regulations, 2011). Although Virginia groundwater standards are enforceable, groundwater criteria are intended to provide guidance in preventing groundwater pollution and are not mandatory or enforced (Virginia Register of Regulations, 2011).

Table 1. Tests Conducted and Relevant Regulatory Standards

Tests	National (U.S. EPA) Standards in mg/L	Virginia Groundwater Standard (S) or Criteria (C) in mg/L[3]	Virginia Solid Waste Management Requirements for Finished Compost[5]
Leachate			
NO_3-N	10[1]	5 (S)	
Total Organic Carbon		10 (C)	
Chloride	250[2]	25 or 50[4] (C)	
NH_3-N		0.025 (S)	
Compost			
Compost Stability			Temperature decline to near ambient conditions when not the result of improper management of the composting process
Salmonella or			Median of all samples shall be less than 3 most probable number (MPN) per 4 grams of total solids (dry weight basis) at the time the finished compost is prepared for sale or give away in a container for application to the land
Fecal Coliform			Median of all samples shall be less than 1000 MPN per gram of total solids (dry weight basis).
Helminth ova			The density of viable Helminth ova in the finished compost shall be less than 1 per 4 grams of total solids (dry weight basis) at the time the finished compost is prepared for sale or give away in a container for application to the land

[1] National primary drinking water standard (U.S. EPA, 2011a).
[2] National secondary drinking water standard (U.S. EPA, 2011b).
[3] Virginia Register of Regulations, 2004.
[4] Value varies based on Physiographic Province.
[5] Virginia Register of Regulations, 2011.

Federal regulations stipulate that to ensure destruction of indicator pathogens (*Salmonella* strains, fecal coliform strains such as *E. coli*, and *Ascaris* ova) compost material must meet the time and temperature conditions of 53° C for 5 days, 55° C for 2.6 days, or 70° C for at least 30 minutes (U.S. EPA, 2003).

Pathogens Listed in Regulatory Standards

E. coli and *Salmonella* are common indicators of fecal contamination and the presence of pathogens in waste water or sewage sludge. Certain strains of these bacteria can cause food poisoning and other illnesses in humans, though most strains of *E. coli* are part of the normal flora of the gut and are not pathogenic (Jones et al., 1997). According to a literature review conducted by CWMI, there is little to no occurrence of *Salmonella* species in white-tailed deer. Although there are conflicting accounts in the literature regarding *E. coli* (a fecal coliform), other coliforms are present in deer and can be a source of human infection (Schwarz et al., 2010). In order to ensure complete pathogen destruction, CWMI suggested a composting duration of 12 months before use (Schwarz et al., 2010) but maintained that after 6 months the windrow compost material can be used as the cover material for new windrows (J. Bonhotal, personal communication).

Ascarids are a genus of parasitic worm (or helminth) and include species that are common intestinal parasites of domestic animals. Humans and animals can become infected by ingesting larvated eggs from contaminated areas (Jones et al., 1997). Ascarid eggs are highly resistant and are therefore frequently used as indicator organisms for water and sewage treatment processes (Jones and Martin, 2003). Windrow composting methods have been found to be effective in destroying ascarid eggs (Hays, 1996; While and Westerberg, 1969). Ascarid eggs of the genus *Toxocara* were reported as being destroyed in as few as 3 minutes when kept in a moist atmosphere at 50º C (Uga and Kataoka, 1995).

Although not investigated in this study, chronic wasting disease (CWD) is a relatively recent concern in Virginia. CWD is a fatal neural disease affecting deer, and 84 cases have been reported in West Virginia since 2005. The Virginia Department of Game and Inland Fisheries has discovered two positive cases of CWD in Virginia and has designated the areas west of I-81 in Frederick County and west of I-81 and north of Route 675 in Shenandoah County as a containment area. Until more information is available regarding the temperatures required to inactivate the prion (an infectious protein) responsible for the disease, the department recommends that composting deer be excluded from the containment area (N. Lafon, personal communication).

Leachate Contaminants Relevant to Animal Mortality Composting

Much of the literature on the environmental effects of composting pertains to farm-scale composting. The growing concern about the impact of agricultural practices on water quality has resulted in an increase in composting by U.S. farmers (Kashmanian and Rynk, 1998). Research on farm-scale composting commonly includes a discussion and/or analyses of leachate constituents from composting windrows. Organic nitrogen compounds are common constituents in leachate from windrows containing livestock carcasses, livestock manure, and other farm waste materials. These compounds are toxic to fish and humans in high concentrations (Weiner, 2000). According to farm-scale composting studies, NH_3-N, ammonium (NH_4^+-N), and NO_3-N are the most concerning in terms of groundwater pollution potential (Ballestero and Douglas, 1996; Glanville et al. 2006; Glanville et al. 2009; Martins, 1992; Peigne and Girardin, 2004). Because NH_4 and NH_3 are transformed into NO_3 by nitrification in the soil, these two ions may have similar effects in terms of groundwater pollution, and their chemical characteristics make them particularly susceptible to either leaching through the soil profile into groundwater or being transported into nearby surface waters (Ballestero and Douglas, 1996; Basso and Richie, 2005; Peigne and Girardin, 2004). The proportion of these nitrogen compounds in leachate depends on when leaching occurs during the composting process and on the forms and contents of nitrogen compounds in the cover material (Peigne and Girardin, 2004).

Cl and TOC are also commonly analyzed leachate contaminants from animal mortality compost windrows (Bonhotal and Shwarz, 2009; Glanville et al., 2009). TOC, the amount of carbon bound in an organic compound, is commonly used as an indicator of water quality (Bonhotal and Shwarz, 2009). Chloride is an abundant anion in mammals and also occurs in the environment as a result of weathering of chloride minerals and salting of roads, among other sources. The chloride ion is extremely mobile; it is not sorbed to soils and moves with water with little or no retardation (Glanville et al., 2009; Weiner, 2000).

The choice of cover material used to construct windows and the construction of the windrow (in terms of size dimensions and layering) are essential elements to controlling nutrient losses and subsequent groundwater pollution from windrows (Glanville et al., 2006; Peigne and Girardin, 2004). Glanville et al. (2006) found high variability in concentrations of leachate contaminants from test windrows comprising cattle carcasses, with pollutant concentrations of all nutrients analyzed (NO3-N, NH_3-N, and TOC) consistently highest in leachate from windrows constructed of straw and manure combinations and 2 to 4 times lower in those constructed of silage or ground cornstalks. Given the high nitrogen content of cover materials available to farms (Ballestero and Douglas, 1996), results from livestock mortality compost research may have limited applicability to animal mortality composting conducted by transportation agencies.

Researchers at CWMI have conducted composting studies of particular relevance to transportation agencies. Their research includes leachate and pathogen analyses from windrows constructed of deer carcasses and woodchips (Bonhotal and Schwarz, 2009; Schwarz et al., 2006; Schwarz et al., 2010). CWMI efforts contributed to the development of guidelines and implementation of windrow composting by the New York State DOT. Static windrows in New York are constructed along sections of right of way obstructed from drivers' views (J. Bonhotal, personal communication) and on paved asphalt, concrete, and compacted millings in maintenance areas (New York State DOT, 2006). Leachate or liquids leaving the site are not required to be captured but must be kept away from sensitive areas. Following a recommended composting period of 1 year, finished compost is primarily used for grass establishment within the right of way (J. Bonhotal, personal communication).

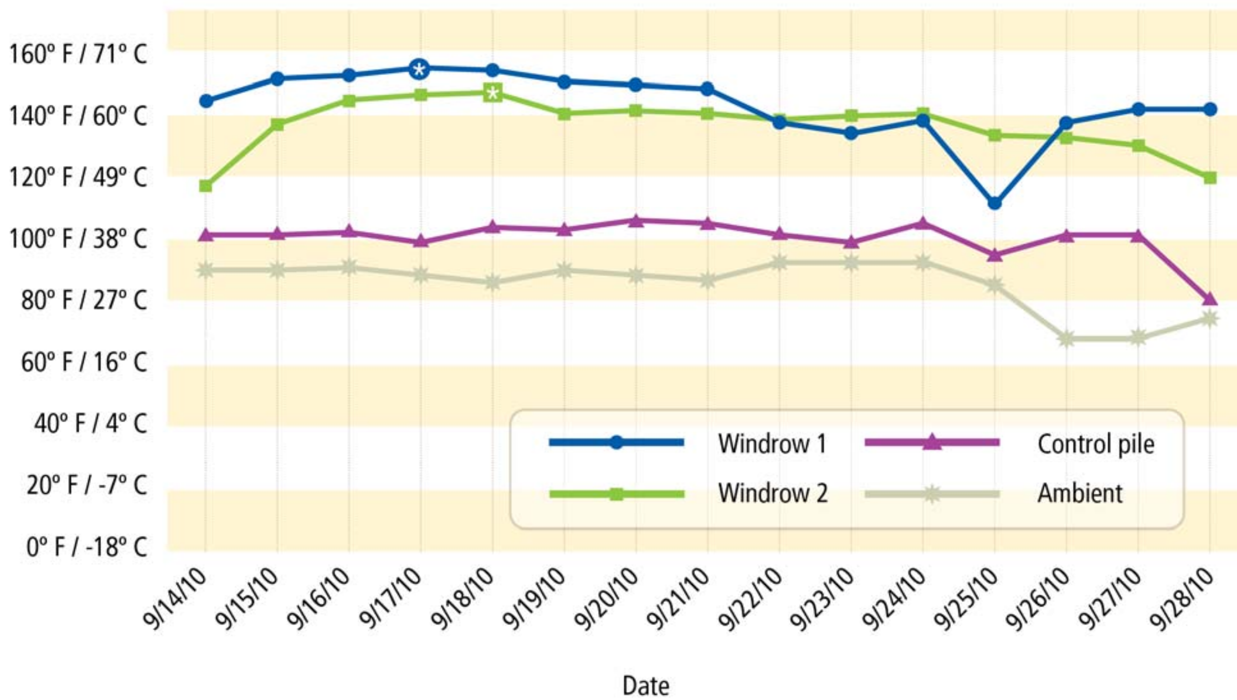
Although the referenced animal mortality composting studies have analyzed contaminants in leachate captured at the base of windrows (with no soil filtration), no published studies of animal mortality composting were found that analyzed leachate below the soil in order to assess the degree to which filtration affects contaminant concentrations.

Results of Monitoring and Data Analysis

Temperature

Figure 6 illustrates the highest daily temperatures during the first 2 weeks following windrow and control pile construction. Differences in maximum temperature between the windrows on the first day of composting may be attributed to the fact that Windrow 2 was constructed later in the day than Windrow 1, after ambient temperatures had decreased. Any slight differences in the placement of data loggers relative to each windrow's hottest location would also have contributed to temperature discrepancies. Despite the differences in highest daily temperatures, the maximum temperature (156° F / 69° C) attained in both experimental windrows was obtained by Day 4. By Day 5, both experimental windrows met the federal time and temperature pathogen destruction composting requirements of maintaining 55° C for 3 days (;U.S. EPA, 2003).

Although windrows were constructed in mild temperatures, deer carcass windrows have been found to attain temperatures sufficient for pathogen destruction when constructed in cold temperatures. Deer carcass windrows constructed in November in New York heated to high temperatures within 2 weeks, despite cold ambient temperatures. Pathogen levels in these windrows were reduced to near zero as a result of high windrow temperatures (Schwarz et al., 2010).



*Designates date at which time/temperature conditions of 53° C for 5 days or 55° C for 3 days have been met (U.S. EPA, 2003).

Figure 6. Highest Daily Temperatures in First 2 Weeks (9/14-9/28) After Construction

Figure 7 illustrates predicted daily average ambient temperatures and those of both windrows and the control pile. Using the daily average temperatures collected over the course of the study, a spline regression was developed to create predicted mean values, assuming separate intercept and slope for each condition (Figure 7).

Temperatures were reviewed to determine the points at which "compost stability" was achieved. VSWMR (2011) considered compost finished once it passed a compost stability test, which can be determined by the windrow's "temperature decline to near ambient conditions." Significant differences in Figure 7 are depicted by non-overlapping shaded bands; overlapping bands indicate temperatures that are not different to a statistically significant degree. The analysis illustrated in Figure 7 indicates a statistically significant difference between the daily average ambient temperatures and the daily average control pile temperatures throughout the 1-year study period (at a 0.01 significance level). Control pile temperatures were, therefore, viewed as more suitable for examining compost stability in this study. Temperatures of both windrows converged with control pile temperatures in February, approximately 5 months following windrow construction. Windrow temperatures then began diverging from and becoming higher than control pile temperatures, presumably indicating an increase in windrow bacterial activity following a dormant period in the winter. In June, or Month 9, windrow

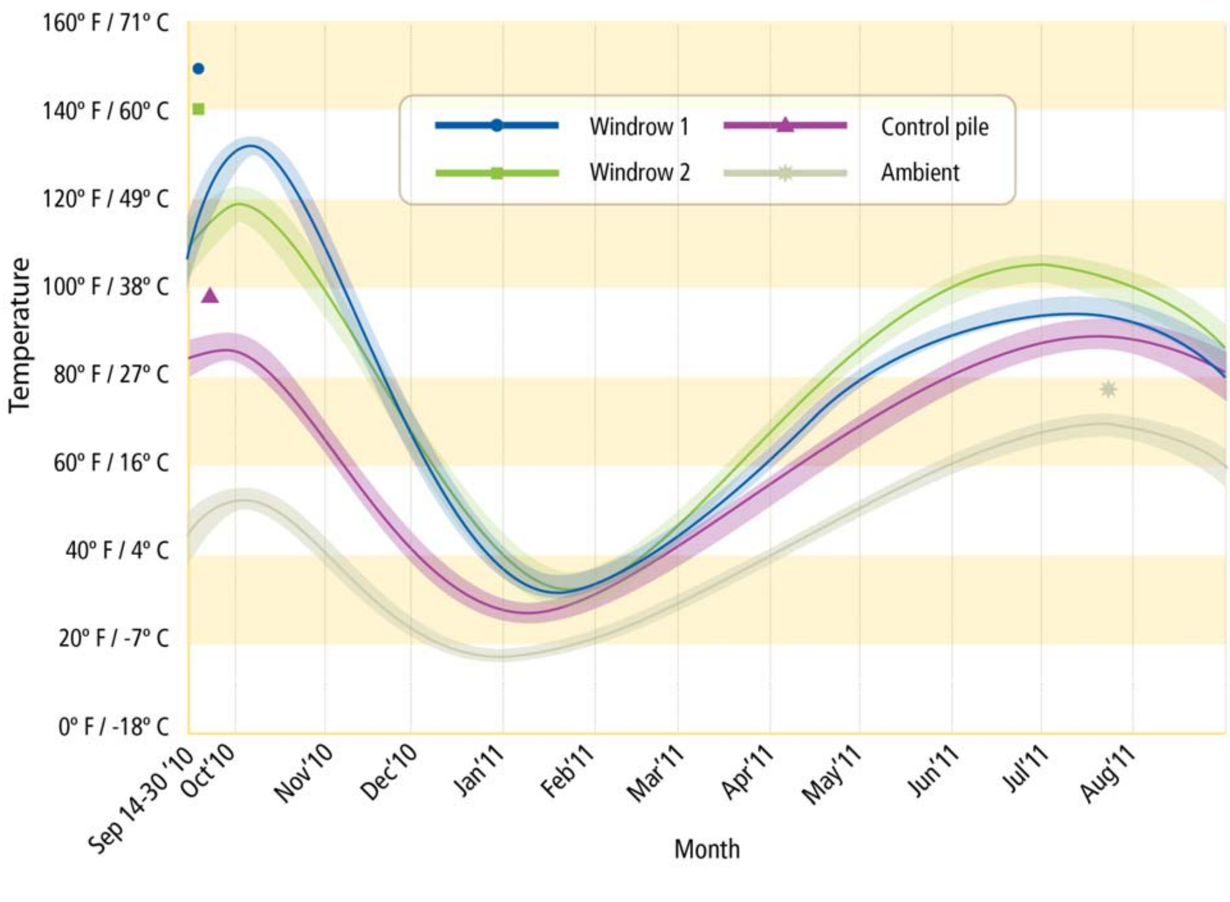


Figure 7. Predicted Mean Temperatures: based on the daily average temperatures collected over the study period (September 2010–August 2011). ***Shaded bands*** **along each regression line indicate the 95th percentile interval of the predicted mean temperatures. The** ***points*** **designate the highest temperature attained.**

temperatures approached control pile temperatures. Windrow 1 temperatures were the same (i.e., not different to a statistically significant degree) as control pile temperatures in July (Month 10), and Windrow 2 temperatures were the same as control pile temperatures in August (Month 11).

Pathogens

Pathogens in Flasks

E. coli and Salmonella. *E. coli* and *Salmonella* flasks in Windrows 1 and 2 were reduced by 99.99% by the first sampling date (Day 7) and reached undetectable growth by the second sampling date (Day 14) of the study (Figures 8 and 9). *E. coli* bacterial numbers in Windrow 1 and 2 flasks were significantly lower than those in the control pile flask on all sampling days until Day 49 ($p < 0.05$) and lower than the laboratory control flask on all sampling days after Day 0 ($p < 0.05$; Figure 8). *Salmonella* bacterial numbers in Windrow 1 and 2 flasks were significantly lower than those in the control pile flask and the laboratory control flask on all sampling days ($p < 0.05$; Figure 9).

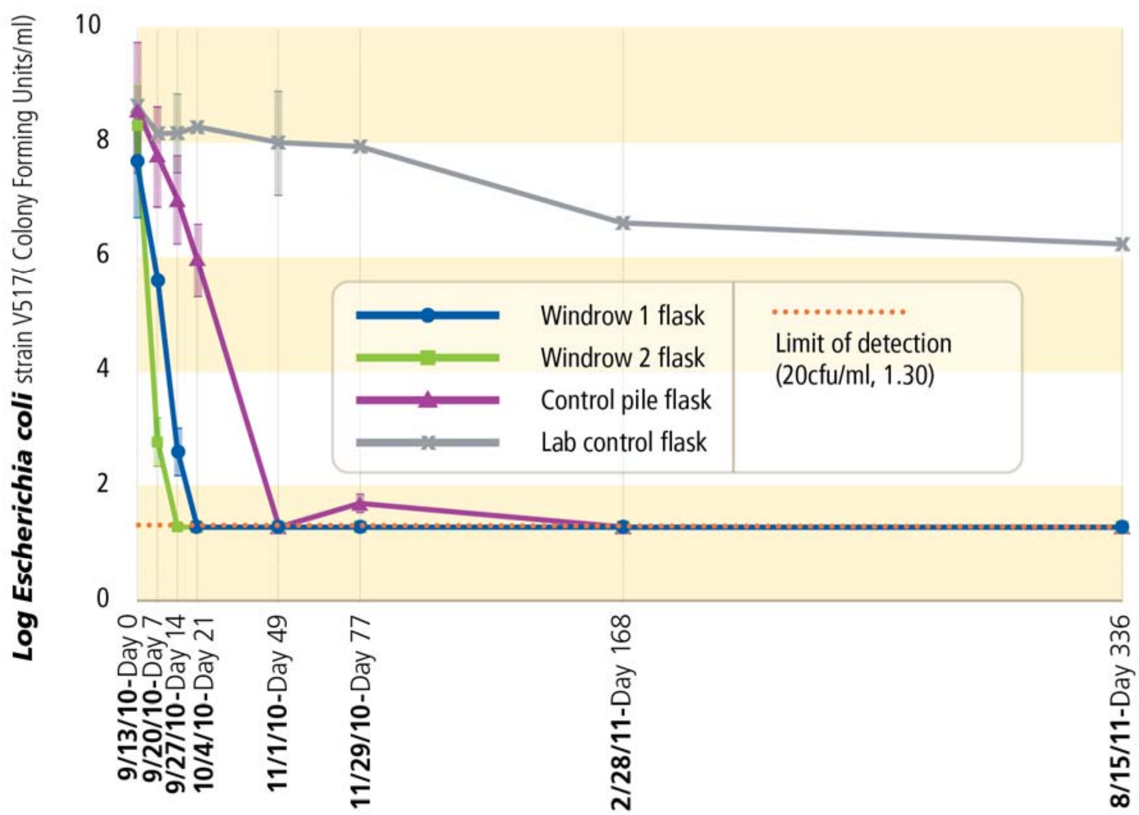


Figure 8. Concentrations of *E. coli* Strain V517 in Flasks

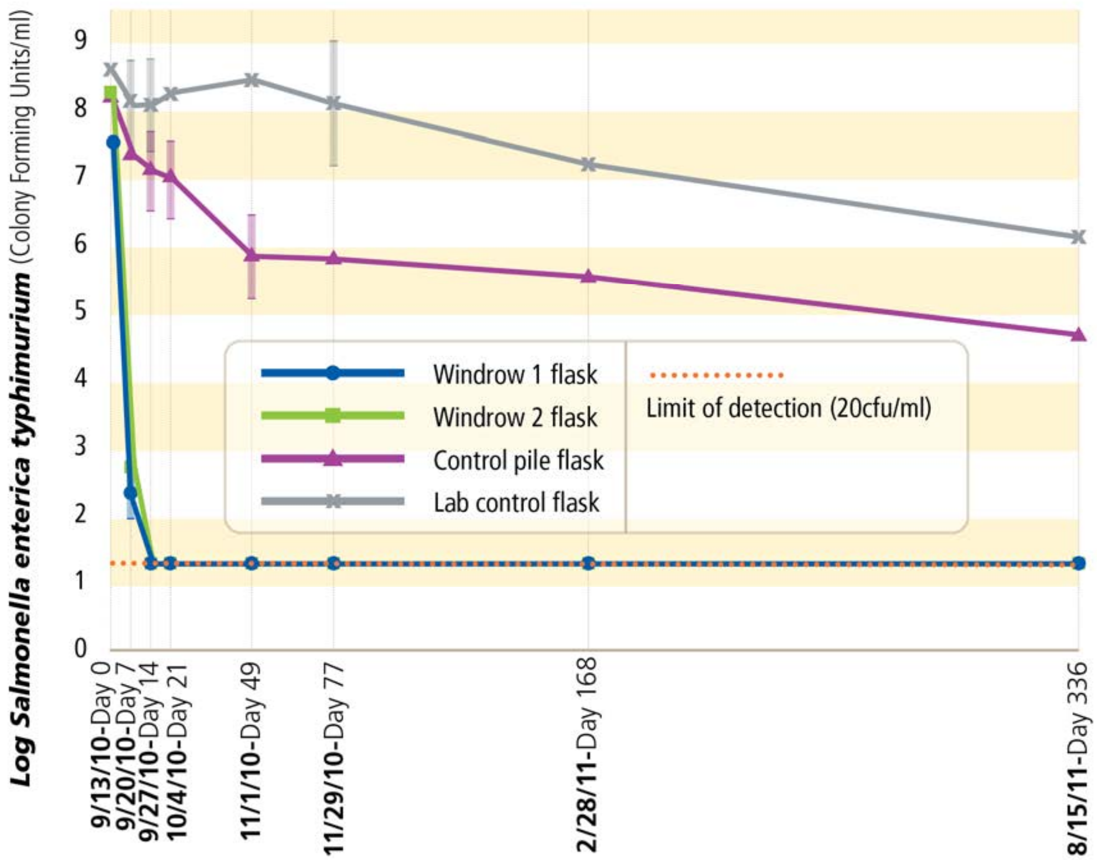


Figure 9. Concentrations of *Salmonella enteric typhimurium* in Flasks

Ascarids (Toxocara* sp*). Figure 10 illustrates the percentage of intact ascarid eggs in samples taken from experimental and control flasks. The percentage of intact ascarid eggs in Windrow 1 and Windrow 2 flasks was significantly lower than those in the laboratory control flasks on all sampling days after Day 0 ($p < 0.05$), and significantly lower than those in the control pile flask on all days except Day 0 and Day 49 ($p < 0.05$; Figure 10). Ascarid results were not reported for the final sampling day (Day 336) because of the inability to detect a large enough sample size from each flask. This was presumably a result of degradation of the eggs and larvation in the control flask.

Although Figure 10 illustrates the percentage of intact ascarid eggs, it is important to note that an egg being "intact" is not a guaranteed indication of its viability. In samples taken from the laboratory control flask (stored at room temperature), all observed ascarids had larvated by Day 77. Although some eggs were considered intact in the other three flasks (from Windrow 1, Windrow 2, and the control pile), no larvation was observed. This fact, coupled with windrows heating to what has been reported as above tolerable temperatures for ascarids (Hays, 1996; Uga and Kataoka, 1995), suggests that eggs were no longer viable in windrows within the first few days after pile construction.

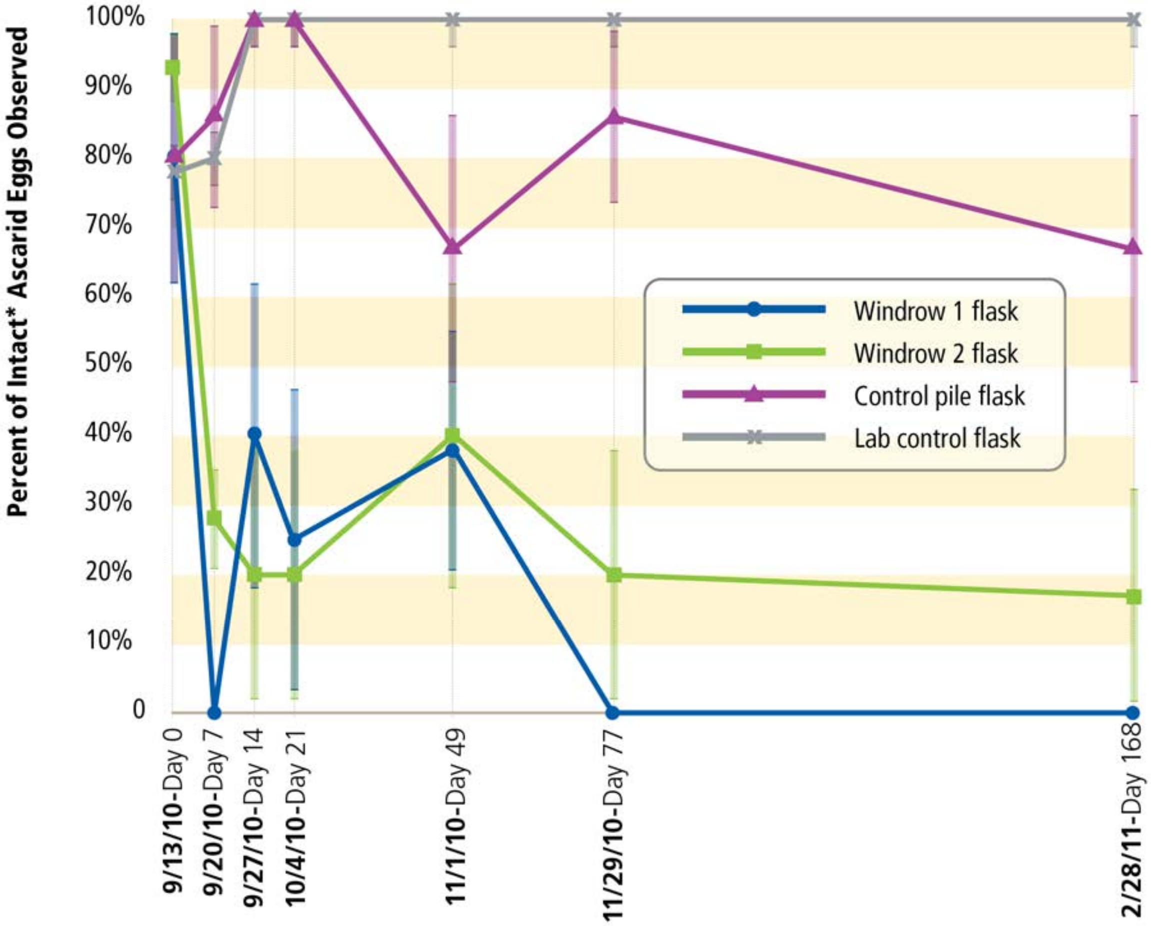


Figure 10. Percentage of Intact Ascarid Ova in Flasks

These results indicate that the temperatures met and sustained in both windrows were sufficient to destroy the indicator pathogens listed in both federal (U.S. EPA, 2003) and Virginia (Virginia Register of Regulations, 2011) compost regulations. Regrowth of these pathogens did not occur within the 1-year study period. According to a literature review conducted by CWMI (Schwarz et al., 2006), the most hardy pathogen of concern in road-killed deer is a bacterial species *Streptococcus faecalis*. In studies of the thermal destruction of this pathogen in food, a temperature of 60º C sustained for 11.3 to 15.7 minutes is required for its destruction (Schwarz et al., 2006). Windrow temperatures in this study exceeded this threshold. Beginning on Day 4, windrow temperatures remained at 60º C or higher for 61 consecutive hours.

Pathogens in Compost Samples

Although the analyses of pathogens in flasks provide a clear depiction of their destruction in response to temperature, the presence of pathogens was also determined by analyzing samples of the compost matter itself in accordance with the VSWMR (2011) testing requirement for finished compost. Results of compost sample analyses in all sampling events (Months 3, 6, 9, and 12) were negative for *Salmonella* and *Ascaris* ova.

Moisture content in both experimental windrow samples ranged from 50% to 60%. These values are within the optimum moisture range for micro-organism activity in compost windrows (Fuchs, 2010; Peigne and Girardin, 2004).

Fecal coliform (as *E. coli*) results are presented in Table 2. As indicated in Table 1, VSWMR regulations stipulate that the median of all samples be less than 1,000 MPN (most probable number) fecal coliform per gram of dry solids (Virginia Register of Regulations, 2011). Concentrations were below this threshold in both experimental windrows and the control pile for each sampling event (Table 2).

Table 2. Results of Fecal Coliform (as *E. coli*) Analyses of Compost Samples

Test Pile	Month 3 (MPN/g)	Month 6 (MPN/g)	Month 9 (MPN/g)	Month 12 (MPN/g)
Windrow 1	89	< 7.2	89	230
Windrow 2	15	190	<7.2	500
Control Pile	< 6.5	420	<7.5	180

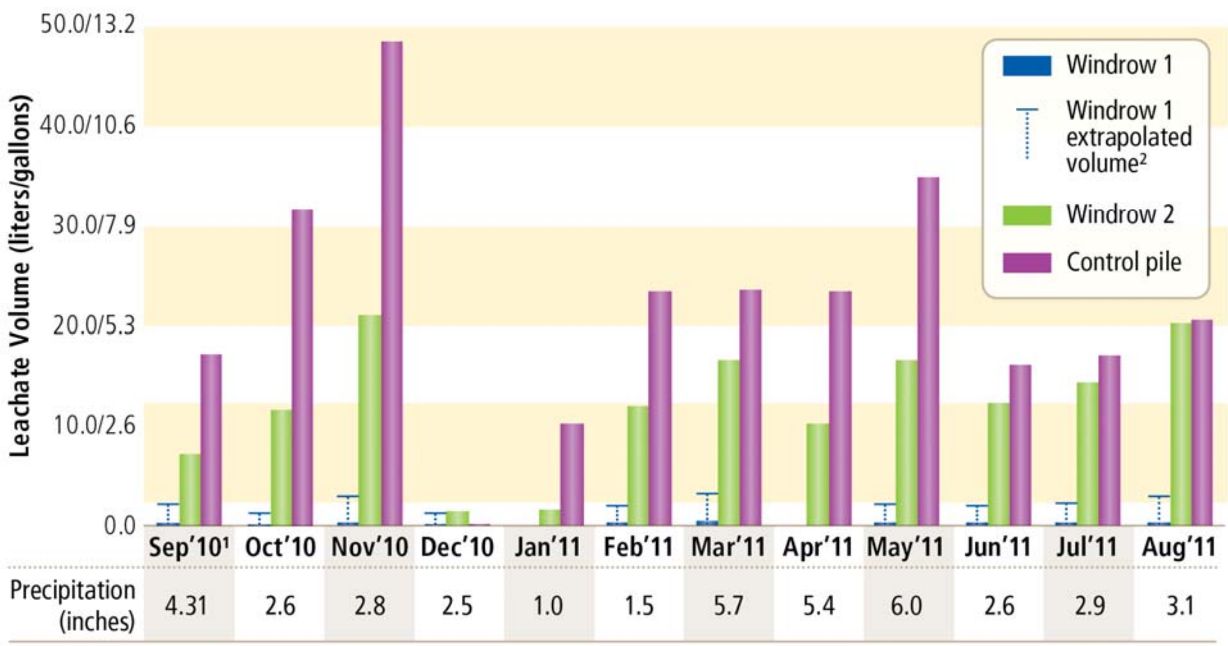
MPN = most probable number.

Leachate Volume

Total precipitation over the course of the 1-year monitoring period was 40.38 in at the study site. This was 3.54 in (8%) higher than the average rainfall volume over the previous 5 years.

The woodchips were highly absorbent and also facilitated evaporation of the absorbed precipitation, as evidenced by visible water vapor rising from the windrows during the active composting phase in cooler temperatures. As a result, relatively little of the contaminated water leached out of the piles. Leachate volumes captured beneath Windrow 2 averaged 2% of the total precipitation landing in the plot during the study period, and volumes captured beneath the control pile averaged 5% of the total precipitation. Glanville et al. (2006) similarly found leachate volumes from cow compost windrows to be less than 5% of precipitation that fell during the year. These results demonstrate an important benefit of static windrow composting; that is, leaving windrows unturned reduces the release of leachate (Bonhotal and Schwarz, 2009).

Figure 11 illustrates monthly precipitation and leachate volumes over the course of the study. Leachate volumes were relatively low in September (during the first 2 weeks following windrow construction) despite heavy precipitation, presumably a result of the large volume of precipitation required initially to saturate the piles. Leachate volumes from Windrow 1 were lower than those from Windrow 2 and the control pile in part because the buried lysimeters did not cover the entire area below the windrow. (Windrow 1 bars may be difficult to see in Figure 11 because they are only slightly higher than 0.0.) Calculations were, therefore, conducted to estimate the leachate volume of Windrow 1 as if lysimeters *had* covered the entire area beneath Windrow 1; these values are depicted as “Windrow 1 extrapolated volume” in Figure 11. The values are based on the assumption that the distribution of precipitation and contaminant concentrations percolating from the windrows to the lysimeters was equal across the entire plot. Although only approximations, it is apparent that leachate volumes from Windrow 1 were substantially lower than those from Windrow 2. This is likely a result of leachate sorption by and/or evaporation from soil between precipitation events. Any sorption and/or evaporation of leachate would result in a decreased volume of leachate reaching groundwater.



[1]September 14-30.
[2]Estimated total leachate volume from Windrow 1.

Figure 11. Monthly Leachate Volumes and Precipitation

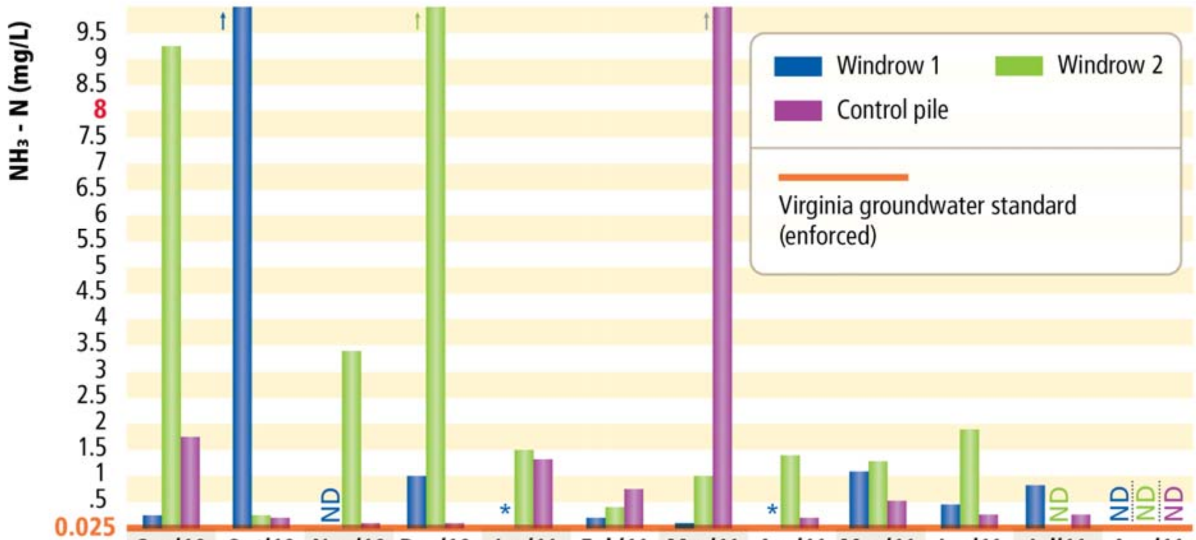
The total leachate volume from Windrow 2 was 46% lower than that from the control pile. The largest differences occurred in the first 3 months of the study. This period corresponds with the most active period of composting, when (1) the most oxygen is consumed by microorganisms during degradation of organic matter (Peigne and Girardin, 2004) and (2) evaporation rates are highest as a result of high windrow temperatures. Differences in leachate volumes between Windrow 2 and the control pile were smaller in the final months of the study period. December was the only month when the leachate volumes from the windrows were greater than that from the control pile, as a result of freezing temperatures in the control pile (while temperatures remained above freezing in the windrows).

Leachate Contaminants

One or two leachate samples from each windrow and the control pile were taken per month, depending on the frequency and volume of precipitation events. Figures 12 through 15 illustrate the concentrations for each contaminant; values were averaged for months with two sampling events (September, February, and May). The analyses of cumulative contaminant concentrations were found the most effective means to detect differences among the windrows and control pile. Results of statistical comparisons of the cumulative contaminant concentrations among windrows and the control pile are shown in the Appendix.

Individual Contaminants

NH3-N. The concentrations of NH3-N in leachate from Windrow 1 (with soil filtration) generally exceeded the groundwater standard of 0.025 mg/L (Figure 12). The cumulative NH3-N concentration over the 1-year study period was statistically lower (by 23%) in the filtered leachate from Windrow 1 than that from the unfiltered leachate from Windrow 2 (at a 0.05 significance level; see the Appendix). There was no statistical difference in cumulative concentrations between Windrow 2 and the control pile.

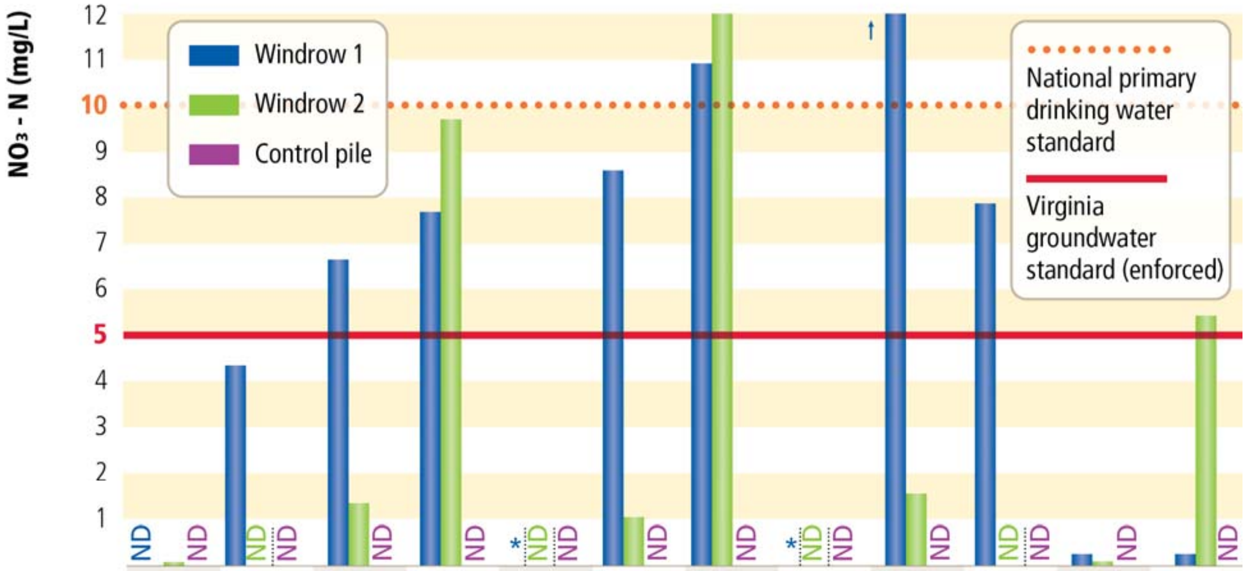


	Sep'10	Oct'10	Nov'10	Dec'10	Jan'11	Feb'11	Mar'11	Apr'11	May'11	Jun'11	Jul'11	Aug'11
Windrow 1	0.3	16.8	ND	1.04	*	0.2	0.1	*	1.2	0.5	0.8	ND
Windrow 2	9.2	0.4	3.5	39.9	1.5	0.4	1.02	1.44	1.3	1.8	ND	ND
Control pile	1.7	0.2	0.1	0.2	1.3	0.8	16.4	0.38	0.6	0.2	0.3	ND

*Insufficient leachate volume for analysis.
ND indicates a concentration that is not detected or above the minimum reporting level.

Figure 12. Average Monthly Concentrations of Ammonia-Nitrogen in Samples of Leachate

NO3-N. Average monthly concentrations of NO3-N in leachate from Windrow 1 exceeded the Virginia groundwater standard on six sampling events but were below the national primary drinking water standard in all but two sampling events (Figure 13). The 1-year cumulative concentration of NO3-N was statistically higher (by 35%) in the filtered leachate from Windrow 1 than in the unfiltered leachate from Windrow 2 (at an 0.05 significance level; see the Appendix). This finding was unexpected, given the lower concentrations of NH3-N in leachate from Windrow 1. The high NO3-N concentrations from Windrow 1 may be explained by the fact that the process of nitrification is dependent on aerobic soil bacteria. The oxidation of ammonia and oxygen into nitrite followed by the oxidation of nitrites into nitrate, therefore, requires some degree of aeration (Philippot and Germon, 2010). Whereas the soil beneath Windrow 1 would have allowed for aeration and drainage, any saturated conditions at the plastic base of Windrow 2 may have inhibited oxygen diffusion in the compost and thereby reduced nitrification (and allowed for a higher concentration of NO3 than would have otherwise existed; Ballestero and Douglas, 1996).



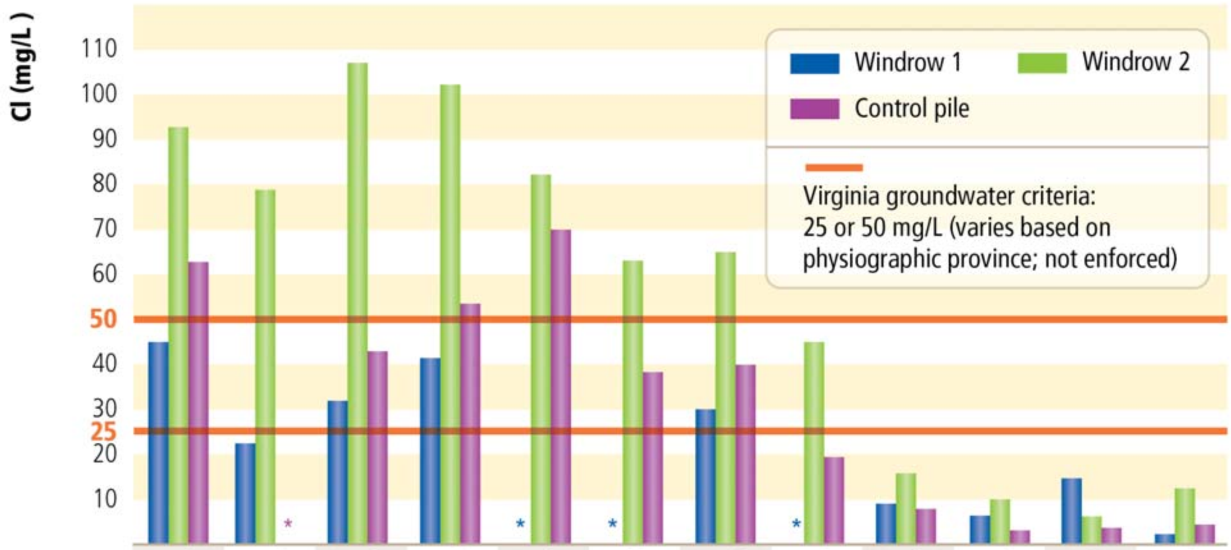
	Sep'10	Oct'10	Nov'10	Dec'10	Jan'11	Feb'11	Mar'11	Apr'11	May'11	Jun'11	Jul'11	Aug'11
Windrow 1	ND	4.5	6.6	7.7	*	8.5	10.9	*	12.1	7.8	0.2	0.3
Windrow 2	0.1	ND	1.5	9.7	ND	1.1	12	ND	1.7	ND	0.1	5.5
Control pile	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

*Insufficient leachate volume for analysis.
ND indicates a concentration that is not detected or above the minimum reporting level.

Figure 13. Average Monthly Concentrations of Nitrate-Nitrogen in Samples of Leachate

Cl. Average monthly concentrations of Cl in leachate from Windrow 1 remained below the Virginia groundwater criterion of 50 mg/L throughout the study period and fell below 25 mg/L the last 4 months of the study period (Figure 14). Despite chloride's little to no tendency to be absorbed by soil or transformed by soil microbes (Glanville et al., 2009; Weiner, 2000), the 1-year cumulative concentration in the filtered leachate from Windrow 1 was statistically lower (by 59%) than that in the unfiltered leachate from Windrow 2 (at an 0.05 significance level) and significantly lower than that in the unfiltered leachate from the control pile (at an 0.05 significance level; see the Appendix).

TOC. Although average monthly concentrations in leachate from Windrow 1 remained higher than the Virginia groundwater standard of 10 mg/L (Figure 15), the 1-year cumulative concentration in the filtered leachate from Windrow 1 was statistically lower (by 78%) than that from the unfiltered leachate from Windrow 2 and statistically lower than that from the unfiltered leachate from the control pile (at an 0.05 significance level; see the Appendix). The cumulative concentration in leachate from Windrow 2 was significantly higher than that from the control pile (at an 0.05 significance level; see the Appendix).



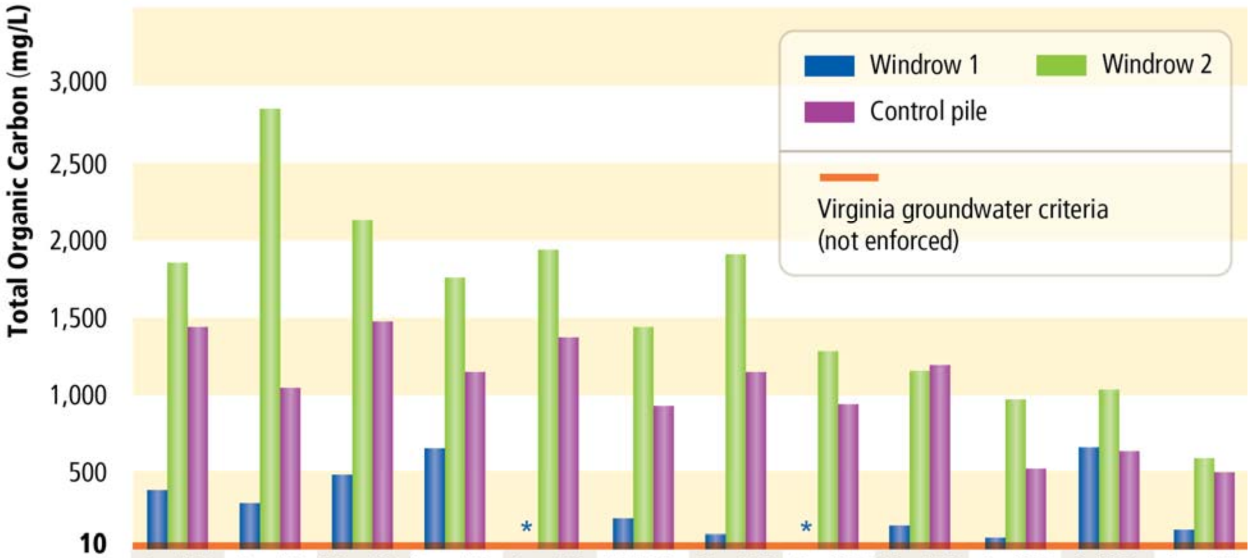
	Sep'10	Oct'10	Nov'10	Dec'10	Jan'11	Feb'11	Mar'11	Apr'11	May'11	Jun'11	Jul'11	Aug'11
Windrow 1	45	22.3	31.7	41.8	*	*	30.7	*	9.7	7.7	14.7	2.9
Windrow 2	92.3	79.6	107	102	82.5	63.6	64.2	44.5	15.2	10	7.0	11.8
Control pile	62.1	66.0	42.8	53.4	70	38.6	39.7	19.6	8.1	3.2	3.7	4.4

*Insufficient leachate volume for analysis.

Figure 14. Average Monthly Concentrations of Chloride in Samples of Leachate

Summary

Leachate results illustrate that soil filtration was effective at removing three of the four leachate contaminants analyzed (i.e., NH_3-N, Cl, and TOC), as evidenced by the significantly lower contaminant concentrations in leachate from Windrow 1 (after soil filtration) than those from Windrow 2 (with no soil filtration). Contaminants from deer windrows that may percolate to groundwater are expected to be even lower than those from Windrow 1 in this study. Although the mixed media (comprising crushed gravel and native soil) on which Windrow 1 was constructed was useful in this study in that it may represent a common surface type for potential future VDOT composting activities, gravel has the highest hydraulic conductivity of all soil types. Because of leachate's rapid percolation through this soil type, there is minimal contact between contaminants and soil particles (Buscot, 2010). The opportunity for contaminant removal was, therefore, minimized in this study, given that a portion of the 10 in through which leachate from Windrow 1 filtered was gravel rather than strictly native soil. To reach groundwater, leachate may filter through several additional feet of native soil, thereby increasing the degree of soil contact and the potential for protection from groundwater contamination (Das, 2010). Despite the fact that the remediation capability of soil was not fully realized in this study, results for three contaminants showed significant degradation from even minimal soil filtration.



	Sep'10	Oct'10	Nov'10	Dec'10	Jan'11	Feb'11	Mar'11	Apr'11	May'11	Jun'11	Jul'11	Aug'11
Windrow 1	330	268	496	610	*	215	100	*	172	86	699	113
Windrow 2	1830	2820	2180	1770	1900	1471	1890	1280	1119	984	1060	678
Control pile	1455	1070	1450	1150	1370	903	1110	967	1180	512	673	493

*Insufficient leachate volume for analysis.

Figure 15. Average Monthly Concentrations of Total Organic Carbon in Samples of Leachate

NO_3-N was the only contaminant with lower concentrations in unfiltered leachate from Windrow 2 than the filtered leachate from Windrow 1. However, it cannot be assumed from these results that soil filtration does not reduce NO_3-N concentrations. As described in the text associated with Figure 13, NO_3-N concentrations from Windrow 2's leachate may have been low as a result of saturated conditions created from the impermeable surface beneath Windrow 2 (which may have reduced the conversion of NH_3-N to NO_3-N). If so, this would invalidate a comparison between the pre-filtered NO_3-N concentrations from Windrow 2 and the filtered NO_3-N concentrations from Windrow 1.

Contaminant Mass Load

The contaminant mass loads for each studied contaminant are listed in Table 3. Because the total annual volume of leachate could not be definitively determined for Windrow 1 (i.e., lysimeters did not cover the entire area beneath the windrow), contaminant mass loads for Windrow 1 were extrapolated using the contaminant concentrations from Windrow 1 and the leachate volume from Windrow 2.

Contaminant mass load calculations were based on four deer per 8 ft by 12 ft plot, or the theoretical equivalent of 1,815 deer per acre. Because of the unlikelihood that this number of deer would be composted annually at any 1-acre VDOT site, the per acre values in Table 3 represent worst case scenarios. Nevertheless, contaminant mass loads were low, largely a result of the low volumes of leachate leaving the windrows following precipitation events. Although the cumulative concentrations of Cl and TOC were higher in leachate from the windrows than

Table 3. Contaminant Mass Loads From Windrows and Control Pile (per Plot and the Acre Equivalent)

	Contaminant Mass Load (lb/yr)							
	NO_3-N		NH_3-N		Cl		TOC	
	Plot	Acre	Plot	Acre	Plot	Acre	Plot	Acre
Windrow 1[1]	0.002	0.844	0.001	0.304	0.007	3.31	0.098	44.5
Windrow 2	0.001[2]	0.375[2]	0.002	0.726	0.018	8.17	0.503	228
Control pile	0	0	0.001	0.490	0.020	9.11	0.602	273

[1]Calculated using the contaminant concentrations from Windrow 1 and the leachate volume from Windrow 2.
[2]Intermittent saturated conditions may have affected nitrification in Windrow 2.

from the control pile (Figures 14 and 15), the mass loads of these contaminants were lower from the windrows as a result of the windrows' smaller leachate volumes. This volume discrepancy also explains the similar NH_3-N mass load values from the control pile as that from the windrows.

NO_3-N and NH_3-N are the most concerning contaminants in terms of groundwater pollution potential from farm waste composting and crop fertilization practices (Ballestero and Douglas, 1996; Glanville et al., 2009; Martins, 1992; Peigne and Girardin, 2004; Mid-Atlantic Regional Water Program, 2006). Comparing typical nitrogen losses from fertilizer application of common agronomic crops in Virginia provides perspective on nitrogen losses found in this study. Because NO_3-N is the end-product of nitrification (and NH_3-N is quickly transformed into NO_3-N in non-saturated soil), the total theoretical load of NO_3-N in leachate from a windrow was determined for comparison with NO_3-N losses from fertilizer application. This value was calculated by using the molar values of NH_3-N and NO_3-N to convert the mass load of NH_3-N (Table 3) to NO_3-N, and adding that value to the known mass load of NO_3-N (Table 3; G. Evanylo, personal communication). This calculation was conducted for Windrow 1, since intermittent saturated conditions may have affected nitrification (and therefore the mass load of NO_3-N) in Windrow 2. The result was a total NO_3-N loss of 1.9 lb/acre/year (2.1 kg/ha).

Common agronomic field crops (i.e., wheat, corn) typically receive 80 to 150 lb of nitrogen per acre during fertilizer application (Mid-Atlantic Regional Water Program, 2006; Virginia Department of Conservation and Recreation, 2005). A typical nitrogen use efficiency (or the proportion of nitrogen assimilated by plants) for wheat and corn in Virginia ranges between 50% and 60% (Allison, 1966). The remaining 40% to 50% is either sequestered in the soil, lost to the atmosphere as a gas, or lost by leaching as NO_3-N (Mid-Atlantic Regional Water Program, 2006). Although there is some variation in the literature regarding the proportion of NO_3-N lost by leaching from typical fertilization applications (5%-50%, Meisinger and Randall, 1991), a reasonable estimate given the soil and climatic conditions in Virginia is approximately 10% to 30% (Mid-Atlantic Regional Water Program, 2006). Losses are in the higher part of the range in coarse-textured (i.e., sandy) soils and at the lower part of the range in fine-textured (i.e., clay and loamy) soils (Mid-Atlantic Regional Water Program, 2006). Applying this range to the 80 to 150 lb of nitrogen applied to typical agronomic crops results in a NO_3-N loss of 8 to 45 lb/acre, compared to the 1.9 lb/acre loss by leaching from Windrow 1.

Observations Regarding Odor, Presence of Scavengers, Runoff, and Remaining Tissue or Bones

Within the first 4 weeks of composting, a slight odor was present up to approximately 20 ft of the windrows. These observations corresponded with the period of highest windrow temperatures. No odor was detected 50 ft from the windrows, the property line setback distance specified in VSWMR (Virginia Register of Regulations, 2011). Odor from properly constructed windrows is not expected to be detected at the 200 ft setback distance from a residential property or public facility (DEQ, 2011).

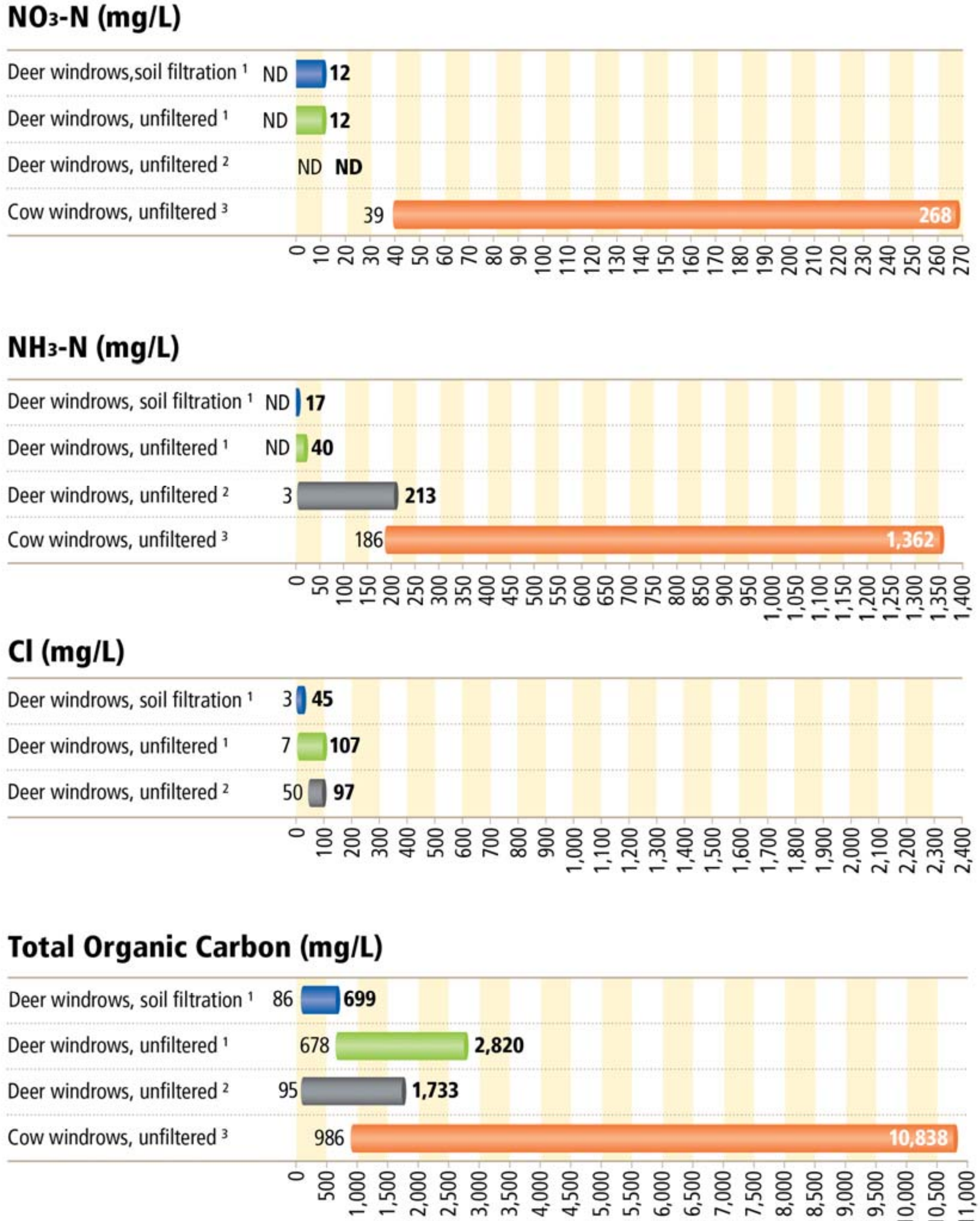
At Month 6, a narrow hole approximately 6 in deep was visible in Windrow 2. This was the only evidence indicating that scavengers may have investigated the windrows. Scavengers are presumed to be deterred from high windrow temperatures during the active composting phase (J. Bonhotal, personal communication).

The 1-year monitoring period included 28 visits to the study site during and immediately following precipitation events. Paths of water extending from the windrows (i.e., leachate or runoff) were not visible during any of these visits.

At the end of the 1-year monitoring period, windrows were dismantled and examined for remaining bones or tissues. A total of five bones ranging in length from 2 to 5 in were found in the experimental windrows. In New York state composting operations, bones are added to new compost piles (J. Bonhotal, personal communication).

Regulatory Context for Study Results

Like U.S. EPA, DEQ promotes composting to reduce the volume of organic waste disposed of in Virginia (DEQ, 2009). In 2009, DEQ issued a waste guidance memo that was drafted as an emergency measure following a mad-cow disease rendering ban for cattle (G. Simmerman, personal communication). This memo, entitled *On-site Composting of Routine Animal Mortality* (DEQ, 2009), provides guidance specifically for animal carcass windrows associated with livestock, poultry, and aquaculture mortality. Although this document was written to address farm animal and aquaculture mortality, its guidelines for constructing windrows are similar to those for "roadkill" composting methods followed by New York state and Montana transportation departments and those recommended in the recent VCTIR study (Donaldson and Moruza, 2009). In March 2011, changes to the VSWMR reflect this guidance document's criteria for farm animal carcass composting. Under 9 VAC 20-81-95.D.4, composting animals onsite at the farm of generation is exempt from the solid waste composting requirements (Virginia Register of Regulations, 2011). With adherence to certain site requirements and setback distances, compost animal mortality windrows constructed at the farm of generation can therefore be constructed on bare ground with the natural filtration of leachate. This exemption was made in order to provide agricultural operations greater flexibility for managing mortalities given recent changes in rendering facility requirements that increased restrictions on the use of animal carcasses (DEQ, 2011).



[1]Current study's range of contaminant concentrations in leachate grab samples collected over a 1-year period. *Soil filtration* refers to samples collected from lysimeters buried 10 in beneath a windrow. *Unfiltered* refers to samples collected from a windrow constructed on an impermeable surface. Woodchips were used as the cover material.
[2]Bonhotal et al. (2009). Range of contaminant concentrations in leachate grab samples. "Unfiltered" refers to samples collected over a 2-month period from a windrow constructed on an impermeable surface. Woodchips were used as the cover material.
[3]Glanville et al. (2006). Mean contaminant concentrations in leachate composite samples collected over a 1-year period. Mean values were derived from 2 trials for each of 3 cover materials (a straw/manure combination, silage, or cornstalks).

Figure 16. Comparison of Leachate Contaminant Concentrations From Deer Windrow and Cow Windrow Studies

These changes in rendering facility requirements also limited carcass management options for some VDOT maintenance areas (R. Jones, personal communication). However, the equivalent form of DEQ's regulatory relief and guidance document for livestock mortality composting (DEQ, 2009) does not exist for composting animal killed from vehicle collisions. VDOT composting activities must therefore follow the more rigorous VSWMR requirements. Given the initial capital construction and operating costs and labor required by VDOT maintenance areas to satisfy these requirements, these factors may be perceived by VDOT maintenance staff as negating the benefits of composting and might inhibit its implementation at VDOT maintenance areas.

Figure 16 provides a useful comparison between the pollution potential for cows, a common farm animal exempt from current windrow composting regulations, to that for deer, an animal that represents a disposal challenge for VDOT. Of particular interest are the relative contributions of nitrogen compounds, pollutants of particular concern in terms of surface and groundwater contamination.

Although the study results shown in Figure 16 varied with regard to sampling intervals and techniques, the findings illustrate that the highest contaminant concentrations from deer windrows constructed from woodchips were 9 times lower than those from cow windrows constructed from cover material common to farms (i.e., straw, manure, cornstalks, silage). This is likely a result of lower nutrient loads in deer mortality windrows (from deer's smaller mass than cows) and the lower nitrogen content in woodchips than in cover material common to farms (Ballestero and Douglas, 1996; Glanville et al., 2009). Despite relatively high concentrations of leachate captured at the base of cow mortality windrows, statistically significant increases in contaminant concentrations following windrow construction were limited to the top 15 to 30 cm of soil with windrows constructed of cover materials having a relatively high water-absorbing capacity and a relatively low nitrogen content Glanville et al., 2009).

SUMMARY OF FINDINGS

- The maximum temperature (156° F / 69° C) in the experimental windrows was attained by Day 4. Temperatures of the two experimental windrows were statistically the same as control pile temperatures 10 and 11 months after windrow construction.
- *E. coli* and *Salmonella* in flasks in both experimental windrows were reduced by 99.99% by the first sampling date (Day 7) and reached zero growth by the second sampling date (Day 14) of the study. Intact ascarid eggs in both experimental flasks were reduced by a statistically significant degree by the first sampling date and ascarid eggs were deemed non-viable by Day 77.
- Of the precipitation that fell on the windrow plots over the course of the 1-year study period, 2% left the piles in the form of leachate. The remaining 98% evaporated from windrows, was absorbed by windrows, and/or shed from the windrow sides (as runoff).

- Soil filtration was effective at reducing the concentrations of three of the four contaminants evaluated: NH_3-N (23% reduction), Cl (59% reduction), and TOC (78% reduction). The cumulative concentrations of these contaminants were lower by a statistically significant degree in leachate that filtered through 10 in of compacted aggregate and native soil than in leachate captured from an impermeable surface. Cumulative NO_3-N concentrations were lower in leachate captured from an impermeable surface than from beneath the soil.

- Nitrate, a contaminant of particular regulatory concern, had an estimated mass contaminant loss of 1.9 lb/acre, compared to the 8 to 45 lb/acre estimated nitrate loss from fertilizer application of agronomic crops in Virginia. This is largely attributed to the low volume of leachate leaving windrows.

- Virginia composting regulations have been recently revised to allow the natural soil filtration of leachate from animal mortality windrows constructed onsite at the farm of generation. Leachate from compost windrows containing deer and other mortality collected from roadways, however, must be captured and prevented from infiltrating soil. The highest contaminant concentrations from deer windrows constructed from woodchips were 9 times lower than those from cow windrows constructed from cover material common to farms.

CONCLUSIONS

- *The high temperatures attained quickly within deer mortality static compost windrows (i.e., a maximum of 156° F / 69° C) meet the federal time and temperature pathogen destruction composting requirements.* In this study, both experimental windrows met the federal time and temperature pathogen destruction composting requirements by Day 5.

- *Pathogens are thoroughly destroyed through thermal destruction within a deer mortality static compost windrow.* From counts of pathogens placed in flasks within windrows, *E.coli* and *Salmonella* were rapidly destroyed and ascarid eggs were deemed non-viable in less than 3 months.

- *Volumes of leachate leaving deer mortality windrows are low (e.g., 2% of the precipitation that fell on the windrow plots left in the form of leachate).*

- *Soil filtration further reduces the concentrations of most evaluated contaminants.* In this study, filtration of leachate through 10 in of mixed media soil was effective at reducing three of the four contaminants analyzed (23% reduction of ammonia-nitrogen, 59% reduction of chloride, and 78% reduction of total organic carbon).

- *Contaminant mass loads from deer mortality windrows are low (e.g., less than 2 lb/acre) as a result of low leachate volume and low contaminant concentrations.* Mass loads were lower than estimated nitrogen losses from fertilizer application of crops in Virginia, which are an estimated 8 to 45 lb/acre.

- *Deer mortality windrows emit odor only in initial weeks; are not affected by scavengers; do not create paths of visible runoff; and break down material with only a few small remaining bones.*

- *Virginia composting regulations have been recently revised to allow the natural soil filtration of leachate from animal mortality windrows constructed onsite at the farm of generation.* Leachate from compost windrows containing deer and other mortality collected from roadways, however, must be captured and prevented from infiltrating soil. Nitrogen compounds and other contaminant losses from deer mortality windrows are much lower than those reported for cow mortality windrows.

RECOMMENDATION

1. *VDOT's Environmental Division may wish to brief DEQ with regard to the results of this study and discuss whether changes in current deer composting requirements may be appropriate.* Decisions regarding the environmental acceptability of deer composting should be made in the context of the potential environmental impacts of VDOT's current carcass management practices (landfill disposal and burial).

BENEFITS AND IMPLEMENTATION PROSPECTS

Potential Cost Savings

Providing VDOT the option to construct windrows on bare ground would meet a need for some maintenance areas that have limited availability of nearby disposal sites or viable burial areas. It also has the potential to reduce carcass management costs. Donaldson and Moruza (2009) used VDOT maintenance area survey responses to calculate potential savings with the implementation of windrow composting. The calculations were developed to estimate the total annual savings to VDOT if a portion of VDOT maintenance areas that currently use a landfill were to replace this disposal method with compost windrows located at the maintenance area or along a routine maintenance route.

VDOT spent an annual average of $4.1 million on carcass removal and disposal in the past five fiscal years (2007-2011). If current practices were replaced by windrow composting at the 46 area headquarters that frequently use a disposal facility and travel off-route to reach the facility or pay a fee to use the facility, the annual savings to VDOT would be approximately $515,440 (Donaldson and Moruza (2009). This estimate would be substantially higher if the 21% of area headquarters that occasionally use a landfill were included in the calculation. In addition, if all area headquarters whose staff travel off-route to disposal facilities composted carcasses at a VDOT maintenance area, the fuel and carbon emissions expended from an estimated 252,000 mi/year of driving could be eliminated (Donaldson and Moruza, 2009).

An indirect benefit from the removal of carcasses from the right of way (as opposed to carcass burial) would be that VDOT would satisfy total maximum daily load (TMDL) requirements regulated by DEQ (R. Mills, personal communication). A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still comply with water quality standards (U.S. EPA, 2008). To be compliant with TMDL requirements, VDOT must identify outfall structures (such as stormwater pipes) in the identified water body and determine the annual stormwater and pollutant discharge for such outfalls through characteristic modeling. This process costs VDOT up to several hundred thousand dollars per project depending on the size of the particular TMDL watershed (R. Mills, personal communication). According to VDOT staff (R. Mills, personal communication), DEQ has stated that VDOT's removal and proper management of animal carcasses (as opposed to burying carcasses in the right of way and the carcasses becoming a potential source of pathogens in the watershed) will satisfy TMDL requirements in those areas where bacteria comprise the pollutant of concern. This will relieve VDOT from conducting expensive studies and likely increase VDOT's emphasis on carcass removal and management (i.e., landfill disposal or composting) (R. Mills, personal communication).

Future Work Toward Implementation

Following completion of an ongoing compost vessel study, discussions with DEQ, and the investigation of compost end use options, VCTIR will work with VDOT to create guidelines and video training for windrow and vessel methods of animal mortality composting. This will increase implementation prospects and provide maintenance areas with more options for carcass management.

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APPENDIX

CUMULATIVE ANALYSES OF LEACHATE CONTAMINANTS

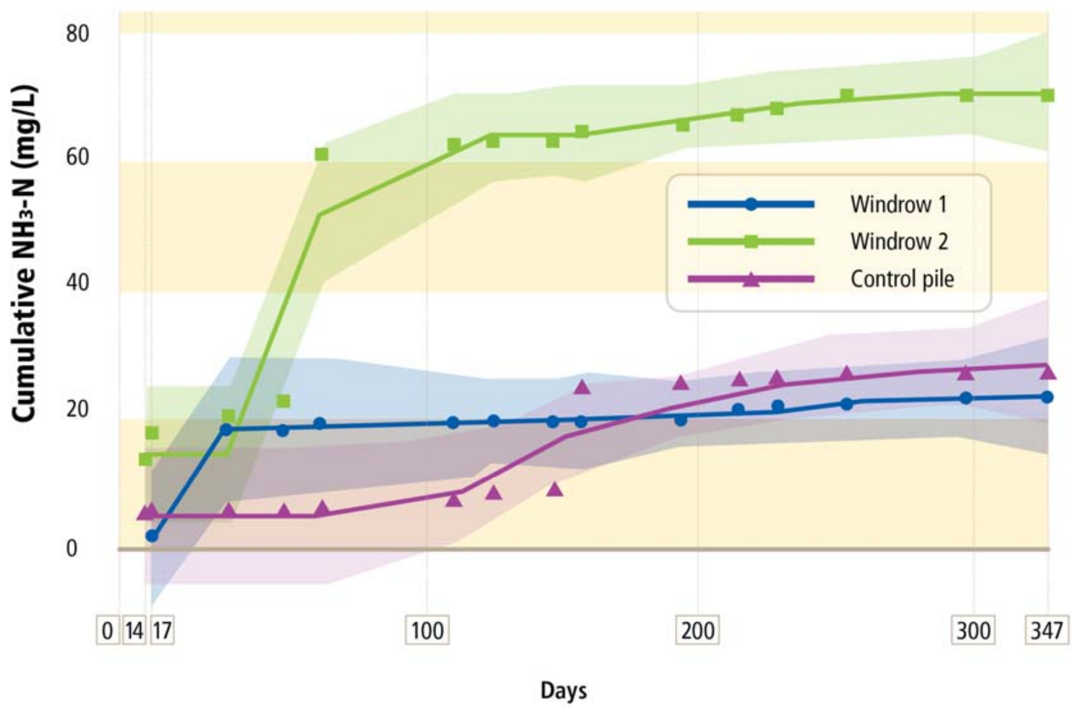

Figure A1. Predictions of Monotone Spline Regressions for Cumulative Concentrations of NH3-N in Leachate Samples. ***Thick lines*** **indicate the predicted mean level of cumulative concentration on a specific day.** ***Shaded bands*** **indicate the 95th percentile interval of the predicted mean level of cumulative concentration.**

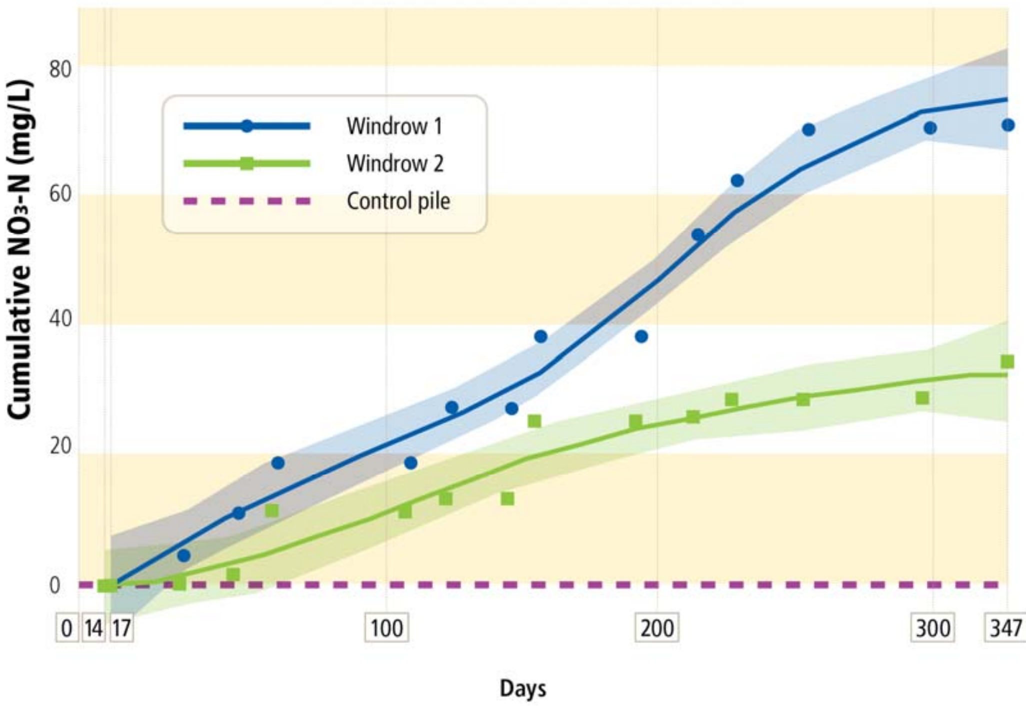

Figure A2. Cumulative Concentrations of NO_3-N in Leachate Samples. ***Thick lines*** **indicate the predicted mean level of cumulative concentration on a specific day.** ***Shaded bands*** **indicate the 95th percentile interval of the predicted mean level of cumulative concentration.**

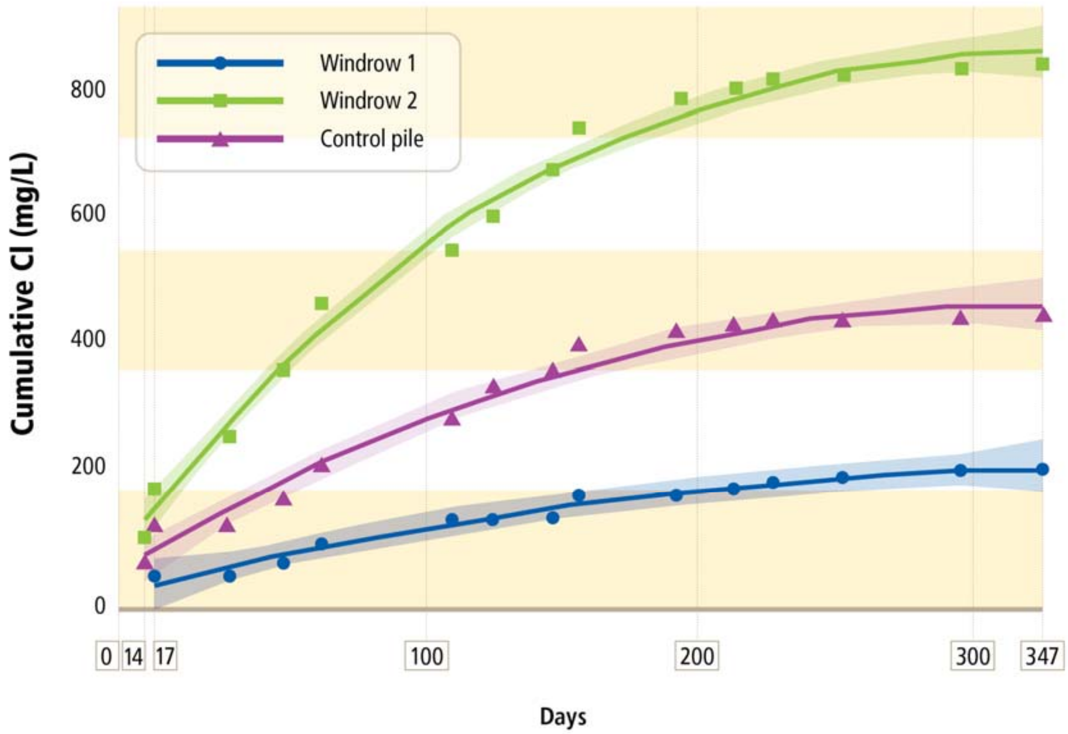

Figure A3. Cumulative Concentrations of Cl in Leachate Samples. ***Thick lines*** **indicate the predicted mean level of cumulative concentration on a specific day.** ***Shaded bands*** **indicate the 95th percentile interval of the predicted mean level of cumulative concentration.**

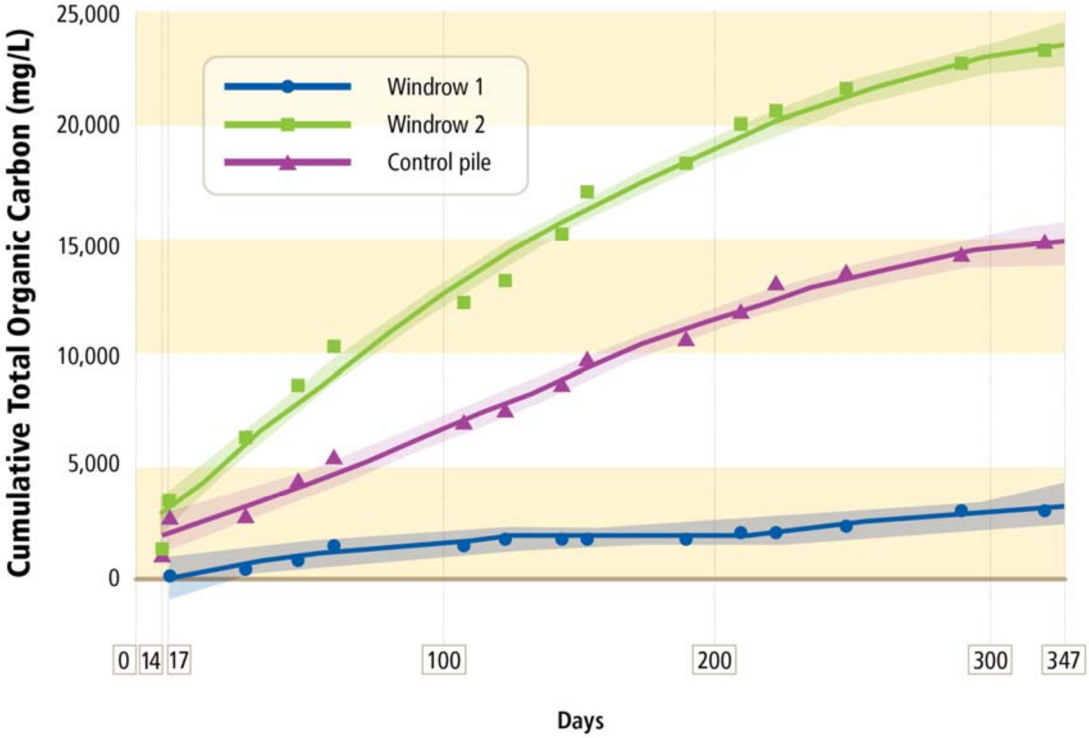

Figure A4. Cumulative Concentrations of TOC in Leachate Samples. ***Thick lines*** **indicate the predicted mean level of cumulative concentration on a specific day.** ***Shaded bands*** **indicate the 95th percentile interval of the predicted mean level of cumulative concentration.**