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Feasibility of Composting as an Alternative Disposal Method for Wildlife Vehicle Collision-induced Carcasses in Colorado Department of Transportation Processes

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16. Abstract

The Colorado Department of Transportation (CDOT) Region 1 Environmental Unit undertook a pilot project that utilized roadkill carcasses as compost material. Wildlife-vehicle collisions (WVC) are the fourth most common type of vehicle collision crash in Colorado. CDOT maintenance staff are tasked with the removal of carcasses from the roadway to prevent further WVCs created by scavengers, eliminate roadside hazards for drivers, and to maintain public health through reduction in pathogens entering into the soil, groundwater, and aquatic communities. Successful carcass composting requires a carbon source (woodchips), a nitrogen source (carcasses), a microbe inoculum (hot finished compost), and water. The physical construction of the compost pile included a combination of these elements in layers, the depths of which vary by season to account for changes in ambient air temperature surrounding the pile. The project used a combination of active and passive composting over the course of the study. Temperature and soil moisture were collected daily to inform pile lifecycle status and pile actions needed. As the site location was not adjoining a CDOT facility, remote monitoring and photographic documentation was collected daily via trail cameras, and by CDOT/project team personnel whenever visiting the site. A total of seven compost piles were started and completed over the course of the pilot project, five of which reached pathogen reduction temperatures. This pilot project determined that carcass composting is viable within the dry Colorado climate, and with a few modifications to current CDOT operating procedures, adequate resources, and staff availability, it could be included in CDOT maintenance workflows to increase efficiency and lower roadkill work order costs.

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Introduction

Background

The Colorado Department of Transportation (CDOT) Region 1 Environmental Unit undertook a pilot project that utilized roadkill carcasses as compost material. Wildlife-vehicle collisions (WVC) are the fourth most common type of vehicle collision crash in Colorado. CDOT maintenance staff are tasked with removal of carcasses from the roadway to prevent further WVCs created by scavengers, and to maintain public health through reduction in pathogens entering into the soil, groundwater, and aquatic communities.

Current disposal methods of carcasses within the study region (maintenance section 5) include above ground relocation away from a roadway, onsite burial or abandonment (moving further into the ditch, away from the roadway, or out of sight), and relocation of the carcass to a landfill facility. Each of these current methods has unique and individual drawbacks. Aboveground relocation refers to when carcasses are picked up and transported to an out-of-sight area and left out for scavengers. This method creates unpleasant odors, as well as poses a public health concern as carcasses are left exposed to the public and allows pathogens to openly persist in the environment. Onsite burial (or abandonment) is where a small hole is dug for the carcass and it is buried at, or near to, the site. This disposal option is more labor-intensive than above-ground disposal, but reduces risk to human health, and allows for nutrients to be returned to the soil. The last commonly used method is disposal within a landfill facility. For this method, CDOT maintenance staff pick-up the carcasses and haul them to a nearby landfill facility. This disposal method creates a useful balance between staff labor and public health but adds to the continued problem of landfill capacity, fuel consumption, greenhouse gas emissions, and has additional disposal costs. Overall, there is no one-size-fits-all approach to the disposal of WVC carcasses. This study aims to investigate if a more controllable, sustainable, and economically viable disposal option may be available and feasible to CDOT staff.

Objectives

The objectives of this pilot project are to:

- Investigate carcass composting as an alternative to current carcass disposal methods and provide guidance and recommendations for future composting facilities in other CDOT regions.
- Determine the feasibility and practicality of carcass composting in statewide CDOT processes, streamlining the process to make it a practical procedure for CDOT maintenance crews.
- Adapt current carcass composting methodologies to Colorado's climate regime.
- Provide site specific oversight, guidance, and best management practices for the carcass composting facility. Document and implement adaptive management strategies to aid project success.
- Provide recommendations related to efficiency, cost, potential water and air pollution, and promote the use of repurposed materials.
- Assist with CDOT's sustainability goals of economic viability, ecosystem protection, and reduced resource consumption.

- Document and develop lessons learned from the study to draft a Colorado-specific maintenance manual for other CDOT regions.

Scope

Planning, creation, and maintenance of a carcass composting facility in Franktown, Colorado, within a CDOT-owned property, for a period of two years from the start of composting. WVC carcasses will be brought to the compost site solely from CDOT Region 1, maintenance sections 5, which was chosen for its high occurrence of WVCs.

Methods

Site Selection

The project team was limited in site selection to those areas currently owned by CDOT within Region 1 that contained adequate space for the project. Potential candidate sites were then assessed for the large-scale, and small-scale considerations listed below. The composting pilot project had to gain approval from the Colorado Department of Public Health and Environment (CDPHE) and go through a Douglas County land use approval process, which included a public comment period. In addition, a compost report was compiled annually by CDOT and submitted to CDPHE by March 1st of each year.

Large-Scale Considerations

Geology & Soils

Data from the Geological Society of America were reviewed to determine geologic and soil characteristics of the sites including geologic formation and age, and landforms (Colorado Geological Survey, 2006). The Natural Resource Conservation Services provided information regarding the soil types in the area including parent material, runoff capacity, frequency for flooding or ponding, and slope stability (NRCS, 2019). The United States Geological Society (USGS) Earthquake Hazards Program was reviewed to determine nearby fault lines (USGS, 2010). The USGS National Atlas was consulted to determine earthquake risk percent (USGS, 2020). The Colorado Geological Survey provided insight into the soil composition and propensity for collapse and the history of landslides at the sites. This data retrieval effort informed the structural integrity of the site location.

Water Resources

As carcasses decompose, they release about 1/3 of their original mass as fluid. This ability to release fluids makes the prevention of water contamination an important consideration. Sites were assessed for their Federal Emergency Management Agency (FEMA) flood hazard rating (FEMA, 2019). The United States Fish and Wildlife Service (USFWS) National Wetland Inventory (NWI) Wetlands Mapper was reviewed for site proximity to aerially identified/interpreted wetlands and waters (USFWS, 2019). A well search was completed through the Colorado Water Conservation Board (CWCB) to determine the presence of permitted water wells at or near the sites (CWCB, 2014). The CWCB also provided information regarding the aquifer characteristics at the sites. This data helped inform potential for leachate or compost material itself to migrate outside of the site or down into groundwater.

Local-Scale Considerations

Additional localized considerations for choosing the project site centered around suitability for the project itself, current and adjacent land uses, visual exposure, and surface water control. The selected site needed to be large enough to accommodate storage of the compost bins themselves and the supporting materials (carbon source, starter compost), as well as compost pile maintenance equipment. The site should, ideally, have access to a water source for easier pile maintenance during the summer months of the project. Adjacent land use, including distance from residential development, was assessed since the project has the potential to create undesirable environmental conditions such as odors if not properly managed. Local topography was reviewed to determine the line of sight from nearby residential areas, and from nearby public thoroughfares such as State Highway (SH) 83, as well as the ability of liquids to migrate to/from the site.

Project Setup

After careful review of large-scale and local-scale considerations, past WVC location and frequency data, the pilot site was selected. Next, the project team determined how to design and implement the compost operations within the selected location. Some of the setup considerations included material used for compost bin construction, the carbon source for compost piles, materials included in the compost piles, type and frequency of data to be collected, and pile maintenance and management practices. These considerations are described in the following paragraphs.

Materials

Compost Bin Construction

Each compost bin was constructed within a three-sided container made of concrete jersey barriers. On the floor of each bin, a semi-impermeable layer of compacted asphalt millings was installed to limit leachate infiltration into the ground. The compacted millings layer could also be installed prior to jersey barrier placement. These bins were originally constructed as approximately 8-feet (ft) by 8-ft. Three bins were constructed at the beginning of the project, two for active composting and one for bulking agent. As the pilot project progressed, two more active composting bins were created. The active compost bins were expanded to 16-ft by 8-ft, and a larger bin (24-ft x 8-ft) for curing compost material was installed on the north end of the site. A total of four composting bins and one curing bin were created at full operational capacity.

Composting Materials

Materials needed to start composting activities onsite included commercially sourced starter compost (inoculation), woodchip bulking material (carbon source), carcasses (nitrogen source), and water. At the start of composting activities, “hot” (still somewhat active) starter compost was used to provide a boost of appropriate microbes for decomposition. The project team acquired commercial black-tea compost, meeting CDOT specifications, from B.O.S.S compost in Fort Lupton, Colorado. This was stored onsite and used initially to start new compost piles. As time progressed and new piles were created, additional black-tea compost was not needed because finished compost generated from the carcass composting operation was available.

For carbon, the project team utilized woodchips that had previously been stockpiled onsite as the bulking agent. These woodchips were generally smaller than fist-sized, and already created as a bi-product of CDOT vegetation management practices. Sawdust is also an acceptable bulking agent but may require modifications in protocol due to its high surface area (additional pile maintenance, change in C:N ratio); however, the pilot project did not test sawdust as a carbon source. Sawdust was successfully used by MDT for composting bighorn sheep in northwest Montana; however, the process was adjusted for the carbon source (Helm 2023).

Carcasses served as the nitrogen source for microbes in the compost piles. Carcass sizes typically ranged from coyote (small) to elk (large), with the majority of carcasses observed to be mule deer. Overall, the ratio of carbon to nitrogen in carcasses is fairly high ranging from 25-40 parts carbon per 1 part nitrogen (MDT, 2020).

Once built, the pile should be wetted, or the woodchips should be wet before building the pile. The Franktown site does not have a readily available water source onsite, so watering was completed using a truck-mounted water tank and sprayer and completed at infrequent intervals.

Water Source

A water source is highly recommended to accurately and safely compost. Ideally, a water tap would be available, but if not, a truck mounted watering tank may be the next best option. For a more "readily available" solution, a water tank stored onsite would create a more consistently available source, if multiple people are managing the operation (as opposed to one person with the water truck/tank combination).

Compost Pile Design

Pile Nomenclature

To reference particular compost piles accurately and consistently within each compost bin, each bin was given a letter at the start of the project. As new piles were started in the same bin, a second identifier for pile iteration was added. For example, pile A-1 is the first compost pile that was placed in compost bin A, while A-2 is the second compost pile created in that same bin.

Pile Construction

Compost piles are comprised of carbon and nitrogen-based components. Carbon acts as the bulking agent, moisture absorber, and microbe food (e.g., sawdust, woodchips, clippings, etc.), and nitrogen provides the microbes with proteins, amino acids, and enzymes for growth (carcasses). Finished compost is also used to inoculate new compost piles with the appropriate microbe community. The physical construction or "build" of the compost pile includes a combination of these elements in layers, the depths of which vary by the season to account for changes in ambient air temperature surrounding the pile. Maintaining pile temperatures is key to achieving overall decomposition and pathogen reduction, and the pile should be constructed accordingly. The main difference between pile builds is an additional layer of finished compost near the bottom of the pile, and varying depths of finished compost and woodchips at the top and bottom of the pile. Figure 1 depicts an example layout of summer and winter pile builds.

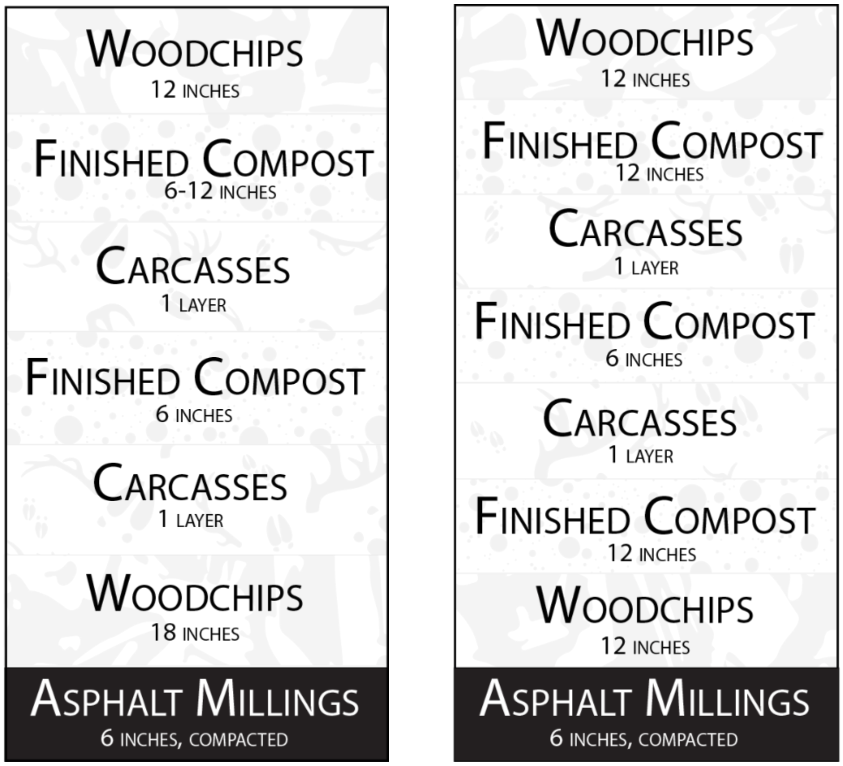

Figure 1. Example compost summer pile build (left) and compost winter pile build (right)

Composting activities at the pilot project site started in Fall of 2021; therefore, the piles were initially built to winter specifications. Starting in May 2022, the summer build was used for piles A2, C2, and D1, before moving back to the winter build for Pile A3 in December 2022.

Composting Approach

Two composting approaches were considered for this pilot project: active and passive composting. Depending on the composting approach, pile management and action were slightly different. In general, passive composting requires less pile interaction than active composting. This means checking the pile temperature and moisture less frequently, and manipulating the pile only when negative environmental conditions exist. Passive composting encompasses a "set-it-and-forget-it" mentality, whereas active composting requires frequent pile actions based on pile conditions. The active composting approach speeds up the composting process as pile conditions are closely monitored with action taken when the piles reach critical moisture or temperature thresholds. The pilot project used a combination of active and passive pile approaches over the course of the study. Active composting methods were applied at the beginning of the project for piles A1 and B1. As the project progressed and maintenance crew involvement fluctuated, the project switched to a passive approach for piles A2, A3, B2, C2, and D1 to achieve composting goals with less pile interaction.

Data Collection Design

Data collection is paramount to determining efficient carcass composting practices in the semi-arid climates of Colorado. Not only is quantitative data, such as temperature and soil moisture, needed to inform pile action decisions, but qualitative data is also needed to assess overall site condition and efficacy of the composting design and approach. The project team took a three-prong approach to data collection that included visual (qualitative) assessments, in-pile condition monitoring including temperature and soil moisture (quantitative), and in-field compost sampling to evaluate process efficacy and pathogen reduction.

Qualitative Visual Assessments

Visual site assessments were conducted via two routes: onsite observations from the project team and maintenance crew, and through cellular-enabled trail cameras. This two-fold approach was chosen since the site was not located directly adjacent to a CDOT facility with daily staffing. This created flexibility for the maintenance crew schedules without sacrificing site observations.

When onsite, the project team took photos and notes regarding overall site conditions, pile conditions, and the presence of negative environmental conditions. The maintenance crew was also required to document onsite conditions when completing pile actions (carcass additions, watering, turning, etc.) via a Google Survey Form or onsite paper log.

To capture observations between personnel visits, cellular-enabled trail cameras were set up at the site to provide close views of each compost pile as well as an overview of the project site. The cameras were set to take photos daily, as well as each time the motion sensor was triggered. Photos taken were uploaded automatically to a Google Drive folder for the project team to review. The photos also captured presence of non-project related trespassers (public), visits from the maintenance crew, and presence of scavengers.

Quantitative Data Collection

Quantitative data collected for each pile included daily temperature and soil moisture measurements. The project team deployed two methods for collecting quantitative data in this remote setting. First, temperature and soil moisture probes (manual probes) were set to face the trail camera which would then record pile conditions via photos, which were then transcribed manually. Secondly, part of the way through the study, a wireless, cellular-enabled datalogger system was installed onsite that automatically collected temperature and soil moisture data via sensors. The data from the sensors transmitted wirelessly to the cellular-enabled datalogger, which uploaded the data to a dashboard hosted online (viewable at any time and depicted in Figure 2). Both methods collected data at an interval of one day or less. The data captured was then analyzed by the project team to determine when pile actions should occur, such as turning a pile once temperatures have peaked and then lowered.

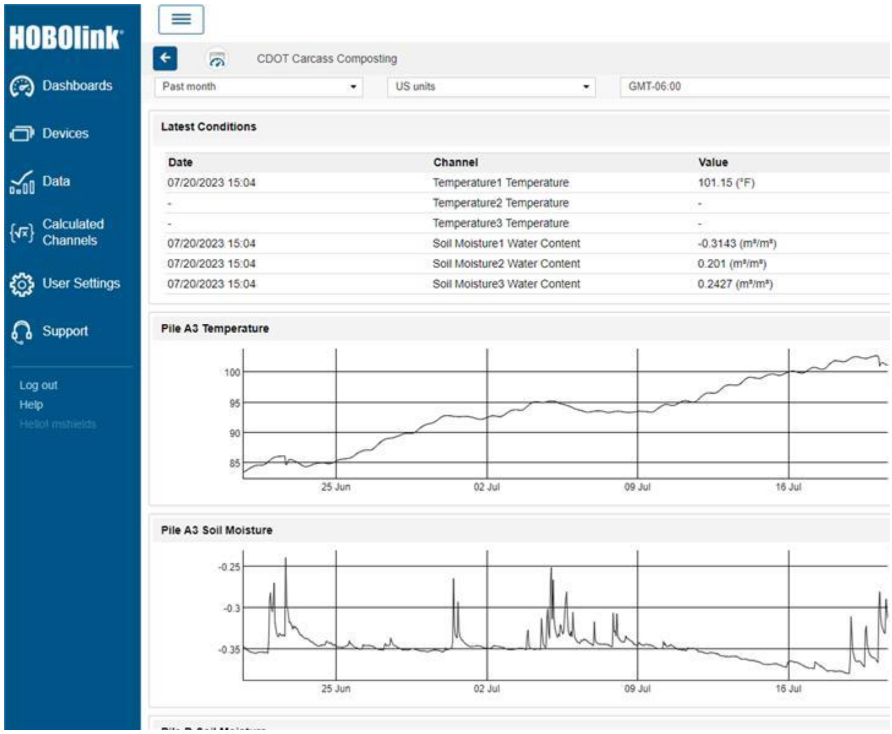

Figure 2. Example of automated data collection dashboard using Hobo data loggers

Physical Sampling: Pathogen Testing

Compost regulations are codified in the Colorado Code of Regulations and regulated through the Colorado Department of Public Health and Environment (CDPHE) (6 CCR 1007-2, Part 1, Section 14.6, 2016). These regulations dictate the sampling standards, frequency, timing, and methodology that should be used for state-permitted compost facilities. Per the regulations, pathogen testing should occur once annually or once every 10,000 cubic yards of compost produced, whichever is more frequent. The acceptable/passing parameters for distribution of the compost product includes a density of fecal coliform of less than 1000 Most Probable Number (MPN) per gram of total solids (dry weight basis); or the density of Salmonella sp. Bacteria in the compost is less than three MPN per four grams of total solids (dry weight basis) at the time the compost is to be sold or otherwise distributed for use.

Results and Discussion

Pile Lifecycle

A total of seven compost piles were started and completed over the course of the pilot project. Due to inaccurate or incomplete reporting, carcasses per pile ranged from 4 to 11, although each pile likely contained more. Yearly pile temperatures ranged from 40°F (Winter 2023) to 160°F (Fall 2021). Most of the piles only completed a single heat cycle before they were moved to cure but were able to achieve temperatures indicative of pathogen reduction (>131°F) during that cycle. Two piles did not achieve pathogen reduction and were moved prematurely to the curing pile. Table 1 below provides a brief synopsis of the lifecycle for each completed pile associated with the project. Further detail regarding each pile is included in the paragraphs below.

Table 1.Summary Table of Pile Iteration Conditions

Pile Iteration	Start Date	Moved to Curing Pile	Active vs Passive	Max Temp	Min Temp	# of Heat Cycles	Pathogen Reduction Achieved	# of Times Watered	# of Times Turned
A1	11/16/2021	4/29/2022	Active	160°F	80°F	2	Yes	0	1
A2	5/3/2022	12/7/2022	Passive	134°F	78°F	1	Yes	1	1
A3	12/7/2022	--	Passive	104°F	40°F	0	No	0	0
B1	12/6/2021	1/13/2022		136°F	87°F	1	Yes	0	1
B2	1/18/2022	12/7/2022	Passive	142°F	88°F	2	Yes	1	2
C2	6/19/2022	12/7/2022	Passive	118°F	96°F	2	No	1	1
D1	6/8/2022	12/7/2022	Passive	140°F	80°F	1	Yes	1	1

Pile A1 Synopsis:

No. Carcasses:	14	Start Date:	November 16, 2021
Times Watered:	0	Turn Date:	March 24, 2022
Heat Cycles:	2	Moved to Curing:	April 26, 2022
Pathogen Reduction:	Yes	Build:	Winter
Min Temp:	80°F	Approach:	Active
Max Temp:	160°F	Δ Air/Pile Temp:	70°F

Pile A1 became very hot which may have resulted in some microbe die-off due to extreme temperatures, which happens around 140-158°F. The added carbon material helped maintain pile temperatures during the winter months and was, on average, 70°F warmer than the average ambient air temperature. Moisture in the pile was not well documented despite soil moisture probe use. The soil moisture probes measure on a scale from 0 to 10, with 10 being saturated. The average soil was 1.17 over the course of the pile life, with the highest moisture readings shortly after the pile was started, likely due to liquid release from the carcasses as they began decomposition. Precipitation data from the National Oceanic and Atmospheric Administration (NOAA) website was reviewed to assess the efficacy of the soil moisture probes. Nine precipitation events (summation of rain and snow totals) were identified from this review, resulting in greater than 2 inches occurred in the area during the Pile A1 life (NOAA, 2023). None of these events corresponded to an increase in pile soil moisture; although a large snowfall event on 1/1/21 obscured probe faces and likely resulted in a change in soil moisture. Onset probes were not installed in Pile A1 and no additional soil moisture data is available for comparison.

Pile A2 Synopsis

No. Carcasses:	11	Start Date:	May 3, 2022
Times Watered:	1	Turn Date:	September 22, 2022
Heat Cycles:	1	Moved to Curing:	December 7, 2022
Pathogen Reduction:	Yes	Build:	Summer
Min Temp:	78°F	Approach:	Passive
Max Temp:	134°F	Δ Air/Pile Temp:	46°F

Despite watering, the soil moisture sensors did not register a change in moisture for the pile. This may be attributed to many reasons including (but not limited to) inadequate water application, the probe was not positioned in an area that received the water, or the probe type is not adequate for detecting moisture in a compost pile environment. On average, the soil moisture probes measured an average of 0.006 over the pile life, indicating the pile was very dry. No large precipitation events (>2 inches) were measured during the life of this pile, which likely contributed to pile dryness. No Onset data was available for comparison.

Pile A3 Synopsis

No. Carcasses:	Unk	Start Date:	December 7, 2022
Times Watered:	0	Turn Date:	N/A
Heat Cycles:	0	Moved to Curing:	N/A
Pathogen Reduction:	No	Build:	Winter
Min Temp:	40°F	Approach:	Passive
Max Temp:	103°F	Δ Air/Pile Temp:	26°F

Despite the inefficient composting processes observed in Pile A3, this was the first pile with a full temperature and soil moisture profile from the Onset probes. The soil moisture probe readings were outside of the expected range which could indicate poor soil/probe connectivity, a non-soil fragment stuck in the probe, interference from the insertion rod, or high sand or salt content. The Onset temperature data for Pile A3 had a higher level of accuracy compared to the manual temperature probe; however, the average difference between the two probes was 2°F. There were a handful of days at the beginning of January where the Onset temperature probe recorded values 10-17° cooler than the manual probe. Once these outliers are removed, the average temperature difference between the two probe types is less than 1°.

Pile B1 Synopsis

No. Carcasses:	6	Start Date:	November, 29, 2021
Times Watered:	0	Turn Date:	January 10, 2022
Heat Cycles:	1	Moved to Curing:	January 13, 2022
Pathogen Reduction:	Yes	Build:	Winter
Min Temp	87°F	Approach:	Active
Max Temp	136°F	Δ Air/Pile Temp:	65°F

The average soil moisture as read by the soil moisture probe was 4 over the course of the pile life, with the highest moisture readings shortly after the pile was started. This is likely due to liquid release from the carcasses as they began decomposition. One precipitation event (including rain and snow totals) resulting in greater than 2 inches occurred during the Pile B1 life. This event included ~4.8 inches of snow, which obscured the probe face from the camera and no soil moisture reading was captured for this day. Onset probes were not installed in Pile B1 and no additional soil moisture data is available for comparison. Due to miscommunication, the pile was moved too early (mid-January) prior to a second heat cycle, and it was placed in the commercial compost pile instead of the curing pile. As the commercial pile is used to inoculate the new piles, this compost will eventually be incorporated into a new pile and undergo further heat cycles.

Pile B2 Synopsis

No. Carcasses:	10	Start Date:	December 7, 2021
Times Watered:	0	Turn Date:	March 24, September 22, 2022
Heat Cycles:	2	Moved to Curing:	December 7, 2022
Pathogen Reduction:	Yes	Build:	Winter
Min Temp:	54°F	Approach:	Passive
Max Temp:	142°F	Δ Air/Pile Temp:	40°F

The average soil moisture from the manual soil moisture probe was 0 over the course of the pile life. Onset probes were briefly installed in Pile B2, but the probe was damaged a week later due to vandalism, and no conclusive data was gained regarding pile conditions. Due to miscommunication, additional carcasses were added to the pile during the second heat cycle and did not undergo pathogen reduction. There is a chance that pathogen reduction may have occurred once placed in the curing pile. Pile B2 was originally named C1 but was re-designated to fit the bin name scheme. Since it was the second iteration placed in Bin B, it was given the name B2.

Pile C2 Synopsis

No. Carcasses:	17	Start Date:	June 18, 2022
Times Watered:	1	Turn Date:	September 22, 2022
Heat Cycles:	2	Moved to Curing:	December 7, 2022
Pathogen Reduction:	No	Build:	Summer
Min Temp:	96°F	Approach:	Passive
Max Temp:	118°F	Δ Air/Pile Temp:	37°F

The average soil moisture from the manual soil moisture probe was 0 over the course of the pile life. Onset probes were briefly installed in Pile C2, but the pile was moved to curing shortly after and no conclusive data was gained.

Pile D1 Synopsis

No. Carcasses:	18	Start Date:	June 06, 2022
Times Watered:	1	Turn Date:	September 22, 2022
Heat Cycles:	1	Moved to Curing:	December 7, 2022
Pathogen Reduction:	Yes	Build:	Summer
Min Temp:	80°F	Approach:	Passive
Max Temp:	140°F	Δ Air/Pile Temp:	58°F

The average soil moisture as read by the manual soil moisture probe was 0 over the course of the pile life. Onset probes were not installed in Pile D1 as probes were only purchased for three piles.

Financial Considerations

Implementation and execution of the pilot carcass composting program included upfront costs for the purchase of materials and construction of the site, and on-going costs associated with the everyday operation and maintenance of the facility. Where possible, the project team utilized materials or by-products of current CDOT processes to meet the needs of the project to reduce costs.

Initial Investment

Pile Construction and Composting Materials

Initial financial investment covers the acquisition of a site (if not using pre-owned property), start-up materials, facility construction. The pilot project used an existing CDOT maintenance yard already being used for storage of woodchip material from roadway maintenance, so cost of a new property acquisition is not addressed in this reporting.

CDOT generates the asphalt millings base material and woodchips through pre-existing CDOT operating procedures, so these materials have no additional upfront cost. Carcasses were provided by the CDOT Region 1 maintenance crew as a part of current operating procedures. Commercial compost is the only composting material with an up-front cost, as 65 cubic yards of black tea compost was purchased from B.O.S.S. Compost.

To construct the bins, the project team used jersey barriers as they were already available at the Franktown CDOT property. These initial construction costs are detailed in Table 2.

Table 2. Initial Cost for Site and Pile Construction

Item	Quantity	Unit Cost*	Notes
Carbon Source (Woodchips)	Variable	$0	Product already created through other CDOT maintenance processes.
Asphalt Millings	Variable	$0	Product already created through other CDOT maintenance processes.
Black Tea Compost	65 cubic yards	$1,300	Provided by B.O.S.S. Compost. Needed only at project start.
Carcasses	Individual	$0	Provided through CDOT maintenance SOPs.
Jersey Barriers	Dependent on bin size	$0	Provided by CDOT.

*Indicates cost of the item beyond the usual cost for production already included in CDOT SOPs. Does not include labor costs for installation of materials.

Pile Monitoring

Beyond the initial purchases for site and pile construction, temperature and soil moisture probes were purchased to monitor in-pile conditions. The project team initially purchased cellular-enabled trail cameras to capture photos of manual probe faces. This method costs ~$1,850 for the monitoring probes/trail cameras. This method relied heavily on data postprocessing by the project team to transcribe probe readings from the camera photos into a spreadsheet for later analysis.

The second equipment purchase was an Onset datalogger and wirelessly connected sensors. This was the more expensive monitoring purchase, with ~$1,610 for monitoring devices and $2000 for custom probe guide rods. The tradeoff for the higher up-front cost was a large reduction in manual hours needed on the back end to transcribe photo data (as needed using the trail camera/manual probe methodology). These probes were harder to insert into the compost piles than the manual probes, which may have affected the accuracy of the readings due to placement. The initial itemized cost of each method is included in Table 3 below.

A third method considered but not utilized due to site location was manual reading/recording of in-pile probes. This method would involve daily maintenance crew visits to take manual temperature/soil moisture readings within the pile and record them manually. This would be the most cost-effective initial purchase option as it would require manual probes (~$680) and a notebook ($3-4) to record observations.

Table 3. Initial Cost for Pile Monitoring Equipment for Manual Capture Using Trail Cameras

Item	Quantity	Unit Cost*	Total Cost	Notes
Manual Soil Temperature Probe	3	$97.82	$293.46	-
Manual Soil Moisture Probe	3	$128.00	$384.00	-
Trail Camera (cellular)	1	$250.00	*$250.00	-
Trail Camera (wireless)	3	$200.00	*600.00	-
Camera Mount	4	$20.00	$80.00	-
Solar Panel	4	$60.00	$240.00	-
Misc. Installation Supplies	Variable	-	$300.00	T-posts, bird deterrent spikes, locks, C-clamps, etc.
Total			**$2,147.46**	

Table 4. Initial Cost for Pile Monitoring Equipment for Datalogger and Wireless Probes

Item	Quantity	Unit Cost*	Total Cost	Notes
Onset Datalogger	1	$850.00	$850.00	-
Onset Soil Temperature Probe	3	$210.00	$630.00	-
Onset Soil Moisture Probe	3	$290.00	$870.00	-
Custom Probe Guide Rods	3	$666.67	$2000.00	-

Misc. Installation Supplies	Variable	-	$150.00	T-posts, C-clamps, zip ties etc.
Total			**$4500**	

*Does not include the cost of a cellular plan.

Ongoing Expenditures

Once site construction was complete and the compost bins were ready to accept carcasses, the direct costs for the pilot project dropped significantly. A few recurring expenditures such as data/cellular charges or heavy equipment use were required, but the majority of direct costs were replaced by labor costs for both the maintenance crew and the project team.

Recurring Data Charges

There were some additional charges associated with pile monitoring methodologies. Both methodologies included a cellular data charge: $42.70 for the trail camera charged monthly, and $20.83 for the datalogger (billed annually at $250 but the price has subsequently increased to $299, or $24.92/month as of July 2023.). Pricing for both cellular options is based on type of cellular plan, data volume, and connection timing.

Annual Equipment Use Costs

A second subset of recurring costs includes the use of dedicated equipment to maintain the compost piles. This was trialed during the pilot project for earth moving equipment (front-end loader) but did not last due to the need to utilize the loader at other locations. Use of the front-end loader has an hourly rate of $4.53, with an estimated yearly cost of $217.44 for use (assuming 4 hours per month, 12 months). The pilot project was not able to obtain an onsite water tank so costs for onsite watering equipment was estimated using a dump truck and water tank. Use of this equipment is $101.93 per hour, totaling $4,892.64 annually. This dedicated, onsite equipment is very important for reducing labor hours and expediting the incorporation of carcasses into the compost pile, which reduces scavenging and odors. Without onsite equipment, maintenance crew labor time can increase by 1-3 hours a visit. This estimate was based on time needed to load and drive equipment from the Franktown CDOT yard and back.

Table 5. Estimated Yearly Equipment Use Costs

Equipment Type	Hourly Rate	Estimated Cost per Month*	Estimated Cost per Year
Front-end Loader	$4.53	$18.12	$217.44

Mid-range Dump Truck with Water Tank	$101.93	$407.72	$4,892.64

*Includes fuel and maintenance costs and assumes 4 hours per month, or two site visits with pile manipulation and watering.

Labor Cost Estimates

Labor costs are broken down by the group completing the labor (CDOT vs Project Team). The labor associated with pile creation, carcass additions, and facility maintenance was typically conducted by the CDOT Region 1 maintenance crew. The research project team ended up completing most of the pile observation and monitoring labor.

For future composting projects, ideally CDOT maintenance crew labor would be used to complete and document pile actions and status. Since there was no specific code for the maintenance crew to track their time to the pilot project vs general roadkill activities, labor estimates below are based on best available knowledge of task timing, level of effort, and cost. The average labor cost for a CDOT maintenance level II or III employee including benefits is $40/hour. Labor estimates for the pilot project are based on an average drive time of 2 hours, with 30 minutes estimated for completing routine composting activities, and an hourly rate of $40/hr, totaling $100 in labor cost per visit. Based on an average number of work orders per month of 23 (CDOT 2023), and assuming 1-2 carcasses per work order, the total labor needed for routine carcass drop-offs per month would total approximately $2,300. When activities onsite are more time consuming, for example turning or moving multiple piles, an estimate of 2 hours onsite was used alongside the two-hour drive time, for a total of $160 worth of labor per visit. Assuming these site visits occur twice a month (active composting methodology), this site visits would be an additional $320 in labor per month, or $3,840 annually. Table 5 below details these labor estimates.

Table 6. Estimated Labor Costs for Composting Activities

Visit Type	Estimated Drive Time (hours)	Estimated Time Onsite (hours)	Hourly Rate ***	Total Labor Cost Per Visit	Monthly Cost
Routine Carcass Drop-off	2	0.5	$40	$100	$2,300**
Pile Maintenance Activities	2	2	$40	$160	$320***
				Total Labor Cost per Year	**$31,440**

*Labor estimates assume a permanent, full time employee including benefits in the hourly rate.
**Assumes an average of 23 roadkill disposal work orders per month. This is only an estimated average, as WVC frequency changes based on the month.

*** Assumes two visits per month.

Additional labor hours are needed for the review of pile data and differ based on the type of monitoring methodology used. For the manual pile monitoring, it's estimated that an additional two hours per month should be spent reviewing the pile condition logs and making decisions based on the recorded values. For the trail camera methodology, an additional 2 hours per week is needed for sorting photos, recording pile values, and making pile action decisions. For the datalogger methodology, an additional 2 hours is needed per month to review the data and make decisions based on the recorded values. This breakdown of additional labor needed is provided in Table 6.

Table 7.Estimate of Additional for Data Management Costs

Monitoring Methodology	Hours Per Month	Hourly Rate	Cost per Month	Cost per Year
Manual Probe Reading/ Recording	2	$25	$50	$600
Trail Camera Photos/ Manual Transcription	8*	$25	$200	$5,000
Datalogger/ Values Review	2	$25	$50	$600

*Assuming a 4 week month.

These labor estimates do not include any technological troubleshooting associated with trail camera or datalogger maintenance, which was considerable.

Cost Comparison

The average annual cost for roadkill work orders for CDOT Region 1 from 2012 through 2020 (pre pilot project) was $57,235, with ~$26,206 derived from labor annually (CDOT 2022). This equates to an average of ~$15,150 per quarter (including labor, which accounts for ~6,940 of this cost). This also includes landfill costs associated with roadkill removal. Table 7 below compares the average annual cost of the traditional disposal methodology with the estimated cost for composting both in the initial year (higher direct costs) and subsequent years, using three separate compost pile monitoring methodologies.

Table 8. Cost Comparison Between Traditional and Composting Disposal Methods

Disposal Method/ Monitoring Method	Year Deployed	Labor Cost*	Direct/ Additional Cost(s)**	Total Annual Cost	Cost per Quarter	Notes
Landfill Disposal	All Years	$26,206	$31,029*	$57,235	$15,150	Landfill fees included in Direct Additional Costs. Does not account for price increases due to inflation or otherwise.
Composting - Manual	First	$22,650	$2,050	$24,700	$6,175	Does not include equipment costs.
Composting – Trail Cameras	First	$27,050	$3,447.46	$30,497	$7,624	Does not include equipment costs.
Composting - Dataloggers	First	$22,650	$5,800	$28,450	$7,113	Does not include equipment costs.
Composting - Manual	Subsequent	$22,650	-	$23,950	$5,988	Does not include equipment costs.
Composting – Trail Cameras	Subsequent	$27,050	-	$28,350	$7,088	Does not include equipment costs.
Composting - Dataloggers	Subsequent	$22,650	-	$23,950	$5,988	Does not include equipment costs.

*For Composting methods, includes base labor cost for compost pile maintenance of $22,050 and data management labor cost based on monitoring methodology.
**Additional cost for traditional disposal not broken out into specific items.

Data Collection

Quantitative Data

Temperature and soil moisture were collected daily to inform pile lifecycle status and pile actions needed. As the site location was not adjoining a CDOT facility, photographic documentation was collected daily via trail cameras, and by CDOT/project team personnel whenever visiting the site. The project team explored multiple data collection techniques to determine the most time and cost-efficient method for collecting pile condition data.

The first method of onsite data collection considered was provided in the MDT Mortality Composting documentation. These monitoring techniques have been successfully used to compost carcasses in Montana since 2004. Pile temperatures are monitored using a manual temperature probe stuck into the center of the pile and written down on a paper log onsite. Pile moisture was monitored using a “squeeze” test, where facility maintenance workers squeeze samples from different sections of the compost pile in their gloved hand. If the compost product crumbles and does not hold shape, it is too dry. If the compost product readily drips moisture, it is too wet. In the ideal squeeze test, the compost product should hold shape without being excessively wet or dry. This data collection route would likely be the most cost effective, as only one temperature probe would be needed per pile; however, depending on site location, there is a larger time requirement for CDOT maintenance staff. The CDOT project team adapted this manual temperature monitoring technique but did not utilize the squeeze test due to crew availability onsite and the increased direct human contact with the compost piles.

The second method considered, and the first deployed onsite, involved the use of manual-read temperature and soil moisture probes. Four-foot long stainless steel VeeGee brand temperature probes were purchased from Grainger to monitor temperature at each pile. Four-foot long stainless steel Moisture Meters were purchased from ReoTemp Compost to monitor soil moisture at each pile. The probes were calibrated prior to deployment using manufacturer recommended methodologies. One temperature probe and one soil moisture probe were inserted from the back of each compost pile, so that the probe face was near the back of the compost bin itself while the probe tip (where readings are taken) was placed at the approximate center of the pile. Probes were placed in each pile as soon as carcasses were added. Probe placement was adjusted again once the pile build was completed to capture readings at the thickest part of the pile. Due to the more rural location of this site and the lack of daily maintenance crew interaction, Cuddeback Trail Cameras were setup behind each pile to take daily photos of the probe faces that were then cellularly transmit them to a Google Drive folder. These photos were reviewed by the project team and transcribed into an excel workbook, which was routinely reviewed for pile status or action. This methodology worked fairly well and was one of the more cost-effective options for daily temperature and soil moisture monitoring. Some daily data was lost due to camera placement, probe face legibility in varying light conditions, and physically obscured probe faces due to vegetation or snow.

For these first two data collection methods, temperature and soil moisture readings were captured either manually onsite using a paper log, or digitally using a Google Survey form. Over the course of the pilot project, neither methodology (paper or digital) was used consistently by the CDOT maintenance crew to track in-pile conditions, and the project team ended up capturing the data every few weeks.

The third method considered, and the second used onsite, included the purchase and deployment of an Onset Datalogger system. This method was deployed to help combat lack of availability and participation from the CDOT maintenance crew for monitoring pile conditions. The Onset setup consisted of a centralized datalogger box that wirelessly connected to temperature and soil moisture sensors in each pile. Hourly readings were captured and cellularly transmitted to an online portal where data could be viewed and downloaded. These sensors were deployed alongside the manual-read probes for comparison. The probes associated with the datalogger did not have an effective insertion device, so CORVUS contracted Weld-Wright Fabricators to build an insertion guide rod for each pile that would hold both the temperature and soil moisture sensor on a single insertion rod, with protective plating above the sensors for the insertion process (see attached photolog).

The insertion rod was heavy duty and ended up being harder to insert than the manual probes. This method was the most cost prohibitive up front but reduced the labor hours needed for site visits to capture manual probe readings. There is also additional technical knowledge and troubleshooting needed when using a technology-based solution like a datalogger. Shortly after deployment, site vandalism by a member of the public broke some of these probes, and it is unclear if the probes would have had issues were it not for this vandalism.

Qualitative Data

The project team explored three options for capturing and tracking pile actions and environmental conditions: a free internet-based (Google) survey form, paper logs, and digital correspondence such as text message or email. The goal of this data collection was to understand the actions taken at each pile including carcass additions (number, type of animal), action timing, and environmental conditions.

Initially, the project team created and deployed a Google Survey form to capture actions and conditions for each pile. The form was explained to the maintenance crew, and a QR code linked to the form was provided for easy form access. This methodology was not widely used by maintenance crew, with the bulk of their use occurring in the first two months of the pilot project. The project team also used this form to record daily temperature and soil moisture readings from the trail camera photos. By the end of the pilot project, 1% of entries in this form were completed by CDOT maintenance crew and 99% were completed by the project team.

Given the lack of participation using the Google Survey form, a second methodology was deployed to capture pile actions and environmental conditions. A paper log was created and placed inside a waterproof box, which was placed in the temporarily onsite loader. Data requested in this log was simplified to capture date, initials of the crew capturing the data, number of carcasses added, the bin letter, a Yes/No checkbox for if the pile was watered or turned, and a notes section. This method was met with greater success than the digital form; however, once the loader was moved offsite the log was lost. A second iteration of the paper log was deployed in a mailbox installed onsite. This log was not utilized by the maintenance crew members.

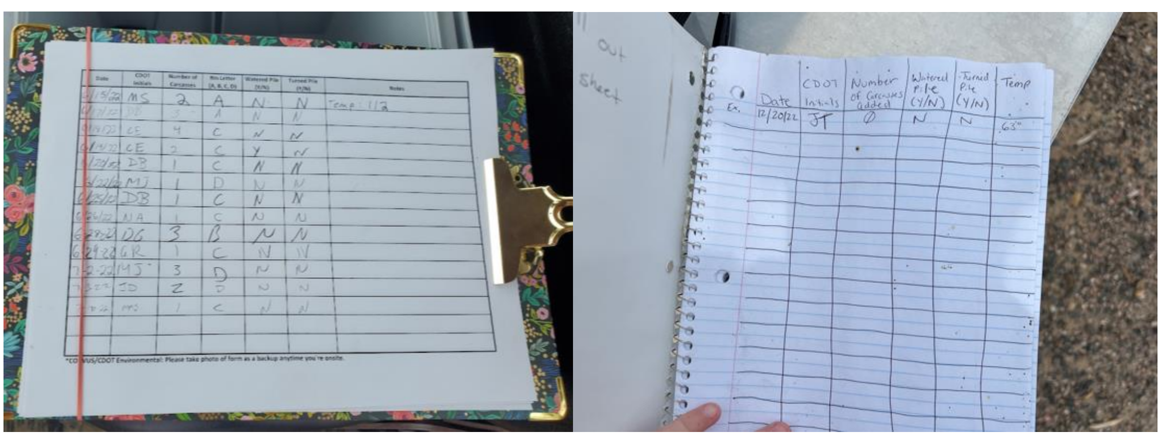

Figure 3. Examples of onsite paper log used to capture pile actions showing mixed adoption by the CDOT maintenance crew.

Last, to further simplify data collection, the project team requested that pile actions and environmental conditions be communicated directly to the project team via email, text, or phone call. This was deployed both in the beginning (emails) and near the end of the pilot project and was met with a moderate level of success.

Project Oversight and Maintenance

Project oversight and maintenance were key to maintaining pile efficiency and negating undesirable environmental conditions. Oversight was completed through continual communication both within the project team and between the project team and the maintenance crew. Compost site maintenance was achieved through monitoring and management of datasets and continual technology troubleshooting.

Oversight

Continual communication between the project team and maintenance crew is vital to project success. At the beginning of the project, the project team provided the current maintenance crew with a run-through of the composting operations, how they would track data, what type of pile actions they might need to complete, and pathways to communicate with the project team. Throughout the course of the pilot project, communication between the project team and the maintenance crew became more infrequent. Part of this was due to the transition into winter when the maintenance crew had higher priority tasks to complete like snow removal. In Spring 2022, the project team met up with the maintenance crew onsite to discuss continued operations and improvements that the team could make to help with data collection. Beyond project team to maintenance crew correspondence, the project team itself kept in contact via email and virtual meeting to track progress, brainstorm improvements, and ensure the project was continuing to operate efficiently.

Maintenance

Monitoring and maintaining datasets were also an important aspect of the pilot project. Data obtained from the cameras was transcribed manually for each day and input into a Google spreadsheet. To help the data capture process, CORVUS created an automation that would move camera photos directly from email and load them into a Google Drive folder that the project team had access to. This ensured there was little to no delay between the photos being submitted by the cameras and being available to the team for review. Towards the end of the project, even the task of transcribing the temperatures became time intensive as vegetation near the cameras triggered a photo, and each day captured thousands of photos, mostly unusable. Once the Onset datalogger system and probes were installed, data management became a lot easier. The datalogger automatically logged values for temperature and soil moisture per pile and hosted the data online, where it was subsequently downloaded for analysis. A dashboard view was also available through a web browser so checking pile conditions took minimal time.

The last and arguably largest maintenance item encountered centered around technology. Since the site was not visited daily, remote monitoring techniques were deployed using different technologies to track pile conditions. The trail cameras required a lot of “hands-on” fixes, from adjusting placement and angle, updating the power source, troubleshooting data gaps, to replacing broken parts. During the project life span two of the cameras had to be sent back to the manufacturer because they had stopped working and in-field troubleshooting did not yield a solution.

The Onset datalogger system did not require as much “hands-on” troubleshooting in the field; however, it was not deployed in working condition as long as the trail cameras due to site vandalism. Of the Onset probes that did continue working, little time was spent on in-field troubleshooting.

Adaptive Management

Given the dynamic nature of the pilot project, the team employed an adaptive management approach to troubleshooting that was informed through qualitative and quantitative data collection methodologies. Data was collected and reviewed on a weekly to monthly basis, depending on the time of year and composting approach, and action items were created based on these observations. Adaptive management actions fell into five main categories:

- Pile Management
- Action
- Data Collection
- Communication
- Negative Environmental Conditions
- Site Safety

Pile Management

Challenges encountered with compost pile management included a lack of bin space, site operation confusion between personnel, and a lack of consistency in pile nomenclature. The lack of bin space and unclear site operations led to confusion with field staff when completing pile actions, which in turn led to inaccurate or incomplete data collection from the crew. The inconsistency with pile nomenclature made it difficult for the project team to track quantitative data for the piles like temperature, humidity, or carcass additions.

Solutions identified to address the lack of space and maintenance crew confusion over which pile to place new carcasses included being more active with pile management, depending on maintenance crew availability, and checking the piles more often so that pile milestones weren't missed. The project team placed orange construction cones in front of the bins that were not accepting new carcasses. The team designated a single bin at a time to accept new carcasses which did not have cones placed at its entrance.

To address the lack of consistency with pile nomenclature, the team ordered signs (including the bin name and sometimes bin type) from the CDOT machine shop and placed temporary signs onsite immediately while the more permanent signs were created. The active compost bins were labeled alphabetically A through D. The team also designated specific curing and finished compost bins (which also had signage installed). Trail cameras were renamed to include the bin letter and pile iteration number, which helped match the correct pile with the corresponding photographs and data. The Google form was updated to reflect the bin letter and iteration number. Additionally, the project team installed a mailbox on the jersey barrier of Pile A that contains a new paper log for the crew to fill out for pile actions.

Pile Actions: Equipment Needs, Maintenance Crew Availability

The project team monitored the pile status through temperature and soil moisture probes remotely and notified the maintenance crew when pile actions were required. Pile action requests included watering the pile, turning the pile, or adding carbon material. The project encountered delays in pile actions. Delays were mainly due to a lack of dedicated equipment onsite but were also influenced by staff availability, communications, and weather.

Since the compost site has no direct access to water, the project team had planned on bringing a portable water tank in the back of a maintenance vehicle to provide water for the site. This technique was used once, but it took a lot of time and energy from the maintenance crew to fill and drive over, so watering became less frequent than was required to maintain pile efficiency. To combat this, the project team discussed the possibility of securing a dedicated onsite water tank to alleviate issues with watering delays. The project team reached out to the CDOT Maintenance Deputy Superintendent to procure a dedicated tank and pump, but no tank and pump were secured.

The project team had also planned for pile-turning activities to be completed by equipment hosted at the CDOT maintenance yard on the north side of Franktown. The intent was to drive the equipment, a front-end loader, back and forth between the maintenance yard and the compost site, as needed. After the first few iterations of this methodology, the maintenance crew indicated that it was not feasible due to drive time between locations. In response, the CDOT procured an onsite loader that was kept on the west side of the facility for a couple of months. Within this timeframe, the loader was needed more frequently at other sites and was removed.

Last, the project team encountered issues with pile maintenance. Through a combination of heavy workloads (including snow removal) and limited staffing and staff turnover, the maintenance team could not keep up with pile action requests, with many requests open for a longer duration of time with a delay in completion.

Data Collection: Consistency, Adoption

The project team collected quantitative and qualitative data to inform pile action decisions. Initially, the project team deployed manual temperature and moisture probes to collect this data. Since the site was not visited daily, the project team set up trail cameras to relay photos of the probe faces to capture pile conditions. A full discussion regarding the data collection techniques is included in the Data Collection section above. This methodology worked well most of the time, but some persistent problems became apparent. Despite claiming to send full-resolution photos, the photos sent from the trail cameras were pixelated, making the probe readings difficult, but not impossible. Additionally, sometimes the probe faces were obscured by vegetation or snow, or not in the camera frame, and data for those instances was lost.

To reduce data loss, the team explored other data collection options including using a cellular-enabled Onset datalogger and wirelessly connected probes (additional detail in the Data Collection section). This data collection route reduced the manual hours for data transcription and photo review, while providing consistent, near real-time data. However, this setup was compromised by site vandalism soon after it was installed.

The team also encountered issues with the camera's battery life. This issue was most prevalent at night, or during the colder months, when the batteries couldn't hold as much charge. To combat this, the project team installed self-contained solar panels at each camera. These solar panels worked well and no additional battery issues were encountered with the cameras.

Last, the team encountered issues with both quantitative and qualitative data collection from the maintenance crew, namely missing reports or inaccurate reports on carcass additions.

Communication

Before beginning composting activities, the project team and maintenance crew met onsite to discuss site layout, operating procedures, and data collection needs. The general communication pathway for pile actions started with review of data observations (qualitative and quantitative) as provided by the probes and onsite observations. The project team would make a pile decision based on these observations, and then the CDOT contingent of the project team communicated directly with the maintenance crew lead on action items.

The first issue encountered was with pile observation reporting. Field crew dropping off carcasses did not report on the number or type of carcasses or which bins they were placed in, which led to uncertainty regarding the number of carcasses in each pile and timing of the decomposition process. The project team tried clarifying how to use the Google Form to complete entries, and simplified access to the form with a QR code, but the form was never fully adopted. Second, the project team created a paper log to capture and communicate pile actions between the project team and maintenance crew. This log was placed in the equipment onsite and was utilized more often by the maintenance crew. This log was subsequently lost when the loader was removed from site and the data was never recovered. Since the paper log was the most successful method employed, a third log was printed and placed in a mailbox that was attached to the jersey barrier on bin A.

The project team solicited feedback from the maintenance crew to identify friction points in the workflow or potential time-saving efficiencies associated with the project and implemented many suggestions. This led to the onsite equipment, and discussions surrounding an onsite water tank. The team also brainstormed additional solutions for this challenge applicable to future CDOT compost operations, such as modifying the site location to be closer to CDOT facilities/services, and by employing designated staff to complete and manage operations. Feedback from the maintenance crew also indicated a general hesitation to work with carcasses, specifically within the compost piles. The project team re-iterated safety protocols and personal protective equipment (PPE) that would minimize exposure to bacteria.

Negative Environmental Conditions

The main negative environmental condition encountered by the project was the continued presence of scavengers. Earlier in the project, larger scavengers (coyote) were observed accessing uncovered carcasses or portions of carcasses and pulling them out of the pile. This led to bones and half-decomposed bits of carcass scattered outside of the jersey barriers, which will attract additional scavengers, exacerbating the problem. To combat this, the project team reviewed photos more frequently to identify uncovered carcasses sooner, and fewer large pieces of carcass were pulled out of the pile.

Figure 4. Coyote visiting the site at the beginning of the project.

The next main scavenger issue was turkey vultures and other avian scavengers. These birds would land on the pile and pick at the pile from the top, but they did not lead to excessive compost material outside of the bins. However, perching birds did damage the trail camera antennas. To rectify this, the project team replaced the antennas, and then installed bird spikes on top of the cameras to deter perching. This method was effective.

Site Security

Due to the rural location of the pilot project site and the immediate access provided along state highway (SH) 83, having the public access the site was a concern from the beginning. The project is directly visible from the roadway, and there is no gate restricting access.

The site had two instances of public trespassing, and one instance of vandalism. The first trespasser was on June 2, 2022, and the second was on June 9, 2022. It's unclear if the two people are associated, or the same person entirely. In the second photo, it looks like the person was collecting something from the site as they are holding a plastic bag. To deter further public use, the project team installed "No Trespassing" and "Surveillance Cameras in Use" signs at the front of the compost site. A truck visited the site at night on July 20, 2022, but the camera did not capture a person getting out of their vehicle. The truck appeared to be shining a light, looking for animals, as it had a large spotlight on the side.

On November 13, 2022, a man visited the site in mid-morning and vandalized the Onset probes that had very recently been installed in the piles. He pulled the probes out of the piles themselves and opened the enclosure boxes to expose the circuitry to the elements, which happened to occur just before a large snowfall. The Colorado State Patrol (CSP) were involved and opened an investigation into the case. CSP also increased patrols around the area, and the CDOT maintenance crew took data on all vehicles observed at the site. After this incident, many of the probes did not work, but due to the impending end of the pilot project, they were not replaced.

Conclusions

This pilot project determined that **carcass composting is viable within the dry Colorado climate**, and with a few modifications to current CDOT operating procedures and with adequate staff and resources, it **could be included in CDOT maintenance workflows to increase efficiency and lower roadkill work order costs**.

In addition, mortality composting supports corporate sustainability initiatives by recycling current SOP by-products, re-use of construction materials, and reduction in fuel consumption, which yields a usable product for revegetation efforts along CDOT ROWs.

For the best results, a site would be located at, or near, an existing CDOT Maintenance facility, have access to the proper equipment, and contain a reliable water supply.

Recommendations

Feasibility/Practicability

- Locate a compost site adjacent to an existing facility for ease of pile monitoring, access to resources (water), and equipment. This will also provide an added level of security and reduce public access to the site.
- Designate someone, or a small team, for consistent hours dedicated to pile management. This position could be part-time, up to full-time, depending on budget and operation size.
- Use a single, agreed-upon communication process between those working on the compost site to ensure accurate and timely pile actions.
- Designate a specific billing code to track maintenance crew time spent on carcass composting to refine the labor estimates provided in this document.

- Develop a training program for new crew members so they know how to maintain the compost site and can receive education on health concerns and safety protocols.

- Educate how to avoid dangerous bacteria exposure if the correct precautions are taken. It's a sizable challenge to overcome the sensory experience, and stigma of working with carcasses.

- Consider accepting carcasses from alternative sources (farm, ranch, feedlot, county, CPW etc.) for a fee to offset labor costs, or free as a community service. This could provide various mutual benefits to CDOT and the carcass source including convenience, reduced predator/scavenger attraction, cost savings, and economy of scale.

Colorado-specific Composting Methodology

A separate, stand alone, CO specific composting Methodology document is included as Appendix A. In summary, we recommend the following:

- Use winter and summer build piles (Compost Pile Design section, Figure 1). The winter pile build lowers the number of available carcass space per pile, but helps keep temperatures higher, even in warmer months. Actively managed summer piles can process carcasses faster, creating room for additional carcasses to be composted.

- Use analog (low-tech) composting probes with manual data tracking. This eliminates the technological troubleshooting and high up-front cost of equipment. Analog probes are easy to replace when they malfunction.

- Water more often, as necessary, based on pile moisture content. Soil moisture probes were not effective in monitoring/tracking pile moisture, which may be due to a small area-of-influence associated with the probes, or obstructions in the area-of-influence (i.e., bone). Instead, use the squeeze test (with a gloved hand or a shovel against the ground) to assess soil moisture.

- If remote data monitoring is necessary, use a more manual insertion technique for automatic probes (like the Onset probes) like a shovel or spade so that there is no obstruction to the probe readings and less potential to damage the probe itself.

- Use "hot" compost instead of pre-made compost. Some of the piles had a hard time getting up to temperature after they were created, and it may be partly due to lack of microbe presence or activity. Using hot compost ensures microbe activity remains high by transferring it directly from one active pile to the target pile.

Sustainability

- Over the course of the project, approximately 112 carcasses were composted and kept out of landfills. Since most of the compost piles in the pilot project utilized a passive composting approach, this number will likely increase greatly with active pile management, as carcasses will move through the decomposition process faster, creating room for more carcasses to be composted.

- Beyond the initial starter compost purchase, all composting materials were sourced directly from current CDOT sources. The woodchip pile was routinely refreshed as new branch/tree trimming tasks were completed, creating a sustainable and efficient use of this maintenance by-product. Carcasses were sourced from WVCs in maintenance section 5. Once the commercial compost has been used, onsite “hot” compost from the curing pile can be subbed in to inoculate and insulate new piles as they are created.

  - If a CDOT carbon source (woodchips/tree trimmings) isn’t available, consider partnering with a local landscaping company or sawmill, or a tree recycling/mulching operation.

- Site construction materials were also repurposed from current CDOT workflows. Jersey barriers are commonly used during roadway construction projects and serve as an excellent bin construction material. Asphalt millings were used to create a semi-permeable base for the piles by grinding old roadway material. These millings were already available at the CDOT Facility north of Franktown.

- With a well-sited project location, reduced individual drive time to and from the landfill will lower CO_2 emissions produced.

- Creation of in-house compost can be applied in CDOT rights-of-way, reducing the cost to purchase compost or soil amendments from a third-party provider during revegetation efforts.

- Coordinate with CPW to determine if any chronic wasting disease concerns would prohibit carcass composting or the application of finished compost within CDOT right-of-way. Based on coordination with CPW as part of this project, all of CDOT Region 1 is considered chronic wasting disease positive so this was not a particular concern but finished compost from this operation cannot be sold or transported outside of Region 1. In addition, the application of finished compost is approved solely for application in CDOT Region 1 right-of-way.

Appendix A – CO Specific Maintenance Manual

Available on request

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