

# Fate of Ketamine and Xylazine in an Active Mortality Compost Pile

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## **Abstract**

Composting is a widely accepted method for managing livestock mortalities due to its environmental benefits, including organic matter recycling, pathogen reduction, odor control, and reduced scavenger attraction. However, the use of injectable euthanasia agents raises concerns about environmental persistence and relay or secondary toxicosis. This study evaluated the fate of xylazine and ketamine during the on-farm composting of 13 cattle (totaling 3,232 kg). The cattle were euthanized during a livestock depopulation event due to per- and polyfluoroalkyl substances (“PFAS”) contamination. Euthanasia was accomplished by initial anesthetization with a total intramuscular (“IM”) dose of xylazine (mean 2.49 mg/kg) and ketamine (mean 0.93 mg/kg) to achieve effective sedation prior to captive bolt application. A compost windrow was constructed using a 50:50 mixture of sawdust shavings and haylage as the base layer, with a 50:50 mix of haylage and manure used to cover the carcasses, which resulted in a total composting feedstock volume of 52.9 m<sup>3</sup>. Sampling of the compost matrix over a 13-week period demonstrated a substantial reduction in both chemical agents utilized. Initial concentrations measured at windrow construction were 198.4 ppb for xylazine and 66.1 ppb for ketamine. By week 13, concentrations of xylazine and ketamine declined to 24.4 ppb and 9.8 ppb, respectively, representing reductions of approximately 88% and 85%. The compost windrow was turned four times during the study, and the internal temperature of the windrow was measured at two depths, along with environmental temperatures and precipitation.

Although leachate from compost windrows is not uncommon, even when appropriate best management practices are implemented, no leachate from the windrow was noted during daily observations throughout this study, which suggests that the reductions of ketamine and xylazine were not the result of losses from transport out of the windrow in leachate. It is reasonable to assume that the microbiological, thermophilic composting environment actively degraded the compounds and resulted in their transformation to other metabolites. Further, sorption of these compounds onto organic matter particles likely created easy access for microbes and facilitated rapid breakdown of these materials through various chemical processes.

These findings suggest that active composting effectively degrades xylazine and ketamine, supporting its use as a safe disposal method following chemically assisted euthanasia in livestock. Furthermore, this study offers practical guidance for effective on-farm composting design.

**Keywords:** carcass disposal, compost, secondary toxicosis, fate of injectable anesthetic agents, ketamine, xylazine

## **Introduction**

Humane euthanasia of livestock is warranted on welfare grounds, including cases of severe illness, injury, chronic pain, emaciation, debilitation, or failure to thrive (Shearer, 2018). Depopulation, a related process, may be necessary during emergencies such as disease outbreaks or in cases of contamination with foreign substances, which may require the rapid destruction of many animals with as much consideration for animal welfare as possible.

The American Veterinary Medical Association guidelines for the euthanasia of animals recognize three primary methods of euthanasia for cattle. These include the intravenous (“IV”) administration of a lethal dose of barbiturate, gunshot with the appropriate firearm and ammunition applied to the correct anatomical site, or the application of a penetrating captive bolt with an adjunctive method such as exsanguination, pithing, or IV administration of potassium chloride or magnesium sulfide (AVMA Guidelines for the Euthanasia of Animals, 2020). Many veterinarians choose a combination of a chemical method to first sedate or anesthetize the animal, followed by an adjunctive dispatching method to achieve a calmer euthanasia and/or more visually acceptable process.

The most common method of euthanasia in equine practice is the administration of IV pentobarbital, resulting in concerns for soil and water contamination during burial, as well as secondary or relay toxicosis of wildlife or domestic animals that may feed on the carcass. There is a movement to find alternative methods that produce less environmental contamination. The use of intrathecal lidocaine in an anesthetized patient is a more recent method of humane euthanasia. The main anesthetic agent that is used in a large animal patient is ketamine, often combined with a sedative agent such as xylazine. As this euthanasia method gains wider adoption, the behavior of both xylazine and ketamine in an active compost pile becomes a more critical question to answer.

Following euthanasia or depopulation events, the remaining carcass presents a disposal problem that requires immediate attention, as carcasses are putrescible and their decomposition is often odorous and attractive to scavenging animals.

Traditional disposal methods, including rendering, burial, and incineration, have proven to be dependable and cost-effective approaches in the past. However, tightening of rendering

regulations in response to livestock disease outbreaks of Bovine Spongiform Encephalopathy in Europe and Canada, coupled with a general decline in the demand for rendered products, has resulted in the disappearance of rendering facilities (Final Report on Emission Factor Documentation for the U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Emission Factor and Inventory Group, 1995). Additionally, O'Connor et al., (1985) found traces of pentobarbital in carcass remains that had passed through the rendering process, making it ineffective for euthanasia agent destruction. Finally, threats to groundwater from burial practices, especially in areas with high seasonal water tables and shallow-to-bedrock soils, along with allegations of declining air quality and public health risks from incinerator emissions, have forced producers to seek suitable alternatives elsewhere (Langston et al., 1997).

Composting is a widely accepted practice for disposing of animal carcasses after depopulation events and for routine on-farm mortalities due to its many environmental benefits, including recycling of organic material, reduction of leachate potential, pathogen destruction, and reduction of odors, making the carcasses less attractive to scavengers. During composting, organic ingredients, including soluble nutrients, are consumed through microbial activity and transformed into complex organic compounds that are resistant to breakdown, contain very low levels of biological activity, and are resistant to leaching (Rynk, 1992).

When injectable agents (chemical methods), most commonly pentobarbital, or anesthetic agents like ketamine and sedatives like xylazine are used in the euthanasia process, the risk of environmental contamination and secondary toxicosis to domestic and wild species should be considered. Studies have demonstrated that many euthanasia agents may persist in carcass blood and tissues long after the animal is deceased (Payne et al., 2015). Pentobarbital is widely distributed throughout the body at the time of death, remains in the body because it is not significantly metabolized prior to death, and clinicians may have varied understanding of the risks (Hess et al., 2023). There is well-documented evidence of secondary toxicosis to numerous species that consume the remains, including scavenging wildlife, companion animals, and captive carnivores (Wells et al., 2020; Kollias et al., 2023). Although secondary toxicosis has been documented in scavenging wildlife and in other animals from feeding on the remains of livestock that were the subject of chemical euthanasia, there is minimal risk to domestic or farm animals, or to wildlife, from composting those mortalities, provided that the composting is done in conformance with appropriate best management practices.

Several recent studies have demonstrated that composting activity may reduce concentrations of various medications and euthanasia agents used during livestock operations (Arikan et al., 2007; Dolliver et al., 2008; Peck et al., 2014; Schwarz et al., 2013). Schwarz et al. (2013) reported significant pentobarbital reductions in equine liver samples following 83 days of composting. In contrast, Payne in 2015 conducted a similar study and found that there was no clear trend in the reduction of pentobarbital levels after 367 days of composting, and that soil samples taken below the pile showed the leaching potential of pentobarbital residues into the soil. However, the author

goes on to state that carcass degradation followed by homogenous compost mixing does allow for dilution of any remaining pentobarbital residues and that the addition of a thick carbonaceous cover provides a physical barrier that discourages scavenging activity and potential for secondary toxicosis.

Xylazine, the most frequently used drug for sedation in large animals (Abrahamsen, 2008), has been shown to be rapidly absorbed and distributed throughout the body after administration and is readily metabolized to numerous metabolites (JECFA 1998a, EMEA 1999). Previous research conducted in laboratory settings showed that xylazine has a slow rate of dissipation and degradation within soil systems. This finding, along with the compound's relatively small size, was thought to be linked to its potential for environmental accumulation (Lin et al., 2014; Pugajeva et al., 2017).

Ketamine is a common anesthetic, often used in combination with other medications due to its quick onset and short duration of action, and only mild cardio-respiratory depression compared with other general anesthetics. Ketamine undergoes extensive metabolism and degradation into numerous metabolites, some of which continue to be active (Dinis-Oliveira, 2017). Studies on the environmental fate of ketamine in soil indicate that it is stable and persistent. Likewise, ketamine also appears stable in water and moist soils (Xega et al. 2019). Studies have also shown that ketamine is not susceptible to microbial degradation or hydrolysis (Lin AY., et al.).

In the present study, we evaluated the effectiveness of composting in degrading two commonly used chemical agents, ketamine and xylazine, following a livestock depopulation event due to PFAS contamination. . The animals exceeded Maine's Action Level for perfluorooctanoic sulfonate or PFOS, in beef (Maine PFAS Screening Levels, 2025), which rendered them unfit for the market. Depuration was deemed infeasible within a reasonable time frame. Depopulation was therefore deemed necessary, and carcass management options were evaluated. State landfills were unwilling to accept the carcasses "as is" and burial was not a suitable option given the shallow water tables surrounding the property. Composting was the most viable option for managing the mortalities on farm, while also producing a final product that could be handled more easily, allowing for a variety of end uses, provided that the final compost meets state and federal guidelines for use (King et al., 2005). Finally, this field-based study provided an opportunity to assess the behavior of ketamine and xylazine in practical field conditions, especially since a comprehensive literature search failed to note prior compost studies using these two medications.

## **Materials and Methods**

### **Depopulation**

All animals were euthanized by a veterinarian and received an initial IM injection of xylazine and ketamine, followed by penetrating captive bolt application and pithing through the entry site

produced in the skull. On average, animals weighing between 272.16 kg and 317.51 kg received 5 ml of xylazine and 2 ml of ketamine; doses were adjusted based on weight and temperament. In some instances, additional doses were administered to achieve the desired level of sedation (Table 1). In total, 27 ml of 100 mg/ml ketamine and 76 ml of xylazine 100 mg/ml were used. The total weight of animal carcasses was estimated at 3,232 kg.

Table 1. Ages and weights of cattle and doses of ketamine and xylazine administered

Approximate age of animals	Sex	Bodyweight (kg)	Ketamine administered (mg)	Xylazine administered (mg)	Total drug (mg)
2y	Female	272-318	200	500	700
2y	Male	272-318	200	500	700
2y	Male	272-318	200	700	900
2y	Female	272-318	200	500	700
2y	Female	272-318	200	500	700
1y	Female	272-318	200	400	600
2y	Female	136-150	200	900	1100
2y	Male	272-318	200	700	900
2y	Male	272-318	200	700	900
2y	Female	227-250	200	500	700
2.5y	Female	409-450	400	1000	1400
2y	Male	272-318	200	500	700
1mo	Male	34-45	100	200	300
Total weights:			2700	7600	10300

### **Bulk Density Calculation**

Prior to windrow construction, weights and bulk densities were determined for each of the feedstocks used. Bulk densities were estimated using the industry standard of a 5-gallon bucket (18.9-liter capacity), for which a tare weight was obtained. The composting material then was added to the bucket, which was dropped vertically from a height of approximately 30 cm to the ground 10 times to simulate settling. Following this, the bucket was refilled to top and weighed. To calculate the bulk density, the weight of the material, excluding the bucket weight, was multiplied by 40. This factor is based on the approximation that one cubic yard contains 757 liters. The resulting value represents the bulk density in kilograms per cubic meter ( $\text{kg/m}^3$ ) (Table 2).

Table 2. Weights and bulk densities of each of the feedstocks used to form the windrows during the compost trial.

Feedstocks	yd <sup>3</sup>	m <sup>3</sup>	Bulk Density (lbs./yd <sup>3</sup> )	Bulk Density (kg/m <sup>3</sup> )	Total Weight (lbs.)	Total Weight (kg)
Start						
Waste Feed	24	18	1,200	712	28,800	13,063
Shavings	24	18	520	309	12,480	5,660
Manure	21	16	1,760	1044	39,640	17,980
Carcasses					7,125	3,231
<b>Total Weight</b>						<b>39,934</b>

**Compost Windrow Construction**

The compost windrow was constructed following the 2017 Livestock Mortality Composting Protocols developed by the USDA-APHIS (Miller, et al., 2017). A single windrow measuring 1.83 m tall by 3.66 m wide by 10.67 m long was constructed at the farm in central Maine. The compost area was situated at the edge of a cleared section adjacent to forested land designated for carcass management activities. A base was constructed measuring approximately 10.67 m long by 3.66 m wide by 0.61 m in depth (Figure 1) to hold 12 adult beef cattle and one calf. This included 7 adult cow/heifer beef cattle, 12 months or older, averaging 298 kg (range 136–544 kg); 5 adult bull beef cattle, 12 months or older, averaging 295 kg; and one calf weighing under 91 kg.

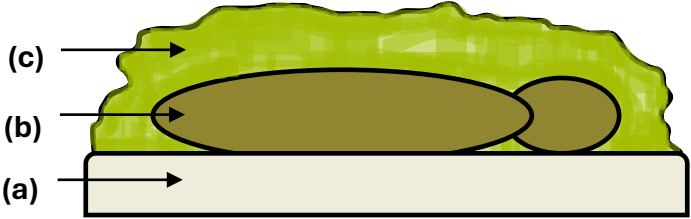


Figure 1. Cross section of a compost windrow showing: (a) 0.61-m-thick compost bed with a 50:50 mix ratio of shavings and haylage, (b) carcass placement, (c) a 0.61-m-thick 50:50 mix ratio of haylage and cow manure. The diagram illustrates the typical layer structure used for carcass composting in windrow systems.

The base was constructed with a 0.61-m-thick 50:50 mixture of sawdust shavings and chopped haylage, and mortalities were placed on the bed immediately following dispatch in a manner to efficiently utilize space on the windrow. Animals then were covered with a 0.61-m-thick, 50:50 blend of haylage and manure on the sides and top of the windrow. The entire process of covering the carcasses was completed within approximately three hours following dispatch. The composting recipe was developed with ingredients known to result in microbial activity that would produce thermophilic temperatures and rapid decomposition of the carcasses.

### **Sampling for Xylazine and Ketamine Residues**

At the start of the study, the total mg of ketamine and xylazine administered to the animals was used to calculate the starting concentration of drugs (see table 3). Composite samples of the composting mixture were collected from pre-determined locations in the windrow after the animals had composted for 4, 8, 11, and 13 weeks. The samples consisted of 25, 170-gram aliquots that were mixed in a stainless-steel bowl from which subsamples were collected for laboratory analysis.

Table 3. Total weight of ketamine and xylazine administered in mg that was used for sedation/anesthesia in the animals.

Drug Mass at Study Start	Weight (mg)	Weight (kg)
Ketamine	2,700	0.0027
Xylazine	7,600	0.0076
Total		0.0103

Throughout the 13-week active composting phase, daily temperature readings were taken at three separate temperature sampling points in the windrow. At each sampling point, a 0.3-m and 0.9-m reading were recorded. The 0.3-m reading reflects aerobic activity in the oxygen rich zone within the outer 0.3 m of the windrow surface, and the 0.9-m reading reflects microbial activity in the slightly less oxygen rich core. The temperature readings were taken consistently by two USDA-recognized subject matter experts in carcass composting and samples were collected exclusively by a specialist in sample collection. Additional observations were made for leachate breakouts, odors, and any apparent vector activity. Data on environmental temperature and precipitation were collected from the National Oceanic and Atmospheric Administration and are presented in Figure 3.

### **Results**

Concentrations of xylazine and ketamine in the compost windrow declined substantially over the course of the composting period (table 4 and figure 2). Initial concentrations at the time of

windrow construction were 198.4 ppb for xylazine and 66.1 ppb for ketamine. By the first turn, at 4 weeks, levels decreased 55% to 87.1 ppb and 44.9% to 29.7 ppb, respectively. Continued degradation was observed through subsequent turns. By the second turn (around week eight), cumulative reductions reached 86% for xylazine and 81% for ketamine. On the third turn (eleven weeks), reductions were 87% and 84%, respectively. By the final turn (thirteen weeks), xylazine concentration was 24.4 ppb and ketamine was 9.8 ppb, representing a decrease of 88% and 85%, respectively.

Table 4. Concentrations of xylazine and ketamine in compost at the start and end of the 13-week composting period, showing mean values (ppb) and percent reduction after composting.

Drug	Amount at Start (ppb)	Amount at End (ppb)	% Reduction
Xylazine	198.41	24.36	87.7
Ketamine	66.14	9.75	85.3

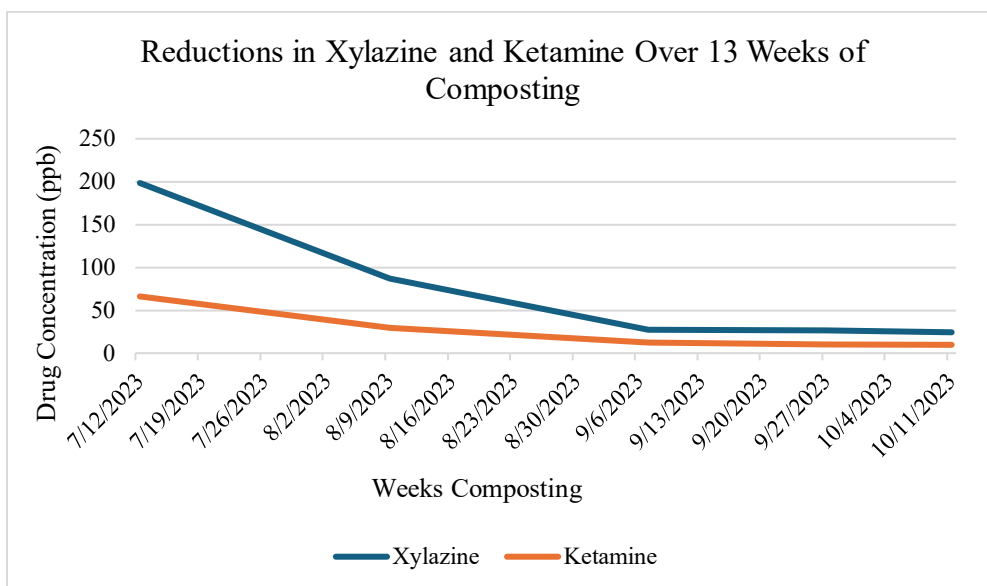


Figure 2. Reduction in xylazine and ketamine concentrations during 13 weeks of composting. Mean concentrations (ppb) of xylazine and ketamine declined steadily over the composting period, with the greatest reductions observed during the first 8 weeks. Both compounds showed over 85% total reduction by the end of the compost period.

Figure 3 shows the average temperatures recorded at two depths (30 cm and 91 cm) during the 13-week compost period. The overall profile showed an initial period of rapid heating during the initial weeks, followed by a period of gradual cooling near the end. The windrow was turned at frequent intervals, with each turn being associated with a temporary drop in internal temperatures, followed by a recovery 24 to 48 hours later. In some cases, pile recovery was delayed if a turn occurred following one of several discrete rainfall events, each exceeding 2.5 cm of precipitation.

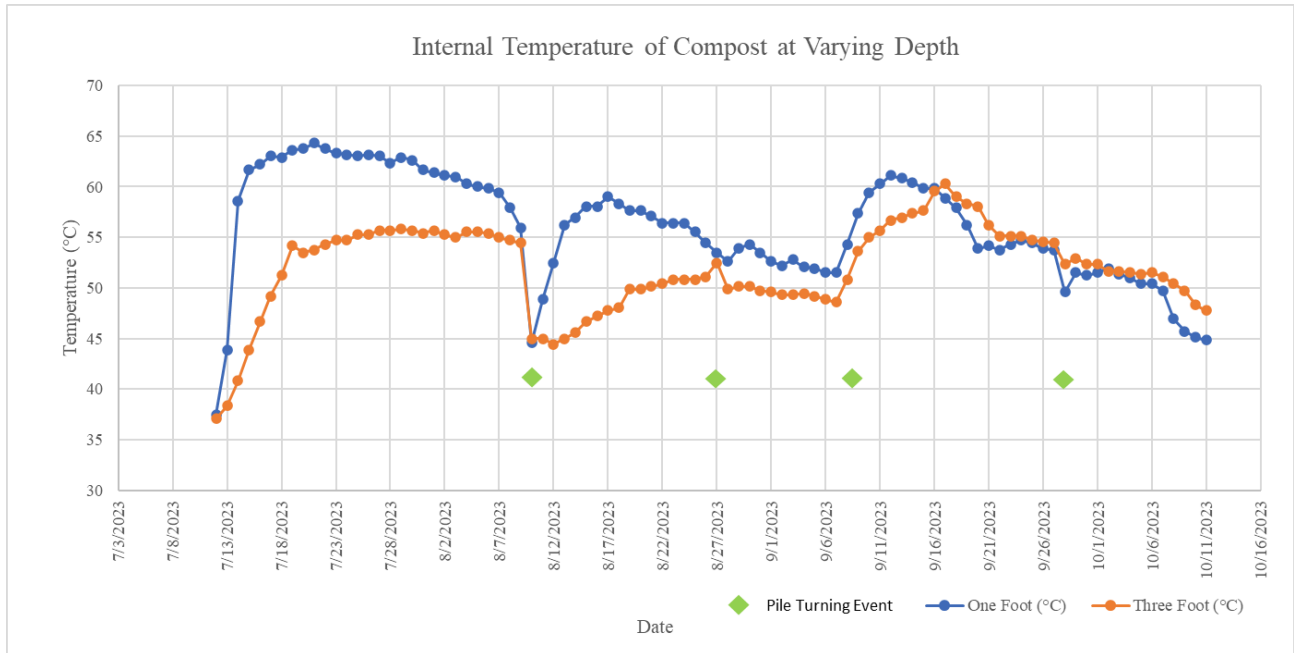


Figure 3. Daily temperatures recorded during the 13-week compost period.

Along with daily temperature monitoring and pile observations, environmental monitoring of the compost site (ambient temperature, precipitation, leachate and vector activity) was also recorded during the 13-week composting period. Figure 4 shows the average daily ambient temperature (°C) and precipitation (cm) recorded during the 13-week period.

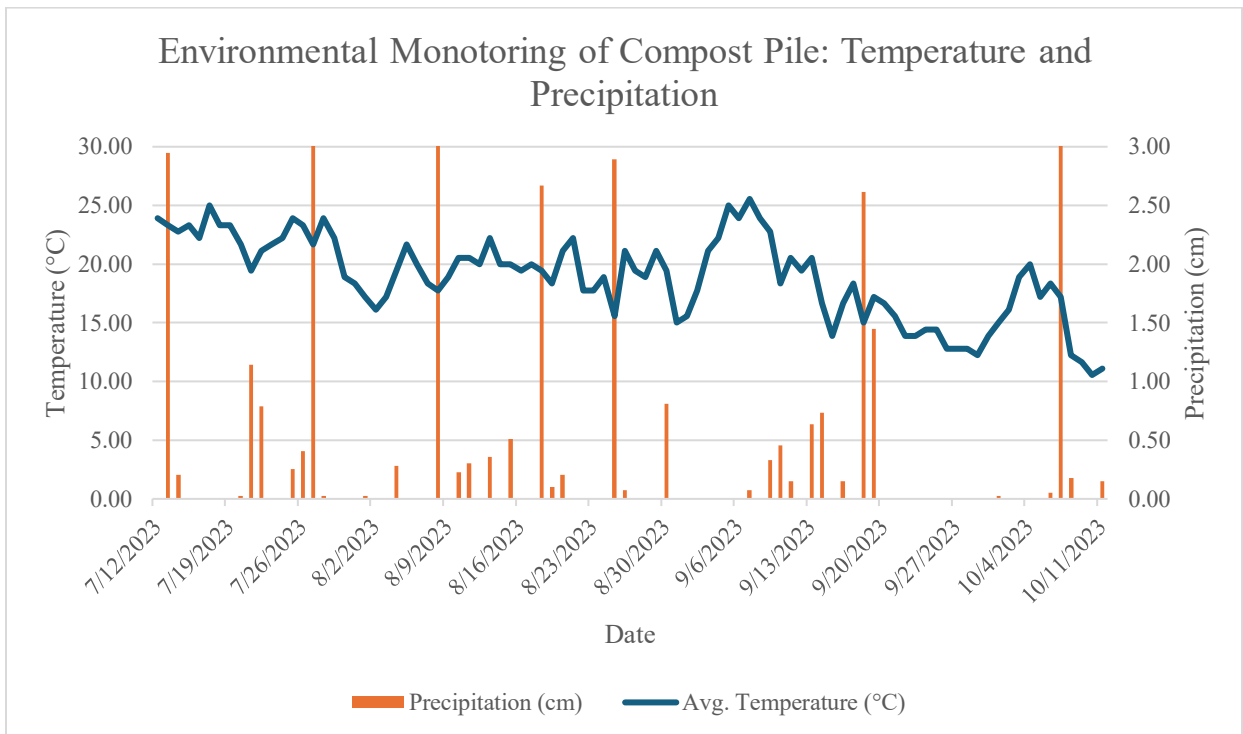


Figure 4. Daily temperature and precipitation events recorded during the 13-week compost period.

Ambient temperatures generally declined from approximately 25 °C in mid-July to below 15 °C by early October. The average ambient temperature remained relatively stable between mid-July and early October, generally ranging from around 15.6 to 26.7 °C, with modest fluctuations. Several discrete precipitation events occurred, with notable peaks in early to mid-August, and in late September and early October, each exceeding 2.54 cm of daily rainfall (Figure 4).

Throughout this study, leachate from the windrow, which could transport the euthanasia agents out of the windrow, thereby influencing the results, was not observed. The thick, absorptive base, which was 0.9 m thick, was likely a significant factor in leachate retention. In addition, odors, which would attract avian or mammalian vectors, were not evident.

## **Discussion**

The findings noted above suggest that composting can effectively reduce both xylazine and ketamine concentrations in a compost medium containing animals administered with these compounds, with the largest reductions occurring within the first eight weeks of composting. This study showed marked reduction of both ketamine and xylazine in a relatively short period, differing from previous studies, which were mostly done in laboratory settings or focusing on environmental degradation in water (Xega et al., 2019).

The windrow noticeably reduced in size and volume over the 13-week composting period, to approximately half of its original volume. This volume reduction has been noted in previous studies and has been attributable to carbon losses through volatilization during an active, robust compost process [(Tiquia and Tam 2000), (Paredes et al. 2000), (Breitenbeck and Schellinger, 2013) and (Themelis and Kim 2002)]. Themelis and Kim further explored the mechanics of the compost process and found that up to 50% of the original organic matter may be degraded in as little as four weeks, provided optimal compost conditions have been met.

The observed decline in ketamine and xylazine concentrations over the 13-week composting period can be attributed to a combination of sorption to organic matter and microbial degradation under sustained thermophilic conditions. Electrostatic binding, hydrogen bonding, and partitioning into organic matter likely occurred rapidly in the first eight weeks and accounts for the early large reductions in compound concentrations (Dr. Sonia Moavenzaheh, Personal Communication).

During active composting, the average pH is 6.5–8.0 (Wilkinson, 2006). In this environment, both compounds, which are weak bases, occur partly in their protonated forms and are strongly attracted to negatively charged functional groups, particularly carboxylates and phenolics in humic substances.

For ketamine, initial interactions with organic matter include hydrogen bonding of the protonated amine group with hydroxyl and amino groups in the compost (Dr. Jean MacRae, Personal

Communication). In addition, the aromatic domain can participate in staking interactions with humic matter and lignin and once sorbed, ketamine is more accessible to microbial enzymatic processes, particularly under the thermophilic compost conditions. These metabolites may be further mineralized into carbon dioxide, ammonium and other low molecular weight compounds, or they may become bound residues incorporated into the humic fraction.

Xylazine behaves somewhat differently due to its smaller molecular size, more polarity, and distinctive imidazole ring with a thioether group. The imidazole nitrogen can participate in electrostatic interactions with carboxylates when protonated and act as hydrogen bond acceptors when neutral. The sulfur substituent is also chemically labile and can undergo oxidation in composting conditions, forming sulfoxides or sulfones, while microbial communities may attack and eventually cleave the imidazole ring. Although xylazine is relatively water soluble and could migrate into wetter parts of the pile, the combined effects of sorption and microbial transformation appear to have restricted its mobility and contributed to the overall reduction in measured concentrations (Dr. Sonia Moavenzaheh, Personal Communication).

While the observed reductions of ketamine and xylazine in this study are likely attributable to the chemical and physical processes noted above, dilution of these agents throughout the mass of the feedstocks in the windrow may imply that the observed concentrations of ketamine and xylazine would decrease because of dilution. However, the 50% volume reduction of the windrow during composting suggests that the concentration of the agents within the medium would increase, which was not observed.

While large precipitation events may have influenced surface moisture levels in the compost windrow, potentially affecting microbial activity, heat retention, and overall moisture, evidence of significant changes in internal compost temperature due to precipitation is lacking. The increased moisture may have somewhat inhibited core compost temperatures, particularly after turning events, when added moisture would be most impactful. Turning the windrow likely had the greatest effect on internal compost temperatures. The first two turns were scheduled based on temperature data and were well-timed; however, the third turn was done earlier than ideal, before peak internal temperatures were reached.

The lack of significant reductions in ketamine and xylazine residues near the end of the composting process may be attributable to physical factors, which may include the remaining compounds being tightly bound to particulate organic matter in the compost medium and, therefore, not bioavailable, or the soluble concentrations of the compounds were below the concentrations required to induce microbial enzyme degradation (Dr. Jean MacRae, Personal Communication).

Another confounding factor may have been the techniques used by the front-end loader operators to turn the compost. One operator completed the first two turns, while another conducted the last two. Turns by the second operator resulted in taller piles (1.8–2 m), likely improving windrow aeration and causing higher post-turn temperatures compared to earlier turns. It is also likely that

the initial wetness of the pile contributed to the lower than expected temperatures. These confounding factors are among the situations commonly encountered in on-farm composting and provide a reasonable example of results expected in the field.

## **Conclusion**

Composting represents an effective and inexpensive method for livestock carcass disposal that minimizes environmental impacts, supports biosecurity objectives, including the reduction of pathogens and, as this study demonstrates, can facilitate degradation of pharmaceutical agents used in euthanasia. With proper management, composting can be implemented year round using readily available materials and equipment on farm premises. Numerous cooperative extension programs and other government agencies provide guidance to farmers on best management practices to ensure accessibility and regulatory compliance.

In this study, the greater than 80% reduction of ketamine and xylazine during the active composting phase is likely the result of multiple overlapping processes. Sorption into organic matter through electrostatic attraction, hydrogen bonding, aromatic stacking, and hydrophobic partitioning rapidly immobilizes these compounds, while microbial transformation processes, including demethylation, hydroxylation, and ring cleavage, further degrade them (Dr. Sonja Moavenzakeh, Personal Communication). Environmental conditions inherent to composting, such as elevated temperatures, periodic aeration during turning, and variable moisture, enhanced both sorption and degradation processes, underscoring composting's capacity to mitigate risks associated with pharmaceutical residues in livestock carcasses. The potential loss of ketamine and xylazine via leaching from the windrow must be considered in the potential concentration reduction of these compounds; however, leachate was not observed leaving the windrow during daily monitoring. The loss of the compounds by translocation from the windrow to the underlying natural soil could not be discounted. Future studies, which should be done to verify these results, could be designed to account for any losses to the soil under the windrow.

This study was initiated secondary to an emergency depopulation event and provides valuable insight for future investigations on the degradation of anesthetic compounds in compost. The findings highlight opportunities to refine experimental design in subsequent studies, particularly those with the capacity for more advanced planning. Incorporating lysimeter or core sampling to monitor leachate would have strengthened the interpretation of compound fate. Additionally, serial core sampling before and after compost turning events to assess changes in the chemical composition would have enhanced the understanding of compost dynamics and degradation processes.

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