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Soil Contamination Caused by Emergency Bio-Reduction of Catastrophic Livestock Mortalities

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Abstract
Catastrophic regional losses of poultry and livestock have caused environmental officials in North America to seek emergency on-farm disposal alternatives that pose less pollution risk to soil and shallow groundwater than burial. Bio-decomposition of remains followed by land application of the resulting product is used throughout the U.S. and Canada for management of routine poultry, swine, and cattle mortalities, and is often cited as being more environmentally friendly than burial since it recycles nutrients and other potential pollutants into the topsoil and crop production cycle, rather than placing them deeper in the ground and closer to groundwater. During emergencies, however, when time and resources are limited, bio-reduction is likely to be done in unsheltered windrows constructed on unprotected soil—conditions that could cause localized soil pollution. Pollution associated with emergency bio-reduction procedures was assessed by comparing pre- and post-bio-reduction concentrations in soil beneath the bio-reduction sites. Small but statistically significant ($p < 0.05$) increases in chloride at depths of 1.2 m indicated that bio-reduction leachate reached this depth. Significant increases in % total nitrogen and % total carbon were observed only in the top 15 cm of soil, but large increases in total ammonia–nitrogen were observed at depths of 30–90 cm. The total mass of N added to soil by bio-reduction was 10–25% of the estimated total N in the cattle carcasses, indicating that bio-reduction poses a lower pollution threat to soil and shallow groundwater than burial.

Keywords
Livestock, Disposal, Composting, Burial, Soil, Pollution

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Abstract Catastrophic regional losses of poultry and livestock have caused environmental officials in North America to seek emergency on-farm disposal alternatives that pose less pollution risk to soil and shallow groundwater than burial. Bio-decomposition of remains followed by land application of the resulting product is used throughout the U.S. and Canada for management of routine poultry, swine, and cattle mortalities, and is often cited as being more environmentally friendly than burial since it recycles nutrients and other potential pollutants into the topsoil and crop production cycle, rather than placing them deeper in the ground and closer to groundwater. During emergencies, however, when time and resources are limited, bio-reduction is likely to be done in unsheltered windrows constructed on unprotected soil—conditions that could cause localized soil pollution. Pollution associated with emergency bio-reduction procedures was assessed by

Note: Due to the heterogeneous inputs and layered structure of on-farm emergency mortality disposal "composting" operations, the authors have chosen to refer to this as "bio-reduction" rather than composting which has long been associated with frequently- and completely-mixed solid waste treatment processes designed to achieve homogeneous matrix characteristics that are considered optimal for high rates of biological activity.

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comparing pre- and post-bio-reduction concentrations in soil beneath the bio-reduction sites. Small but statistically significant ($p<0.05$) increases in chloride at depths of 1.2 m indicated that bio-reduction leachate reached this depth. Significant increases in % total nitrogen and % total carbon were observed only in the top 15 cm of soil, but large increases in total ammonia–nitrogen were observed at depths of 30–90 cm. The total mass of N added to soil by bio-reduction was 10–25% of the estimated total N in the cattle carcasses, indicating that bio-reduction poses a lower pollution threat to soil and shallow groundwater than burial.

Keywords Livestock · Disposal · Composting · Burial · Soil · Pollution

1 Introduction

A Foot-and-Mouth Disease epidemic in Great Britain in 2001, an avian influenza outbreak in British Columbia (Canada) in 2004, hurricanes Katrina and Rita along the U.S. Gulf Coast in 2005, rangeland wildfires in North Texas in 2006, prolonged heat stress in California during the summer of 2006, and a massive blizzard in Eastern Colorado and Western Kansas in 2007 are examples of recent large-scale emergencies in Great Britain and North America resulting in catastrophic death losses of poultry or livestock. Events such as these pose serious environmental concerns in areas with high poultry and livestock population densities. In the state of Iowa for example (ranked #1 in U.S. swine production, # 8 in cattle and calf production, and #1 in laying hens) (USDA-NASS 2007a, b), evaluation of emergency disposal alternatives by the Iowa Department of Natural Resources (IDNR) indicated that open pyre incineration would produce unacceptable air pollution, and that 30–40% of Iowa is poorly suited for mass burial due to shallow groundwater or close proximity to environmentally sensitive areas. Emergency disposal via rendering, the most common method for disposal of routine livestock mortalities, is limited by the small and declining number of rendering facilities, and by costs and biosecurity risks associated with transporting large amounts of pathogen-contaminated material over long distances. With these limitations in mind, the IDNR commissioned a three-year study by Iowa State University (ISU) to evaluate the feasibility, performance, and environmental consequences of using on-farm bio-reduction to heat treat and rapidly decompose large quantities of cattle under emergency conditions.

2 Literature Review

Management of routine production mortalities via bio-reduction and land application was pioneered in the U.S. poultry industry in the late 1980's as availability of rendering service declined and the groundwater pollution potential of continuous on-farm burial of large numbers of birds became a public concern. Researchers at the Universities of Maryland and Delaware were the first to develop low cost on-farm procedures for accelerated decomposition and agronomic recycling of the resulting product on cropland (Murphy and Handwerker 1988; Owings 1990; Blake and Donald 1992; Carter 1993; Glanville and Trampel 1997). Successful use of bio-reduction in the poultry industry led to adaptation of poultry bio-reduction methods for use in the swine industry in the early to mid 90's (Fulhage 1994, 1995; Hermel 1992, 1993; Morrow and Ferket 1993; Morrow et al. 1995; Siera 1995; Rozeboom and Siera 1996). More recently several projects have been initiated to investigate the practical potential for using bio-reduction for non-emergency disposal of cattle, road-kill deer, and other large species (Bonhotal and Harrison 2005; Kirk et al. 2005; Muhktar et al. 2003; Murphy and Harner 2004; Goldstein 2004; Singleton 2002, 2004; Morse 2001).

A massive foot-and-mouth disease outbreak in Great Britain in 2001, and recent worldwide concern regarding the possible spread of avian influenza among wild and domesticated birds, has led to increased interest in the potential for using bio-reduction for emergency disposal of poultry or livestock. In the U.S., bio-reduction has been used for emergency disposal during an avian influenza outbreak in Virginia in 2002, and during a similar incident in 2004 in the Delmarva area (Bendfeldt et al. 2005a, b; Tablante and Malone 2006). The Canadian Food Inspection Agency reported successful use of passively aerated bio-reduction windrows for disposal of poultry carcasses during an outbreak of highly pathogenic avian influenza in British Columbia in 2004 (Stepushyn 2004; Spencer et al. 2004, 2005). These incidents have spawned new research designed to better understand critical operating factors affecting emergency bio-reduction, and to expand the application of bio-reduction to emergency disposal of swine and cattle. Procedures for emergency in-house bio-reduction of poultry were evaluated for the U.S. Poultry and Egg Association by Tablante et al. (2003). More recently, guidelines for emergency bio-reduction of poultry in the U.S. have been developed by the U.S. Department of Agriculture - Animal, Plant, and Health Inspection Service (USDA-APHIS), the Victoria Department of Primary Industries has drafted research plans to study bio-reduction methods for disposal of catastrophic poultry losses in Australia (Wilkinson 2006); and the Canadian Food Inspection Agency is currently conducting studies of emergency bio-reduction procedures for disposal of poultry, swine, and cattle.

Despite increasing reliance on on-farm livestock disposal methods in North America, their environmental impacts have received little scientific study. A review of literature conducted by Freedman and Fleming (2003) located only five published reports on the pollution impacts of burial. These included: studies of the impacts of dead bird disposal on shallow groundwater quality (Ritter et al. 1988; Ritter and Chirnside 1995; Myers 1998; Glanville 2000); monitoring of pollutants in and near swine burial trenches (Glanville 2000), and a study of soil microbiology near human grave sites (Hopkins 2000).

A comprehensive survey of literature on the environmental impacts of all methods of livestock disposal, conducted by Engel et al. (2004) for the National Agricultural Security Center Consortium, reported no studies of soil or water impacts associated specifically with on-farm mortality bio-reduction, but the impacts of on-farm manure bio-reduction have been examined in some detail. Studies of beef and dairy manure bio-reduction by Eghball et al. (1997) and Sommer and Dahl (1999) indicated that less than 0.5% of the initial N in the manure was lost in water. Bio-reduction of farm wastes containing poultry manure, however, was reported to result in high NO_3 losses (Ballestero and Douglas 1996). Nienaber and Ferguson (1994) reported significant accumulation of NO_3 throughout the soil profile beneath on-farm bio-reduction sites that had been used continuously for only 2 years. In their comprehensive literature review of the environmental impacts of farm-scale bio-reduction Peigne and Girardin (2004) concluded that choice of raw materials—particularly their C/N ratio and water-holding capacity—and control of water flux through use of covers and impermeable floors, were key factors in minimizing leachate and runoff.

During livestock emergencies, when large numbers of carcasses must be dealt with quickly to minimize air and water pollution risks and biosecurity concerns, time and resources are limited and bio-reduction is likely to be done on un-compacted soil, without benefit of shelter from precipitation, at high carcass loading rates, and using a variety of carbonaceous materials that are available on the farm. Under such conditions, the risks of soil and groundwater pollution are increased, and quantification of the resulting soil pollution is the objective of this study.

3 Experimental Design

Soil pollution caused by emergency bio-reduction of cattle mortalities in unsheltered windrows constructed on un-protected soil was assessed by comparing concentrations of total nitrogen, total carbon, ammonia-nitrogen, nitrate-nitrogen, and chloride contained in soil cores collected from beneath the bio-reduction area before and after bio-reduction. Since seasonal differences in temperature and precipitation may affect the timing and quantity of pollutants released into the soil, field trials were initiated during spring, summer, and winter months. To observe how soil pollution may be affected by the type of carbonaceous material used to envelope the carcasses, replicated test units were constructed using three types of material commonly found on cattle farms. The original experimental design called for each treatment to be replicated three times, resulting in a total of 27 test units (3 materials × 3 seasons × 3 replications).

4 Materials and Methods

4.1 Envelope Materials

Materials initially selected for testing included corn silage, ground cornstalks, and composted yard waste. The first two were selected because they are feed and bedding materials commonly used on cattle farms. Yard waste compost was chosen because it is available in large quantities at many county or municipal composting facilities, and was believed to be a potentially useful alternative during regional livestock emergencies when sufficient quantities of on-farm envelope materials may not be available. The yard waste compost available to the project was uncharacteristically fine-textured and soil-like and carcass decay was unacceptably slow. This material was replaced by dry leaves after two seasonal trials. These performed better than the fine-textured compost, but their year-round availability was questioned and so were replaced with a "straw/manure" alternative in which the cattle carcasses were covered with a thin layer of moist beef feedlot manure and then capped with ground oat straw. Table 1 summarizes the season and envelope material combinations during each trial. It would have been somewhat more desirable to construct all three seasonal replications during the same season, but this would have greatly increased the quantities of carcasses and envelope materials needed at one time (36 naturally deceased [*not* euthanized] cattle weighing ~450 kg, and approximately 9 m^3 of ground envelope material per carcass). Spreading the seasonal trials over two years resulted in a much more feasible construction goal for each trial.

Furthermore, there were concerns regarding the intensity and duration of odor pollution that might occur during windrow composting of large cattle carcasses. To minimize the potential for odor release and disturbance of landowners located near the research site, it was decided to limit the first year of research to single-replication trials that would permit preliminary assessment of odor while reducing the risks of a serious odor release.

4.2 Test Unit Construction and Operation

Test units were constructed on un-protected cropland soil at the Agricultural and Biosystems Engineering Research Center located near Ames, IA. Soils at the research site are classified by the Natural Resources Conservation Service as Canisteo silty clay loam (approximately 60%), and Clarion loam (40%). The natural drainage classification for the Clarion soil is "well drained," with slope of 2–5% and a seasonal (April) high water table at depth of 122–182 cm. Canisteo is classified as "poorly drained," with slope of 0–2% and a seasonal (April) high water table at a depth of 0–30 cm. Both soils are listed as having moderately-high to high saturated conductivity (NRCS 2006).

Bio-reduction test units consisted of triangular cross-section windrows with an initial peak height of approximately 2.1 m, and base dimensions of 5 m× 6.1 m. During each seasonal trial, three to six test units were constructed end-to-end to simulate typical full-scale bio-reduction windrows, and to reduce external surface area and heat loss during cold weather. Construction was begun with a 60 cm thick base layer of envelope material to absorb leachate. Four 450 kg cattle carcasses were placed in each test unit in a single layer on top of the base, and were covered with 45–60 cm of the same material used in the base. Carcasses in the straw/manure dual-layer units were covered with an additional layer of moist cattle feedlot manure, 15–24 cm thick, prior to being capped with 45–60 cm of ground straw. The straw/manure test units were conducted to assess the feasibility of simultaneously treating contaminated animal manure and carcasses. Cornstalks and straw were run through a mobile tub grinder equipped with a 2-inch screen prior to being used.

Although bio-reduction procedures for routine livestock mortalities typically include periodic turning to

Table 1 Field trials conducted during emergency bio-reduction study

Trial no.	Starting date	Initial seasonal conditions	Envelope material tested and number of test units				
			Corn silage	Ground corn stalks	Straw manure dual layer	Leaves	Fine-textured compost
1	Aug. 2002	Warm/dry	1	1			1
2	Nov. 2002	Cold	1	1			1
3	April 2003	Cool/wet	1	1		1	
4	June 2003	Warm/dry	2	2	2		
5	Nov. 2003	Cold	2	2	2		
6	April 2004	Cool/wet	2	2	2		
Total units tested			9	9	6	1	2

speed carcass decay, turning of pathogen-contaminated mortalities may increase biosecurity risks. Since the objective of this research was to assess the environmental impacts of procedures suitable for use during disease outbreaks, test units were not turned during the study.

4.3 Leachate Sampling and Analysis

Leachate was collected with troughs consisting of half-sections of 6-in. diameter PVC water pipe that were installed in the base of test units in trials 5 and 6. The troughs extended from the centerline to the edge of the windrows where leachate drained into 1-liter polyethylene bottles. Two collector troughs were installed in each test unit. Each was positioned so as to capture an integrated sample of leachate contributed by carcasses and adjacent cover material. Since both carcasses and envelope materials can produce leachate, one of the objectives of the original experimental design was to compare the quantity and quality of leachate originating from envelope materials versus that from carcasses. During early trials, separate leachate capture trays were positioned beneath windrow areas containing carcasses, and below sections containing only envelope materials. Due to the large size of the cattle carcasses, pile segments representing only envelope material were necessarily located near the edge of the windrows where pile thickness was reduced. Review of early leachate data from these locations showed high spatial variability raising concern that this may have been caused by lower water-holding capacity and higher evaporation rates. Because of this, further efforts to compare the quantity and quality of leachate from carcasses vs envelope materials were abandoned in favor of focusing on evaluation of the overall soil pollution impacts of the emergency bio-reduction procedure which were the central concern of the project sponsor.

Leachate samples were tested for total solids, total organic carbon (TOC), nitrate (NO_3), and ammonia-nitrogen (NH_4–N). Total solids were analyzed by method SMEWW 2540 B (APHA 1998) and were reported as the mass of dry solids per volume of wet sample. TOC was analyzed using the persulfate-ultraviolet method (SMEWW 5310 C) (APHA 1998). Nitrate analyses were done by electrode using a Hach Sension 2 ISE meter, and ammonia-N was analyzed using the ammonia selective electrode method (SMEWW 4500-NH_3 D) (APHA 1998).

4.4 Soil Sampling and Analysis

Immediately before construction, and within 30 days after each 12-month bio-reduction trial was dismantled, four soil cores (3.1 cm diameter × 1.2 m deep) were collected from the area (5 m × 6.1 m) beneath each test unit and stored in plastic zero-contamination core tube liners at -5°C. Holes created by removal of cores prior to bio-reduction were sealed with granular bentonite to block preferential flow of leachate into the soil profile.

Each soil core was cut into 6 segments, resulting in a total of 1296 segments (27 test units × 8 cores/unit × 6 segments/core) to be analyzed. To help keep testing costs within the budgeted amount, and to get the most information for the time and money spent on testing, the upper 60 cm of each core—where the highest pollutant concentrations and steepest concentration gradients were anticipated to be observed—were cut into four 15-cm sections, and the lower 60 cm into two 30-cm sections.

Core segments were tested for moisture content, chloride, nitrate–N (NO_3–N), total ammonia–N (NH_3–N+NH_4–N), total carbon (TC), and total nitrogen (TN). Moisture content was determined by weighing, drying at 105°C for approximately 24 h, and reweighing. To prevent nitrogen loss during drying, samples were acidified with 0.44 mol tartaric acid. Nitrate–N and Cl were extracted with de-ionized water, and 2 M KCl was used to extract ammonia–N. Nitrate–N, Cl, and ammonia–N were analyzed using the cadmium reduction method, ferricyanide method, and salicylate modification of the phenate method respectively, followed by ion chromatography on a Lachat QuikChem 8000 automated ion analyzer. Total carbon and TN were determined by combustion analysis using a Perkin Elmer PE 2400 CHNS elemental analyzer.

5 Results and Discussion

Due to lack of test unit replication (explained previously) using the soil-compost blend (N=2) and leaves (N=1), data for these two envelope

Table 2 Mean bio-reduction-related chemical constituents in upper 1.2 m of soil cores collected prior to bio-reduction (N=108, 27 test units × 4 cores/unit)

Depth interval (cm)	Total carbon (%, d.b.)	Total nitrogen (%, d.b.)	Chloride (mg/kg, d.b.)	Ammonia-N (mg/kg, d.b.)	Nitrate-N (mg/kg, d.b.)
0–15	2.40±0.6	0.21±0.04	55.0±33.0	5.2±5.1	12.5±9.4
15–30	2.16±0.78	0.18±0.04	56.2±30.5	3.2±2.6	8.4±6.7
30–45	1.41±0.68	0.12±0.03	58.5±38.0	2.9±1.8	6.4±6.7
45–60	0.91±0.70	0.08±0.03	50.9±48.2	2.5±1.5	6.0±6.4
60–90	0.97±1.03	0.04±0.03	25.6±20.3	1.8±1.4	6.5±7.1
90–120	1.20±0.97	0.03±0.02	21.8±15.2	1.6±1.3	7.1±6.7

materials are not included in the following analysis of results.

5.1 Chemical Concentrations Prior to Bio-reduction

Table 2 summarizes mean chemical concentrations in the soil prior to bio-reduction. Total carbon averaged 2.4% (d.b.) in the top 15 cm of soil and declined gradually to about 1% in the 60–120 cm depth interval. Total N followed a similar trend, ranging from 0.2% (d.b.) in the topsoil to 0.03% at 120 cm. Chloride, a highly mobile anion that is often applied to cropland in the form of KCl fertilizer, remained nearly constant at 51–58 mg/kg in the upper 60 cm of soil, dropping to 22–26 mg/kg in the 60–120 cm depth range. Nitrate, an anion with soil mobility similar to chloride—but one that also is readily transformed by soil bacteria—was present at 12–13 mg/kg in the upper 15 cm, and remained nearly constant at 6–8 mg/kg in the 15–120 cm interval. Like total N, ammonia–N concentrations exhibited a declining trend with depth, ranging from 5.2 mg/kg in the upper 15 cm of soil, to 1.6 mg/kg at 120 cm.

5.2 Leachate Quality

Mean pollutant concentrations measured in composite samples of leachate captured at the base of the bio-reduction test units are shown in Table 3. The data have high variability due to seasonal differences in precipitation and varying stages of carcass degradation throughout the 12 month period when samples were captured.

Pollutant concentrations were consistently highest in leachate from straw/manure test units where concentrations of all analytes were roughly 2–4× those in leachate from test units constructed with silage or ground cornstalks. Elevated pollutant concentrations in leachate from straw/manure test units are believed to have been caused primarily by the layer of manure placed over the cattle carcasses.

Comparing the remaining two envelope materials, total solids and TOC concentrations in leachate from silage test units were 3–4× those in cornstalk leachate. Silage's higher biodegradability—due in part to its favorable initial moisture content for microbial activity (74% vs 29% for cornstalks) (Table 4) and to partial decomposition during the ensiling process—is believed to be the main reason for this. Higher biodegradability for silage was evidenced by internal temperatures in silage field test units that, regardless of ambient temperatures, were consistently 10–30°C higher than in cornstalks (Glanville et al. 2005), and also by laboratory biodegradability tests (Ahn et al. 2008b) showing maximum oxygen uptake rates of 50 and 12 mg O_2/g VS respectively for silage and cornstalks.

Unlike TS and TOC, NO_3–N and NH_3–N concentrations in silage leachate were only about one-half of those in cornstalk leachate. Low pH (initially 3.4) and

Table 3 Mean pollutant concentrations in leachate

Envelope material	NO_3–N (mg/L)	NH_3–N (mg/L)	TS (mg/L)	TOC (mg/L)
Straw/manure (N=27)	186±220	904±1942	29,001±16,773	8,919±12,664
Silage (N=30)	41±79	194±344	18,978±12,275	4,830±6,550
Cornstalks (N=26)	95±154	330±690	5,350±2,214	1,140±1,324

Table 4 Initial moisture content and water-holding characteristics of envelope materials (N=3) (Ahn et al. 2008a)

Envelope material	Field moisture content at beginning of study (% w.b.)	Maximum water holding capacity (g water/g dry material)	Available water absorbing capacity (kg/kg wet material)
Corn stalks	29.2±0.8	4.4±0.3	2.8±0.2
Oat straw	17.3±0.6	3.6±0.3	2.8±0.3
Silage	74.2±0.8	3.8±0.1	0.2±0.04

low O_2 concentrations (minimum values of 4–9%) in the silage are believed to have suppressed N mineralization and nitrification rates relative to those in cornstalks (initial pH 6.7; O_2 range 12–18%).

Naturally occurring variability in factors such as the initial moisture content, pH, and C:N ratio of envelope materials would be expected to impact leachate quantity and quality. So the leachate data shown above, while representative, should not be construed to represent the full range of responses that may occur. Study of relationships between envelope material characteristics and leachate quantity/quality, however, would best be done in the lab where greater experimental control can be exerted over these and other key variables.

5.3 Pollutant Concentration and Depth of Soil Penetration

Figure 1 shows the maximum soil depth increment in which statistically significant increases in bio-reduction-related pollutants occurred.

5.3.1 Chloride

Chloride is widely distributed in nature (Weiner 2000), and elevated chloride concentrations have often been identified near animal burial sites (Glanville 2000; Nutsch and Spire 2004; Engel et al. 2004; Freedman and Fleming 2003). With little tendency to be absorbed by soil or transformed by soil microbes, Cl moves through soil more quickly than most other leachate constituents and is an indicator of the leading edge of leachate migration. This study showed statistically significant ($p<0.05$) increases in Cl concentration beneath all envelope materials, and in all soil depth increments (Fig. 1). The ratios of post-bio-reduction concentrations to pre-bio-reduction concentrations in the same depth interval (Table 5)—were moderate, ranging from a low of 1.6 to a high of 5.7.

5.3.2 Nitrate-N

Although present in leachate from cornstalk and straw/manure test units at average concentrations of

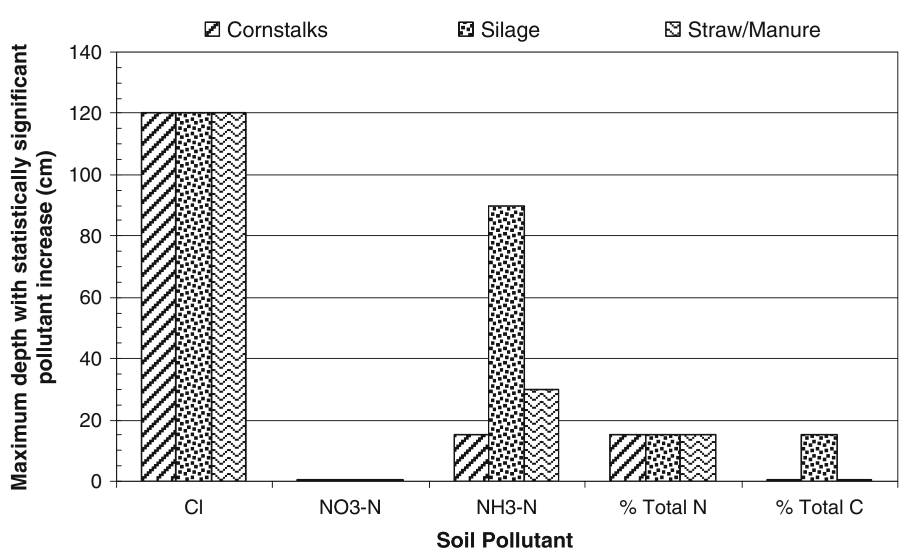

Fig. 1 Maximum depths at which statistically significant increases in soil pollutants were observed beneath replicated test units constructed with three envelope materials

Table 5 Ratio of post- to pre-bio-reduction chemical concentrations within the same depth interval when statistically significant chemical increases occurred

	Chloride		NO_3–N		NH_3–N		Percent total N		Percent total C	
	Max[a]	Min[b]	Max	Min	Max	Min	Max	Min	Max	Min
Cornstalks	2.44	1.76	–[c]	–	59.08	–[d,4]	1.10	–[d]	–	–
Silage	3.21	1.61	–	–	115.81	8.44	1.38	[d]	1.18	[d]
Straw/manure	5.68	1.68	–	–	154.08	40.09	1.43	[d]	–	–

[a] Maximum ratio

[b] Minimum ratio (if more than one depth interval showed statistically significant increases

[c] Indicates no statistically significant increases occurred

[d] Indicates only one depth interval was significantly impacted

100–200 mg/L, no statistically significant increases in NO_3–N were detected in the soil beneath any of the bio-reduction test units (Fig. 1). Denitrification in topsoil continuously moistened with leachate containing high concentrations of TOC (Table 3) is believed to be the most likely explanation.

5.3.3 Total Carbon

Although mean TOC in leachate from the three envelope materials ranged from 1,100–8,900 mg/L, statistically significant ($p<0.05$) increases in % total carbon were detected only in the upper 15 cm of soil, and only beneath silage test units (Fig. 1). The magnitude of the statistically significant increase was low, with post-bio-reduction concentrations of total C being only 1.18× the pre-bio-reduction concentration (Table 5). Failure to detect statistically significant carbon increases in topsoil beneath cornstalk and oat straw test units may be due, in part, to smaller releases of leachate caused by the water absorbing capacities of these materials which were 14× that for silage (Table 4). Relatively high natural soil organic carbon content—3–4% in the top 18 cm of Clarion soil, and 5–7% in the upper 25 cm of Canisteo (NRCS 2006)—also may have helped to obscure soil carbon additions by the leachate. Physical entrapment and sorption of particulate and soluble carbon, and soil microbial uptake, are likely explanations for the limited soil penetration by the organic carbon in the leachate.

5.3.4 Total Nitrogen

As with % total carbon, statistically significant increases in % total nitrogen were limited to the upper 15 cm of soil. Unlike the carbon data, however, increases were identified beneath all three types of test units (Fig. 1). Ratios of post-/pre- bio-reduction % total N concentrations ranged from 1.1 beneath cornstalk test units, to about 1.4 beneath straw/manure and silage units (Table 5).

5.3.5 Ammonia-Nitrogen

Analysis of ammonia-N concentrations indicated statistically significant ($p<0.05$) increases at depths of up to 90 cm beneath test units constructed with silage, and up to 30 and 15 cm respectively beneath straw/manure and cornstalk test units (Fig. 1). The maximum increases—which ranged from 200–800 mg/kg in the top 15 cm of soil—are 60–150× pre-bio-reduction concentrations (Table 5), and are roughly equivalent to fertilizer N application rates of 360–1440 kg/ha.

5.3.6 Impacts on Crop Growth

After removal of all bio-reduction test units, soybeans were no-till planted on the research site the following spring. As shown in Fig. 2 soil areas formerly occupied by bio-reduction test units exhibited very poor soybean emergence. Current literature suggests that even relatively sensitive agricultural crops can tolerate chloride concentrations in soil of 350 mg/kg (USDA-ARS 2007; Maas 1990). Since chloride concentrations in the topsoil beneath most bio-reduction test units were less than 300 mg/kg, it appears unlikely that the poor soybean emergence was caused by chloride in the topsoil. High concentrations of ammonia in soil have also been recognized

Fig. 2 Suppressed soybean growth exhibited in areas previously covered by mortality bio-reduction windrows

as detrimental to seedling emergence and root growth (Britto and Kronzucker 2002; Dowling 1998). Soybeans are among the more sensitive crops to ammonia injury, and the injury threshold may be in the range of 200–400 mg/kg which is at or well below the concentrations identified in topsoil beneath the bio-reduction test units.

The adverse impact on soybean emergence may have been magnified by use of no-till planting techniques. Had the soil been tilled prior to planting, some ammonia–nitrogen would have been lost to volatilization and nitrification, surface compaction would have been reduced, and deeper soil layers containing lower pollutant concentrations would have been mixed into the highly ammonia-contaminated topsoil thereby potentially reducing the phytotoxic effects of bio-reduction-related pollutants. Tillage and subsequent movement of oxygen into the upper soil layers, however, would be expected to lead to nitrification and subsequent movement of nitrate-nitrogen deeper into the soil profile. Planting of crops such as corn, which are less ammonia-sensitive and heavy users of nitrogen, may help to minimize these environmental impacts.

5.3.7 Bio-Reduction vs Burial

The results of this research show that emergency on-farm mortality bio-reduction carried out in uncovered windrows constructed on unprotected soil can contribute high concentrations of certain pollutants, particularly ammonia, to the underlying soil. Conclusions regarding the environmental acceptability of this procedure, however, must be drawn in the context of the likely impacts of alternative emergency disposal options, the most common of which is on-farm burial. In general whole animal carcasses are comprised of roughly 25% meat and bone and 75% water and fat (Auverman et al. 2004). About 50% of the meat and bone is crude protein (National Renderers Association 2006), and nitrogen comprises about 16% of most animal proteins (FAO 2003). As such, whole animal carcasses are about 2% nitrogen, and so the four 450–500 kg carcasses placed in each research test unit contained a total of about 40 kg of N. Soil core data from this study indicate that the mean mass of total N added to the top 1.2 m of soil beneath cornstalk, silage, and straw/manure bio-reduction test units was 4.2, 9.8, and 6.4 kg respectively, or roughly 10–25% of the total N that would have been placed into the soil profile had the carcasses been buried. Not only would the total mass of N placed into the soil by burial have been four to ten times greater than that added by bio-reduction but—since burial is typically done at depths of 0.9–2.5 m—much of the N in the cattle remains would be released below the root zone of crops, and at depths roughly 2–3× the 0.9 m depth that was significantly impacted by ammonia–N from bio-reduction. With the above in mind, the groundwater pollution risks associated with emergency bio-reduction procedures appear to be considerably lower than those posed by burial.

6 Conclusions

Emergency livestock mortality disposal by means of windrow bio-reduction and using three common agricultural products (silage, cornstalks, straw) resulted in statistically significant ($p<0.05$) increases in chloride at depths of 1.2 m beneath all test units. Significant increases in other pollutants—such as total organic carbon, total nitrogen, and ammonia–nitrogen—were limited to shallower depths. Increases in ammonia-nitrogen appear to pose the greatest environmental and agronomic concern. Beneath test units constructed with corn silage—a material with low available water holding capacity and relatively high nitrogen content—statistically significant increase in ammonia–nitrogen occurred at soil depths of up to 90 cm. Beneath test units constructed with ground cornstalks, or ground straw—materials having high available water absorbing capacity and relatively low nitrogen content—statistically significant increases in pollutant concentrations were limited to the top 15–30 cm of soil.

Although statistically significant increases in % total C, % total N, and chloride were detected, their pollution potential was relatively low as the magnitude of their maximum increases were less than 20%, 40%, and 500% of pre-bio-reduction concentrations in the upper 15 cm of soil. Increases in ammonia-nitrogen, however, were very large, ranging from 40–160× pre-bio-reduction concentrations in topsoil. The high ammonia-nitrogen levels in the topsoil would eventually be expected to nitrify, and this could lead to localized nitrate pollution of shallow groundwater if no action is taken to reduce them. This risk could be mitigated through judicious use of tillage to help volatilize the highest ammonia concentrations which are located near the surface of the ground, and through planting of ammonia-tolerant crops with high nitrogen uptake capacity. When compared with the potential groundwater impacts of emergency burial, the impacts of bio-reduction appear to be much lower since the total N contained in buried carcasses is estimated to be 4–10× higher than the increases in soil N contributed by bio-reduction leachate, and burial also would place the N load much closer to shallow groundwater resources.

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