RESEARCHREPORT
ENVIRONMENT

Title: A Two-Year Study of the Effectiveness of Geotextile Covers to Reduce Odor and Gas Emissions from Manure Storages
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Abstract. Odor, hydrogen sulfide (H_2S), ammonia (NH_3) and volatile organic compounds (VOC) were measured between May and October 2000, and between April and October 2001 at three sites in Southwest Minnesota. Each site consisted of a pair of farms (nursery N1, N2; 2,000-head finishing F2A, F2B; 3,000-head finishing F3A, F3B). A manure storage from each pair was selected as treatment, where a geotextile cover (BioCap™) was installed. Results showed that there was a significant deterioration of the performance of geotextile covers in reducing odor and gas emissions from manure storages on the second year of the study. Odor emissions were, on average, reduced by 48% over the two-year period. Emission rates were reduced by 90% in terms of H_2S in the first year, but no significant differences were found between covered and non-covered manure storages in 2001. NH_3 emissions were, in average, reduced by 44% in 2001. No significant differences in total-VOC emissions from covered and non-covered manure storages were observed during the two-year study. Analysis of the ambient H_2S data suggested that the covers were effective in reducing ambient H_2S concentrations near manure storages located at the two finishing sites. Odor and gaseous emission rates from all sites were poorly correlated with most manure characteristic parameters (nutrients, solids, organic matter, VOCs). Cover effectiveness may have been effected by improper management of the cover at one of the sites

Keywords. Swine manure, hydrogen sulfide, ammonia, odor, covers.

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Introduction

Liquid manure storage can be a significant odor source. The anaerobic nature of manure stabilization can cause offensive odors and release of hydrogen sulfide and ammonia along with other gases during storage, agitation and subsequent land application.

The Minnesota Pollution Control Agency (MPCA) currently regulates feedlot air emissions/odor through the state hydrogen sulfide (H_2S) ambient air standard. This standard is a 30-minute average of 30 ppb found more than twice in five days, or a 30-minute average of 50 ppb found more than twice per year. Field-screening data collected by MPCA at 137 individual feedlot facilities around the state using a Jerome Meter indicates that earthen storage basins have the largest number of 30 minutes hydrogen sulfide averages greater than 30 ppb. As a result, many pork producers are considering the implementation of odor control technologies in order to comply with these regulations. Covering manure storages with either straw or geotextile, or with a combination of both, is one strategy considered by producers in Minnesota.

Other states (Colorado, Missouri, North Carolina, etc.) have also put together very strict regulations related to the emission of odor and gaseous emissions from livestock operations, with special emphasis on swine units. In Colorado, for example, air quality regulations have two key components - covers for anaerobic lagoons and management of off-site odor emissions. Covers are a requirement for anaerobic lagoons as stated in the statute. The Colorado Air Pollution Control Division has approved three different categories for covers - rigid or synthetic covers, experimental cover, and alternative cover. Rigid or synthetic covers can be made of reinforced polypropylene, high-density polyethylene, or other synthetic material with a minimum thickness of 40 mils. An experimental cover is either a biocover, such as straw or geotextile, or an aerobic blanket that is at least three feet deep and utilizes air or oxygen. An alternative cover is any innovative design that covers the entire surface of the lagoon and demonstrates a comparable effectiveness to an impermeable synthetic cover. At this point, pork producers must participate in the implementation and evaluation of different cover technologies to remain in compliance with the regulations.

Clanton et al. (1999) studied seven manure cover treatments including a geotextile fabric (Typar, 0.3 mm thick). The geotextile fabric was considered to be a possible cover choice since the cover was self-floating and supported a biofilm that could self-seal the cover. More recently, Clanton et al. (2001) indicated that geotextile cover alone may have only a slight effect on odor and gaseous emissions. It was also found that the geotextile cover effectiveness in reducing odor and hydrogen sulfide decreased more rapidly with time as compared to straw covers. One possible reason given for the poor geotextile cover performance was that the fabric becomes plugged with biomass growth over time, creating an impermeable barrier that allowed gases to built up under the fabric and eventually move to an open space along the sidewalls for venting.

Currently, there is little information available on farm-scale performance of covers for odor and gaseous emission control. Zahn et al. (2001b) conducted micrometeorological flux measurements during three independent sampling periods that ranged from 52 to

149 hours on an anaerobic lagoon in east-central Missouri. Half of the lagoon was covered with a biocover consisting of 0.3 mm geotextile and 0.32 cm closed-cell polypropylene foam. Ammonia (NH_3) and H_2S abatement efficiencies improved from about 15% to close to 60% over a 3-month period. On the other hand, biocover areas exhibited significantly higher flux rates of methane (CH_4) than control areas for the last two sampling periods. This difference was attributed to the development of biomass on the underside of the cover. The main limitation of this study was that control (uncovered) and treatment (covered with geotextile) areas were located in the same lagoon. Therefore, it is likely that gases that are kept into solution in the covered area migrate to the other half of the lagoon (uncovered), causing emissions to be "artificially" higher there.

Miner et al. (2001) have recently reported on the evaluation of a permeable cover to reduce emissions from a 4,000-m^2 swine manure lagoon. The cover consisted of 5-cm foam board made of post-industrial recycled, closed-cell polyethylene foam, and a proprietary biocover. NH_3 emission data was collected on three occasions; before cover installation, one week after cover installation, and three months after cover installation. NH_3 emission decreased from 0.25 g/s before cover installation to 0.007 g/s three months after cover installation.

The objective of this study was to evaluate the performance of geotextile covers on manure storages (earthen basins) in terms of emission of odor, H_2S, NH_3 and volatile organic carbon (VOC) compounds as compared to uncovered manure storages. Data collected during two years are presented.

METHODS

Site Characteristics

Three swine production sites were selected for this study. Each site consisted of two farms that were similar to each other in terms of storage surface area, production phase, number of head, and diet formulation. Farm characteristics are summarized in Table 1. Basins held between 3,800 to 4,500 m^3 (1 to 1.2 million gallons) of manure. A manure storage basin from each pair of farm was selected as treatment (with cover), and the other as control (without cover). Eight ounce, ¼ inch-geotextile covers (Biocap™, Baumgartner Environics, Olivia, MN) were installed on the treatment manure storages. The geotextile covers were installed in early July 2000.

Table 1. Site characteristics

Farm Number	Production type	No. of barns	Manure storage surface dimensions (m)	Type of cover
N1	8,000-head nursery	1	73 x 34	None*
N2	8,000-head nursery	2	57 x 36	Geotextile
F2A	2,000-head finishing	2	82 x 46	None*
F2B	2,000-head finishing	2	45 x 42	Geotextile
F3A	3,000-head finishing	3	73 x 47	None*
F3B	3,000-head finishing	3	59 x 57	Geotextile

* Natural crust developed on the surface of uncovered manure storages during variable periods of time.

Odor and gas samples

Odor and gas sampling on the first year started on May 30, 2000 and ended on October 25, 2000. Samples were taken every two weeks at any one site. Three sets of data were collected from each site before geotextile installation, between May 30 and July 6, 2000. The geotextile covers were installed in the treatment farms on the first week of July 2000. After geotextile installation five sets of data were collected from the nursery site, nine sets of data from the 2,000-head finishing site, and seven sets of data from the 3,000-head finishing site.

A natural crust developed on two control storages (N1 and F2A) by mid June 2000. The crust on F2A lasted until late August 2000, and until early September 2000 on N1.

For every sampling day a treatment and control farm were visited for the appropriate measurements, sampling and data collection. Samples were collected in the morning (between 10 am and 2 pm), and in the afternoon (between 4 pm and 8 pm) at each farm. The order of site and farm sample collection was randomized.

Sampling for the second year started on April 17, 2001 and ended on October 2, 2001. Air emissions samples are collected from each of the six manure storage basins once a day, every two weeks. Seven sets of data have been collected this year so far. Sampling was between 8:00 AM and 6:00 PM. All six farms were sampled in the same day and the order of sample collection was randomized.

A wind tunnel was used for collecting samples from the surface of the geotextile covers and manure (for the non-covered storages). The University of Minnesota Wind Tunnel (Schmidt and Bicudo, 2002) closely resembles a wind tunnel designed and tested at the University of New South Wales, Australia (Jiang et al., 1995). The wind tunnel is designed to simulate wind speed of 0.3 m/s (0.9 fps) on a manure surface and collect a representative sample of air at the exhaust end of the tunnel. Ambient air is drawn through the tunnel by a 12 volt DC fan. The air then passes through a composite filter (Purafil® Select blend media and Purakol® AM media) and flows evenly across the manure surface. The filter is able to remove NH_3, H_2S and VOC efficiently (Schmidt and Bicudo 2002). Removal of NH_3 and H_2S is over 95%, but removal of VOC is more variable. The filter showed low efficiencies in removing volatile fatty acids (VFA), but efficiencies of up to 100% for phenols and indole compounds. Alkane compounds tend to stick to plastic parts of the wind tunnel (fan and tubing) and slight accumulation was observed toward the end of the monitoring period, thus affecting VOC measurements. However, alkanes have relatively high odor detection threshold (37 to 50 mg/m^3 for dodecane) as compared to other VOC groups such as sulphides (0.0003 to 0.16 mg/m^3

for dimethylsulphide), phenolics (0.022 to 4 mg/m^3 for phenol), and nitrogen heterocycles (0.0004 to 0.0008 mg/m^3 for skatole) (O'Neill and Phillips, 1992), and therefore should not have significantly affected odor measurements.

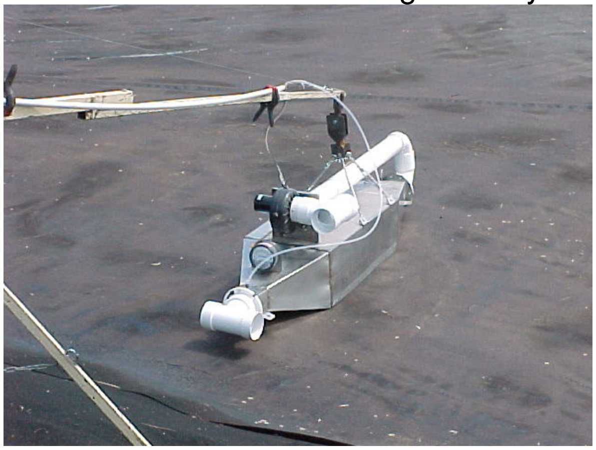

Figure 1. Collection of samples with wind tunnel over the geotextile cover

The wind tunnel exposed surface area is about 0.33 m^2 (500 in^2). Total air exchange is 0.09 m^3/m^2-s. A pressure gauge on the inlet ducting allows the user to monitor the airflow rate in the tunnel continuously. Flux rates for the odor or specific gases are determined by multiplying the concentration of odor or gas in the exhaust air by the flow rate through the tunnel. The wind tunnel is connected through 1/4" Teflon FEP tubing to a vacuum box (Vac-U-Chamber, SKC-West, Inc., Fullerton, CA). The tunnel fan is switched on for about 5 minutes before a sample is collected. An air pump (Aircheck, Model 224-PCXR3/4, SKC Inc., Eight Four, PA) draws odorous air into a 10 L Tedlar bag (SKC Inc., Eighty Four, PA). The sample is taken at 3 L/min for about 3 minutes. Only one sample at one location on the manure storage was taken. Samples were taken between 2 and 3 m from the berm using floats (for liquid surfaces) or using a tripod and metal arm (for geotextile and crust surfaces) to suspend and place the wind tunnel directly on top of the geotextile cover (Figure 1). Safety concerns and the large number of wind tunnel samples that would be required to determine accurate emission rates across the surface of the storages and the high cost of analysis make the collection of multiple samples across the surface area of manure storages unrealistic. In addition, a recent report by Australian researchers (McGahan, 2001) indicated large variations in odor flux rates across the surface of 2,500 to 3,600 m^2 swine manure ponds. Also, no significant relationship was found between the distance to effluent loading point and spatial emission rates.

A triangular forced-choice dynamic dilution olfactometer (AC'SCENT® BETA-1, St. Croix Sensory, Inc., Stillwater, MN) was used to measure odor threshold. Odor measurements were performed according to European Standards (CEN, 1999).

A Jerome Hydrogen Sulfide Analyzer (Model 631-X. Arizona Instrument, Phoenix, AZ) was used to measure H_2S concentration. This instrument measures total reduced sulfur (TRS) compounds, including alkyl sulfides, disulfides, mercaptans, and cyclic sulfur compounds. (Winegar and Schmidt 1998) showed that the response of the Jerome meter was 100% to H_2S and between 0 and 45% for other reduced sulfur gases when exposed to calibrated mixtures. The data presented in this paper are described as TRS but reported as H_2S equivalent. The measuring range is 0.001 to 50 ppm. The accuracy is ± 0.003 ppm at 0.050 ppm. Measurements were taken directly from the Tedlar bags.

NH_3 was collected into boric acid using gas-washing bottles. Samples were transported in coolers and analyzed within 24 hours of collection by titration in the Department of Biosystems & Agricultural Engineering, University of Minnesota.

Volatile organic carbon (VOC) samples taken from the surface of manure storages were analyzed by Solid Phase Micro Extraction (SPME) methodology (Koziel et al., 2001). SPME fibers (Supelco SPME Portable Field Sampler, Supelco, Bellefonte, PA) were used to absorb compounds in the air above the manure/crust surface for analysis by gas chromatography/mass spectrometry (GC/MS). The fused silica fibers were coated with a 75 μm partially cross-linked Carboxen/ polydimethylsiloxane phase material. The fibers were exposed to air drawn from the wind tunnel for 20 minutes inside a gas bulb to allow compounds to equilibrate between the ambient air and the phase coating. Figure 2 shows a diagram of the apparatus used for the collection of both VOC and NH_3 samples.

At the end of the exposure time, fibers were retracted into the sampling unit, and placed inside a cooler and transported to the Department of Biosystems and Agricultural Engineering, University of Minnesota. Field samplers were then shipped via courier the next day to the Department of Animal Sciences, Iowa State University for analysis. A standard swine odor solution was formulated based upon the artificial slurry developed by Persaud et al. (1996) and identification of odorants in samples collected previously. Additional odorous compounds that were consistently present in the initial air samples were identified and added to the standard solution. A total of 33 odorants were contained in the stock standards and therefore, if identified, could be quantified. Standard solutions were prepared at concentrations of 100, 50, 25, 10, and 5% of the stock standard. The stock standard swine odor solutions were stirred for approximately 30 minutes prior to the removal of a 1 mL sample that was placed in a 40 mL glass vial with a Teflon lined septum and hole cap. The SPME fiber was exposed to the liquid in the vial for 20 minutes. From the stock standards a linear prediction curve was generated for individual odorant concentrations based on the area under the chromatographic peak. The equation generated for each odorant was then used to predict unknown concentrations of odorants identified in the collected samples. Liquid standards were used routinely for generation of the linear equation. Gaseous standards were used to establish partition coefficients for each individual compound between the liquid phase and the gaseous phase. Coefficients were then applied to the standards to calculate concentration in the gaseous phase. The SPME samplers were reconditioned (cleaned) for reuse.

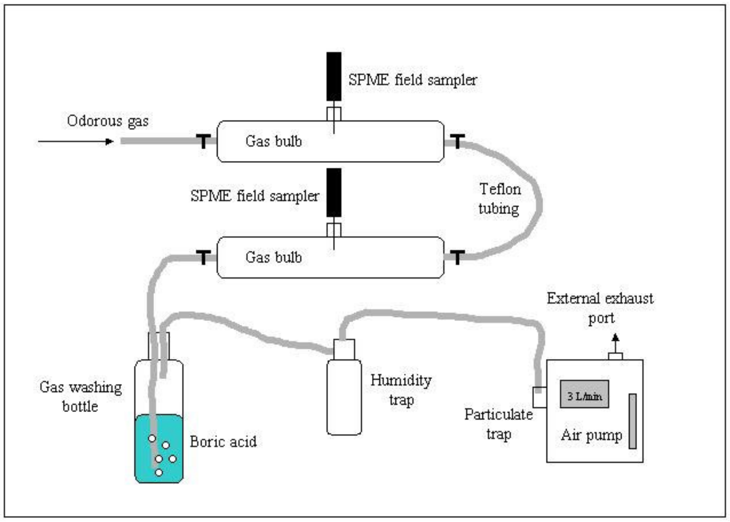

Figure 2. Apparatus used to collect NH_3 and VOC samples

H_2S ambient air concentrations were also measured continuously for different periods of time around the storage basins. Zellweger MDA Single Point continuous air monitors (SPM) were used for this purpose. Bicudo et al. (2000) describe the SPM detection system in detail. The monitors were placed at a total of three locations around the manure storage basin (for example, North, South and East of the basin) at a distance between 3 and 5 m from the edge of the basin.

Automated weather stations (Campbell Scientific, Logan, UT) were used in all three sites. Weather stations continuously recorded wind speed, wind direction, temperature, relative humidity, rainfall, solar radiation, and barometric pressure.

Manure samples

Manure samples were taken every time a source odor sample was taken with the wind tunnel from the top 25 cm (10 in) of the manure surface. The samples were transported in coolers to the Department of Biosystems and Agricultural Engineering, University of Minnesota and frozen overnight. Ice packs were used to keep the samples cool. They were then shipped via courier the next day to the Minnesota Valley Testing Laboratory (MVTL), in Nevada. Iowa. The following parameters were analyzed for each sample according to Standard Methods (WEF, 1992): temperature, pH, total solids (TS), volatile solids (VS), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), organic nitrogen (N-org), total phosphorus (TP), orthophosphate (Ortho-P), potassium (K), magnesium (Mg), Zinc (Zn), total sulfur, and total and soluble sulfide (S^{-2}). VOC in manure samples were determined by GC/MS at the Department of Animal Sciences, Iowa State University.

Statistical analysis

Analysis of variance (ANOVA) was performed with farm type, year, time of the day, and geotextile as main factors. All statistical analysis were conducted using MINITAB® Statistical Software.

RESULTS AND DISCUSSION

The information collected in years 2000 and 2001 for the 3,000-head finishing facility (Farms F3A and F3B) is presented in Figures 3 to 6. Results for the other sites are similar, but the 3,000-head finishing site was the site where more consistent results were obtained. Data is presented in terms of flux rates for samples collected with the wind tunnel on the surface of the manure storages. No significant difference between morning and afternoon samples was observed during the first year of this study at a *p*-value of 0.05. Therefore, the year 2000 data correspond to the averages between the morning and afternoon samples.

Background Data - Before Geotextile Cover Installation

Statistical analysis of data collected prior to geotextile installation (three sets of data for each site, collected between May 30, 2000 and July 6, 2000) indicated that odor emission rates were significantly different (p-value < 5% level) between treatment and control farms for the nursery site only. The natural crust that developed on the nursery control farm affected both odor and ammonia emission rates. There were no significant differences (at the 5% level) on odor and gas emission rates between control and treatment for the 2,000-head finishing site. However, odor concentrations at the berm were found to be significantly different between farms. The 3,000-head finishing farms were not found to be significant different from each other (at the 5% level) in terms of odor and gas flux rates.

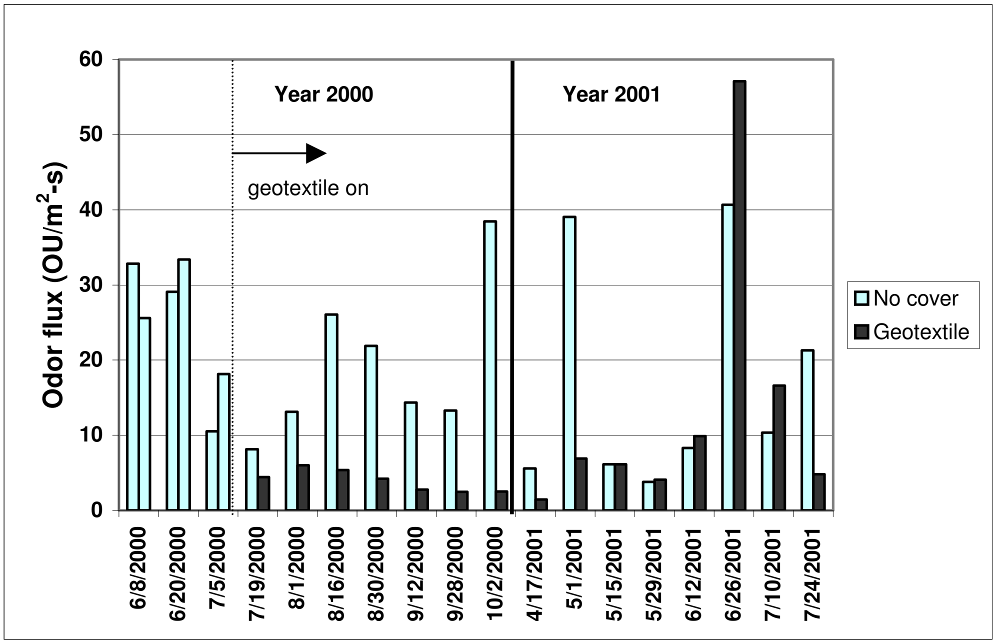

Figure 3: Odor flux from the 3,000-head finishing manure storages

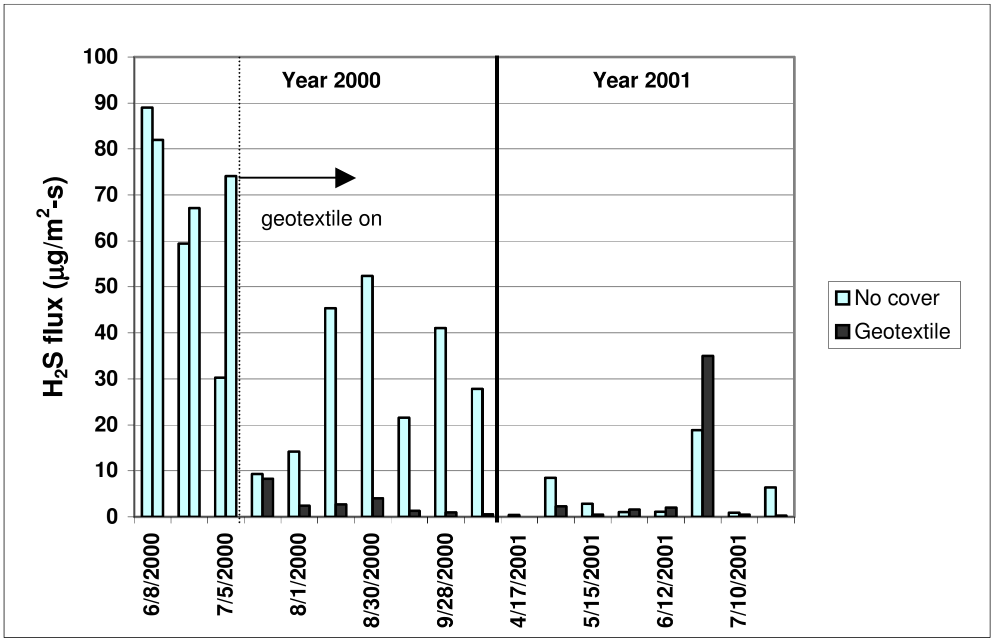

Figure 4: H_2S flux from the 3,000-head finishing manure storages

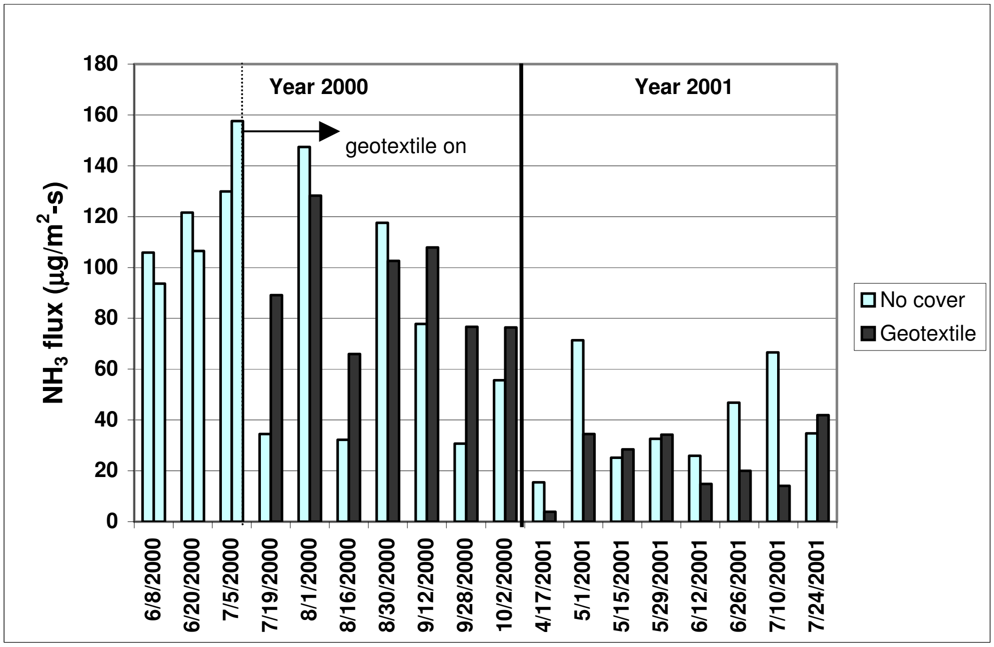

Figure 5: NH_3 flux from the 3,000-head finishing manure storages

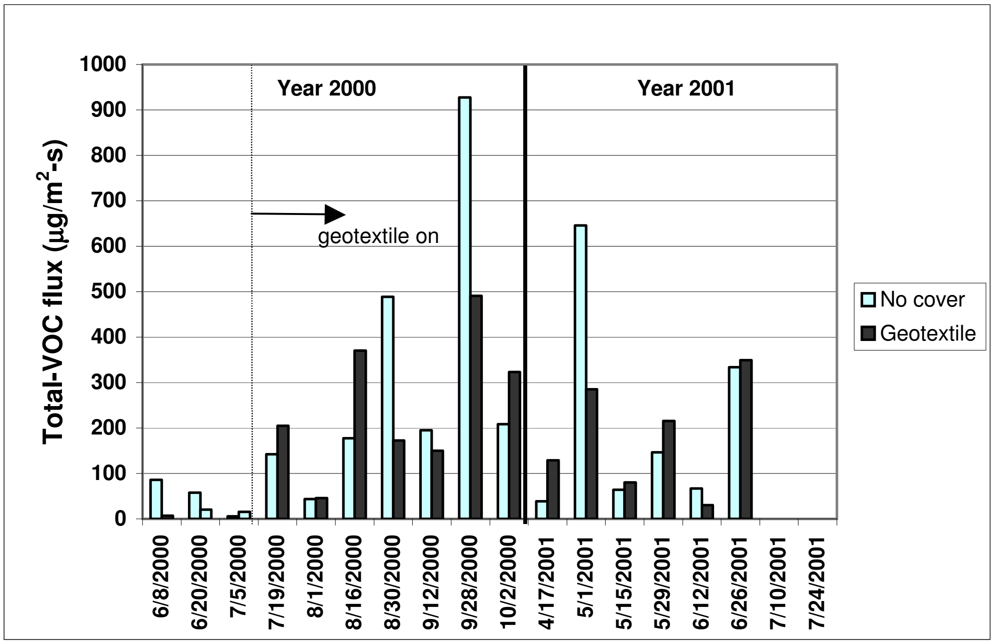

Figure 6: Total-VOC flux from the 3,000-head finishing manure storages

Year 2000 Data

Effect of the Geotextile Cover on Odor and Gas Emissions

In order to evaluate the performance of the geotextile covers during the study period, statistical analysis of the flux data collected was performed. Because sites were different, it was decided to analyze the data separately, *i.e.* for each pair of farms. It was assumed that the error term in a multivariate analysis of variance is due to the variability between dates within a site. Thus F values are probably higher than they should be. For practical purposes, this means that if there is a significant effect of geotextile on odor and gas emissions, this effect (positive or negative) is likely to be lower than what is being reported here. Continuous H_2S and NH_3 measurements were also analyzed.

Odor and gas flux rates as well as wind speed data are summarized in Table 2. The letters “a” and “b” give an indication of the significance of the flux rates and wind speed between control and treatment at the 5% level. Different letters imply significant difference between control and treatment.

The effect of the geotextile cover on flux rates from the manure surface was most significant at the 3,000-head finishing site (F3A, F3B) for odor and H_2S (Figures 3 and 4). This site was the only site where a natural crust did not develop on the surface of the manure at the control farm in year 2000. Similar results were obtained at the 2,000-head finishing site (F2A, F2B) despite the natural crust that covered the control storage at F2A for a certain period of time (between June and September 2000).

Table 2. Flux and wind speed means and standard deviation for treatment and control farms in the year 2000

Farm	No. of obs.	Odor (OU/m^2-s)		H_2S ($\mu g/m^2$-s)		NH_3 ($\mu g/m^2$-s)		Total-VOC ($\mu g/m^2$-s)		Wind speed (m/s)	
		Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
N1 – N2											
Control	22	13.4^a	13.5	29.5^a	71.5	140^a	85	104^a	112	3.9^a	3.6
Geotextile	10	7.2^a	5.8	9.6^a	18.5	66^b	26	201^b	140	4.1^a	3.5
F2A – F2B											
Control	30	13.0^a	11.3	27.8^a	31.0	128^a	48	198^a	291	2.7^a	2.4
Geotextile	18	5.4^b	8.3	6.6^b	23.3	100^a	60	233^a	208	4.3^a	2.9
F3A – F3B											
Control	26	21.9^a	10.4	47.2^a	27.5	93^a	45	183^a	326	4.5^a	3.2
Geotextile	14	4.0^b	1.7	2.9^b	3.3	92^a	24	251^a	181	3.1^a	2.0

There is little information available on the literature related to odor emissions from manure storages or treatment lagoons. McGahan et al. (2001) have recently measured odor emissions from five swine anaerobic lagoons in Australia using a wind tunnel. The ‘standard’ odor flux rates from all the ponds measured were approximately 10 OU/m^2-s, except for a heavily loaded pond where the flux rate was about 17 OU/m^2-s. These values seem to agree well with the odor flux rates listed on Table 2 for control storages.

H_2S flux rates from control storages were higher than values reported by Zahn et al. (2001b) for an anaerobic lagoon (between 7 and 21 $\mu g\ H_2S/m^2$-s), but anaerobic lagoons are usually less heavily loaded than manure storages and higher emission rates are expected. The H_2S flux rates from the geotextile covers were the same order of magnitude as values reported by those researchers for a similar cover material.

NH_3 flux rates from both control and geotextile storages were also within the range of values reported by Zahn et al. (2001b), and also by Miner et al. (2001) for an anaerobic lagoons (between 125 and 180 $\mu g\ NH_3/m^2$-s). Sommer et al. (1993) reported slightly smaller NH_3 flux rates for dairy and swine manure storages than the values obtained in the present study.

No significant differences on NH_3 and Total-VOC flux rates were detected at the 5% probability level between control and treatment farms for both 3,000 and 2,000-head finishing sites. However, the geotextile cover significantly affected a few individual VOC compounds at the 3,000-head finishing site only. The compounds mostly affected were phenol (*p* value = 0.015) and 4-methylphenol (*p* value = 0.063). The effect of the geotextile was toward reduction of these VOC flux rates. Zahn et al. (2001a) reported Total-VOC flux rates from an earthen basin with swine manure slightly higher, about 350 $\mu g/m^2$-s, than the values listed on Table 2.

No significant differences in odor and H_2S flux rates were detected at the 5% probability level between control and treatment nursery farms (N1, N2). On the other hand, the geotextile cover appeared to have a significant effect on both NH_3 and Total-VOC fluxes at this site (no significant effect on individual VOC though) at the 5% level. The effect of the geotextile was toward reduction of NH_3 and increase of Total-VOC fluxes (Table 3). The same effects were observed at the two finishing sites, although differences were not statistically significant as mentioned before. At this point, it is difficult to determine why Total-VOC emissions from the covered storages increased as compared to the non-covered storages. One may speculate that the thick natural crust that developed at the control storage helped better trap some of the volatile compounds than the geotextile cover.

No significant differences were observed in wind speeds between control and treatment farms. The whole data set was considered for correlation analysis in order to verify if outdoor temperature could have affected results. Air temperature averaged 23.4 °C, with a minimum of 7.7 °C and maximum of 37.8 °C. No significant correlation was found between flux rates and outdoor temperatures. The Pearson correlation coefficient (linear correlation) obtained was about 0.12.

Effect of the Geotextile Cover on Ambient H_2S Concentrations

SPM data was analyzed based on wind direction data and on readings greater than 30 ppb (Minnesota ambient standard). A summary is presented in Table 3 in terms of percentage of values greater than 30 ppb for a particular wind direction. In this case, manure storage values are not subjected to building effects; wind directions were such that wind blew toward the buildings and not from the buildings. Building values were not subjected to manure storage effects in the same way, i.e. wind directions were such that wind blew toward the manure storages and not from the manure storages.

Table 3. Percentage of readings greater than 30 ppb for a particular wind direction

Farms	2000	
	Storage	Building
N1 – control	4.6 N 3.4 S	1.4 W
N2 – geotextile	14.3 S 23.7 W	-
F2A – control	17.4 N 41.7 W	20.4 S
F2B – geotextile	1.02 N 11.9 W	0.37 S
F3A – control	52.8 S 45.5 W 5.8 E	21.9 N
F3B – geotextile	19.1 W	2.3 S

It is shown that with the exception of the N1-N2 site, the percentage of values greater than 30 ppb was lower in the treatment (geotextile) farms than in control (uncovered manure storages) farms. A thick natural crust seemed to have contributed significantly to decrease H_2S concentrations around the control storage basin as compared to concentrations obtained from the treatment farm at the N1-N2 site. This observation may indicate that a natural crust can be at least as effective in keeping H_2S emissions down as a geotextile cover.

Effect of the Geotextile Cover on Manure Characteristics

Manure data collected prior and after geotextile installation was analyzed in order to determine if there were significant differences in manure characteristics at the 5% level between farms from the same site (Table 4).

Table 4. Significance levels (*p*-values) of the main effects of farm (before geotextile installation) and geotextile cover on manure characteristics

Parameter	Before geotextile cover installation			After geotextile cover installation		
	N1 – N2	F2A – F2B	F3A – F3B	N1 – N2	F2A – F2B	F3A – F3B
pH	0.001	NS	NS	0.001	0.012	0.0001
Conductivity	0.01	NS	0.0001	0.010	0.016	0.0001
TS	NS	NS	0.0001	0.019	0.014	0.01
VS	NS	NS	0.0001	0.015	0.027	0.022
COD	0.001	NS	NS	0.006	0.024	0.0001
TKN	NS	0.035	0.0001	NS	0.043	0.004
NH_3-N	0.002	NS	0.0001	NS	NS	0.001
TP	NS	0.002	NS	NS	0.039	0.007
Ortho-P	NS	0.007	NS	NS	NS	0.002
K	NS	NS	NS	NS	NS	0.0001
Mg	0.005	0.004	NS	NS	NS	NS
Zn	NS	0.001	NS	NS	NS	0.0001
Total S	NS	NS	NS	NS	NS	0.037
Total S^{-2}	NS	NS	NS	0.020	NS	NS
Soluble S^{-2}	NS	NS	NS	NS	NS	0.024
Indole	NS	0.013	NS	0.046	0.008	NS
Phenol	NS	NS	NS	NS	0.014	0.0001
4-Methylphenol	0.005	NS	NS	NS	0.009	NS

NS - Main effect non-significant at the 0.05 probability level.

Analysis of variance indicated that there were significant differences between farms for some of the parameters sampled before geotextile installation. On the nursery site pH, conductivity and NH_3-N were lower at N2 (treatment) than N1 (control). On the other hand, Mg, COD, and 4-methylphenol were higher at N2 than N1. All significantly different parameters at both finishing sites were lower at treatment farms (F2B and F3B) than at control farms (F2A and F3A). Therefore, finishing treatment farms (with geotextile cover) had already less concentrated manure (in terms of TS, VS, and COD) than control farms.

Solids (TS, VS), organic material (COD), pH and conductivity were found to be significantly different at the 5% level in all sites after geotextile installation. Because finishing treatment farms (with geotextile cover) had already less concentrated manure (in terms of TS, VS, and COD) than control farms, it was difficult to identify if the geotextile covers had any effect on those parameters.

The nursery site was the only site where there were higher concentrations of total sulfide in the geotextile-covered basin than in the control basin, suggesting that the cover was keeping sulfides into solution. On the other hand, there was no significant difference in terms of NH_3 concentrations.

The lower concentration of both solid and organic material in the geotextile-covered basins as compared to the control basins may have been caused by many factors other than the geotextile itself. These include, for example, rapid settling of solid material and more significant anaerobic activity in the bottom of the basin. It is doubtful that any oxidation of the organic material took place near or on the geotextile surface that is in contact with manure as it has been suggested for covers installed on anaerobic lagoons (Zahn and DiSpirito, 1999). ORP measurements gave indication of a significantly reduced environment near the surface in all basins. Also, ORP measurements were not found to be significantly different between treatment and control basins.

Odor and gaseous flux rates from all sites were poorly correlated with most manure characteristic parameters (nutrients, solids, organic matter). However, significant correlation was found between VOC in manure and VOC flux (*e.g.* phenol on both finishing sites with correlation coefficients between 0.6 and 0.7, and 4-ethylphenol on the nursery site with a correlation coefficient of 0.99).

Year 2001 Data

Effect of the Geotextile Cover on Odor and Gas Emissions

All manure storage basins were agitated and pumped during the fall of 2000, and in some cases, also in the spring of 2001. After manure agitation and pumping the geotextile cover stays on the bottom of the storage, as shown in Figure 7.

During winter, manure continued to flow to the basin while snow accumulated on the top of the cover. In the spring the geotextile covers were completely wet due to thawing and did not float on top of the manure. In fact, the three geotextile covers were still almost completely submerged in manure (over 90% of the surface area) by the beginning of May 2001. The geotextile cover at N2 was partially submerged for the whole of the monitoring period, while the covers at F2B and F3B eventually became reasonably dry (15% or less) submersion by the end of May 2001. The geotextile cover at F2B did not dry up as well as F3B. Samples were collected from non-submerged spots at all "treatment" storages. This was done in order to minimize potential cover submersion effects on odor and gas emissions.

Figure 7. Geotextile cover after manure agitation and pump out

Natural crust developed in all control storages. The crust was thicker and covered a larger area (up to 100%) at F3A as compared to N1 and F2A, but it lasted for a shorter period. With the exception of a few samples collected from F3A, all other samples were collected from non-crusted spots at all control storages. As with treatment storages, this was done in order to minimize potential crust effects on odor and gas flux rates.

Analysis of variance (type of facility and geotextile as main parameters) indicated that there were significant differences between covered and non-covered swine manure storages at the 5% level for odor and NH_3 flux rates. Odor flux was in average reduced by 29% and NH_3 flux by 44%. No significant differences were found for H_2S and total-VOC emissions. The type of production facility or the interaction between facility and cover did not cause emissions to be significantly different either ($p = 0.05$). Odor and gas flux rates were presented in Figures 3 to 6 for F3A and F3B. Flux data from the other two sites were similar to F3A and F3B, i.e. showed some reduction in odor and NH_3 fluxes due to geotextile in year 2001, but no significant differences in H_2S and total-VOC flux rates. All flux rates obtained in year 2001 were lower than flux rates obtained in year 2000 (Figures 3 to 6). Statistical analysis of the whole data set indicated that the 2001 data was significantly different from 2000 data for all parameters at the 10% level. These differences were probably due to weather variations, but a variety of other factors such as farm management might have played an important role as well. A slightly different wind tunnel was used to collect air samples in year 2001, but there was no evidence that this factor might have affected results. In fact, because there was an improvement in the design of the tunnel, with consequent improvement of its filtration capacity, higher flux rates would be expected if conditions had been equal to the previous year.

Although type of facility did not significantly affect flux rates at the 5% level, mean flux and standard deviation values are reported for each farm, as well as wind speed (Table 5). As before, the letters "a" and "b" give an indication of the significance of the flux rates and wind speed between control and treatment at the 5% level. Different letters imply significant difference between control and treatment.

Table 5. Flux and wind speed means and standard deviation for treatment and control farms in the year 2001

Farm	No. of obs.	Odor (OU/m^2-s)		H_2S ($\mu g/m^2$-s)		NH_3 ($\mu g/m^2$-s)		Total-VOC ($\mu g/m^2$-s)		Wind speed (m/s)	
		Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
N1 - N2											
Control	13	13.9^a	13.1	3.8^a	6.4	66.4^a	41.3	281^a	169	2.9^a	2.1
Geotextile	13	8.8^a	6.1	2.1^a	3.9	40.0^a	32.9	383^a	264	3.0^a	2.2
F2A - F2B											
Control	13	20.4^a	33.1	13.6^a	39.1	63.7^a	87.9	345^a	228	2.6^a	4.1
Geotextile	13	15.1^a	39.8	5.0^a	17.0	29.1^a	48.6	309^a	180	2.6^a	1.5
F3A - F3B											
Control	13	14.4^a	12.7	4.9^a	6.5	37.2^a	27.0	282^a	178	1.7^a	1.6
Geotextile	13	10.2^a	14.4	3.2^a	9.2	23.7^a	19.9	301^a	195	2.3^a	1.8

As with the year 2000 data, odor flux rates from control storages agreed well with the results obtained by McGahan et al. (2001). On the other hand, both H_2S and NH_3 flux rates for the control storages were lower than values reported previously by Zahn et al. (2001b), Zahn et al. (2001a), and Miner et al. (2001). However, the mean NH_3 flux rates agree well with the values reported by Sommer et al. (1993) on emissions from swine and dairy manure storages.

With the exception of the Total-VOC emissions from N1-N2 site, all emission values obtained from covered manure storages were lower than those obtained from non-covered storages, but not significantly different. These results did indicate deterioration of the geotextile performance in reducing emissions from the first to the second year of operation. The durability of geotextiles is strongly dependent on material degradation. This is influenced by the inherent properties of fibers, such as their chemical nature and properties controlled by processing variables. Material degradation usually results in discoloration, formation of micro cracks, embrittlement, and loss of mechanical properties. This is important not only in terms of the cover performance in helping reducing emissions, but also in terms of physical damage that may result during cover lifting for agitation and pumping of manure.

It is well known that there are many environmental factors which influence aging of geotextile material. Polymers can degrade by exposure to ultraviolet radiation, high temperature (thermal degradation), oxygen and ozone, moisture, radiation, and chemical agents. Multiple exposures, such as combination of light, high temperature, and moisture, can result in accelerated deterioration. Polymer degradation can also result from mechanodegradation, which is caused by the application of stress, such as lifting to allow agitation and pumping equipment into the basin. The stress-induced degradation may result from grinding, crushing, stretching, fatigue, abrasion, or wear. Although chemical and biological degradation may also have affected geotextile performance, synthetic polymers are remarkably stable under most environmental conditions. Suitable environmental conditions at the manure surface can promote the growth of microorganisms such as bacteria and fungi in the surface of the geotextile. These microorganisms produce high protein substances, such as enzymes, that may cause polymer molecule deterioration. Presently, there are no studies available on the biological deterioration of the geotextile due to prolonged contact with manure.

Effect of the Geotextile Cover on Ambient H_2S Concentrations

SPM data was analyzed based on wind direction data and on readings greater than 30 ppb as before. A summary for year 2001 data is presented in Table 6.

Table 6. Percentage of readings greater than 30 ppb for a particular wind direction

Farms	2001	
	Manure storage*	Building**
N1 – control	18.3 N	-
N2 – geotextile	39.3 N 83.7 S 35.0 W	-
F2A – control	70.3 N 0.48 W	11.6 S
F2B – geotextile	21.8 N 3.3 W	12.3 S
F3A – control	99.6 S 33.7 W	1.05 N
F3B – geotextile	51.5 N	1.3 S

* Manure storage values were not subjected to building effects; wind directions are such that wind blew toward the buildings and not from the buildings.

** Building values are not subjected to manure storage effects; wind directions are such that wind blows toward the manure storages and not from the manure storages.

Similar to results obtained in year 2000, there was no effect of geotextile in reducing ambient H_2S at N2 as compared to N1. In fact, the percentage of readings greater than 30 ppb was lower at N1 than N2, which may seem to be odd. The natural crust that developed on the surface of the manure storage at N1 might have helped reduce H_2S concentrations around the storage better than the geotextile did at N2. It should also be noted that the geotextile cover installed at N2 was mostly submerged during 2001. The liquid manure and rainfall retained on top of the cover might have caused H_2S concentrations to increase around the storage at N2.

There was a noticeable effect of the geotextile cover in both finishing sites, towards reduction of the percentage of readings greater than 30 ppb, especially when N-S wind directions were taken into account.

The animal buildings located at F2A-F2B site seemed to have caused H_2S concentrations to increase in ambient air as compared to animal buildings located at F3A-F3B site.

Effect of the Geotextile Cover on Manure Characteristics

Statistical analysis was performed to verify if manure characteristics would differ from site to site, and also to compare manure characteristics in treatment versus control farms. Analysis of the experimental data showed that the control and treatment storage basins from the F3A-F3B site were more heavily loaded in terms of solids, nutrients, organic matter and VOC than storages located at the other two production sites. Table 7 shows mean and standard deviation for selected manure characteristics at each site.

Table 7. Mean and standard deviation values of selected manure characteristics

Parameter	N1-N2		F2A-F2B		F3A-F3B	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
pH	7.3	0.5	7.5	0.3	7.3	0.4
total-N (%)	0.19	0.10	0.16	0.06	0.27	0.08
NH_3-N (%)	0.16	0.06	0.14	0.05	0.22	0.06
TS (%)	1.5	2.0	0.9	0.4	1.8	1.1
VS (g/L)	8.1	11.0	4.0	2.5	9.9	7.7
COD (g/L)	17.7	16.3	8.9	5.6	27.8	16.9
Total-VOC (mg/L)	412	543	128	166	893	1617

Because site differences were significant at the 5% level, a comparison was made within each site:

N1-N2: manure concentrations at treatment storage basin were greater than concentrations at control basin. COD, total-VOC, and sulfur were found to be significantly different between the two basins at the 5% level. Other parameters such as P, total-N, NH_3-N, TS, VS, total and soluble sulfide were not significantly different between the two basins.

F2A-F2B: manure concentrations at treatment storage basin were greater than concentrations at control basin. Total-N, NH_3-N, P, TS, VS, COD, sulfur, total and soluble sulfide, were found to be significantly different between the two basins at the 5% level. Total-VOC was not significantly different between the two basins.

F3A-F3B: manure concentrations at treatment storage basin were lower than concentrations at control basin. Total-N, NH_3-N, TS, VS, and COD were found to be significantly different between the two basins at the 5% level. Other parameters such as P, S, total and soluble sulfide were not significantly different between the two basins.

Differences in manure characteristics in control and treatment basins were due to a variety of factors, including different management, development of a natural crust, or presence of a geotextile cover. It was not possible to isolate the effect of the geotextile cover or natural crust on manure characteristics.

The only significant correlation found between odor emission and manure characteristics was between odor and acetic acid (Pearson correlation = 0.583). No significant correlations were found between H_2S emission and sulfur compounds (total sulfur, total and soluble sulfides), or between NH_3 emission and NH_3-N content.

Year 2000 and 2001 Data Combined

Multi-variate analysis of variance (year, type of facility, and geotextile as main parameters) indicated that there were significant differences in the emission of odor, H_2S and NH_3 from covered and non-covered swine manure storages at the 5% level. However, except for odor, all other emissions were affected by year, i.e. H_2S, NH_3 and VOC emission data collected in year 2000 was found to be significantly different from data collected in year 2001 at the 5% level. The type of production facility did not cause odor and gas emissions to be significantly different. No interaction effects were found to be important either. Odor emissions were, in average, reduced by 48% by the geotextile cover over the two-year period.

Statistical analysis was performed to verify if manure characteristics were affected by year, type of production facility, and geotextile cover. It was found that the type of production facility affected most manure parameters at the 5% significance level. The manure storages at the 3,000-head finishing site (F3A-F3B) were more heavily loaded than manure storages at the other two sites. This agrees reasonably well with the fact that odor and H_2S fluxes were higher for the F3A-F3B site as compared to the other two sites. On the other hand, NH_3 fluxes from the F3A-F3B site was the lowest compared to N1-N2 and F2A-F2B sites.

In addition to the type of production facilities effect, Total-N, NH_3-N, and COD were also significantly affected by year. Concentrations of these parameters in manure were usually lower in 2001 as compared to 2000. Similarly, NH_3 emissions were lower in 2001 than in 2000.

No significant correlations were found between manure characteristics and odor and gas emissions.

Conclusions

The geotextile cover was able to reduce odor and H_2S emission rates from finishing manure storages by 50 to 80%, and by 60 and 94%, respectively in year 2000. The geotextile cover did not seem to have a significant impact on odor and H_2S emissions from the nursery manure storages. The geotextile cover impacted NH_3 and Total-VOC emissions at the nursery site only.

Performance of the geotextile covers in the second year of the monitoring program decreased significantly as compared to the first year. The geotextile covers helped reduce odor and NH_3 emissions from manure by 29% and 44%, respectively. No significant differences were found for H_2S and total-VOC emissions from covered and non-covered manure storages.

Statistical analysis of the whole data set indicates that 2001 data is significantly different from 2000 data for all parameters except odor emission at the 5% level. Odor emissions were, in average, reduced by 48% over the two-year period.

Differences in gas emission data were due to a variety of factors including farm management, atmospheric and weather conditions, geotextile submersion, manure characteristics, etc. Geotextile deterioration due to environmental factors might also have influenced performance in the second year of the study, and this is an area that needs to be further investigated.

Analysis of the ambient H_2S data suggested that the covers were effective in reducing H_2S concentrations around the two finishing sites (F2 and F3). The cover installed at the nursery site did not seem to have caused any effect on ambient H_2S concentrations. The development of a natural crust at the control storage might have contributed to significant reduction of odor and gas emissions, making it difficult to compare with emissions from the treatment storage.

Odor and gaseous emission rates from all sites were poorly correlated with most manure characteristic parameters (nutrients, solids, organic matter, VOCs). Manure characteristics varied from year to year, site to site, and also within each site. This study seems to confirm the idea that emission estimates based on manure chemistry are not deemed to be reliable.

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