Efficacy of a microbial additive in reducing odor, ammonia, and hydrogen sulfide emissions from farrowing-gestation swine operation

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Abstract: To mitigate odor and gas emission concern, different management practices and treatment technologies are available. In this study, the effectiveness of the Digest3+3© microbial additive was evaluated for reducing odor and pollutant gas emission from a swine gestation-farrowing operation in North Dakota. In this experiment, one of the deep pits in the facility was left untreated (GC) and the other deep pit was treated (GT) with the Digest 3+3 (22.68 kg/month). Similarly, shallow pits in one of the farrowing units were treated (FT) with the microbial additive, while another unit was untreated (FC as the control). Air samples were collected from exhaust fans using a vacuum chamber and Tedlar bags. Odor detection threshold values were determined using a dynamic dilution olfactometer, and ammonia and hydrogen sulfide (as total reduced sulfur) concentrations were measured using the Dräger^{TM} CMS and a Jerome^{TM} meter, respectively. Air flow rates from exhaust fans were measured using a portable thermo-anemometer and ventilation rate was determined as the summation of air flow rates of all fans. The average odor concentrations for the GC and GT barn were 954 ± 423 and 908 ± 416 OU/m^3, respectively. Ammonia concentrations ranged from 3.0 to 27.0 ppm in the GC barn, and from 3.1 to 43.0 ppm in the GT barn. In the shallow pit system, ammonia concentrations varied from 2.0 to 15.9 ppm in the FC barn and from 2.0 to 15.2 ppm in the FT barn. The average NH_3 emission, over the entire sampling period, at the GC and GT barn were 28.96 ± 20.69 g d^{-1} AU^{-1} and 33.10 ± 14.24 g d^{-1} AU^{-1}, respectively, whereas they were 2.85 ± 1.28 and 3.51 ± 1.67 g d^{-1} AU^{-1} in the FC and FT barn, respectively. The average H_2S concentration over the entire sampling period at the GC and GT barn were 0.64 ± 0.42 ppm and 0.87 ± 0.41 ppm, respectively. Similarly, H_2S concentrations in the FC and FT barn were 0.45 ± 0.21 ppm and 0.42 ± 0.21 ppm, respectively. Average H_2S emissions were 3.25 and 5.59 g d^{-1} AU^{-1} in the GC and GT barns, respectively, and they were 0.36 and 0.43 g d^{-1} AU^{-1} in the FC and FT barns, respectively. No significant differences in terms of odor, ammonia, and hydrogen sulfide concentrations and emissions were found between treated and untreated units. Overall, the microbial treatment had very little effect in reducing odor, ammonia, and hydrogen sulfide emission.

Keywords: odor, ammonia, hydrogen sulfide, concentration, emissions, farrowing, gestation, Digest3+3©

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1 Introduction

Over the years, the agricultural community and large-scale livestock productions have changed significantly. The trends include an overall reduction in the number of farms, but an increase in intensive livestock production facilities, which is a major source of odor in the rural communities. Odor nuisance and pollutant gas emissions continue to be major issues for the livestock and poultry industries because of their

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potential environmental and health effects on animals, workers, and people who live nearby confined animal feeding operations (CAFOs) (Sun, Guo and Peterson, 2010).

Odors from animal feeding operations (AFOs) are produced primarily via an incomplete fermentation of livestock manure by bacteria. Odor emissions from AFOs are complex mixture of ammonia (NH_3), hydrogen sulfide (H_2S), and a large number of volatile organic compounds (VOCs) (Laor et al., 2007). However, the odor composition can vary with the types of animals raised, the seasonal variations, the stages of animal growth, the types of feed, and sampling locations etc. Offensive odors are the problem that can lead to public opposition of establishing a new livestock facility or expanding an existing facility. In rural areas, odor emissions from livestock operations constitute a major issue. Pollutants, such as NH_3, H_2S, and others (particulate matter, odor, and pathogens) emitted by animal production units represent risks to the health and well-being of animals, workers, neighbors, and to the global environment (NRC, 2003; Elenbaas-Thomas et al., 2005). As a result, animal producers are facing challenges from regulatory agencies and nearby communities to reduce offensive odors and pollutant gas emissions. Because of this, there is major interest in developing new technologies that can substantially reduce odor and pollutant gas emission.

Many technologies have been developed and investigated to reduce odors from swine operations including manure storage covers (Hudson et al., 2008; VanderZaag et al., 2008), mechanical aeration (Al-Kanani et al., 1992; Dong, Zhu and Miller, 2009), microbial fuel cells (Kim et al., 2008), stable aqueous foam-microbial media (Park et al., 2006), biofilters (Chen et al., 2009; Nicolai and Janni, 2000; Hahne et al., 2003 & 2005; Chen et al., 2009), manure additives (Al-Kanani et al., 1992; Kim et al., 2008; McCrory and Hobbs, 2001) and anaerobic digestion (Hjorth et al., 2009; Powers, 1999; Zhang, Tao and Dugba, 2000). Some of these technologies are effective, but tend to be expensive (VanderZaag et al., 2008) and their effectiveness period is short. Most of these technologies were tested in warmer climatic conditions, which are not directly transferable to colder climatic conditions like North Dakota, USA. Clearly, more research is needed to measure the effectiveness of these technologies under different climatic conditions and management practices.

Microbial activities are responsible for the malodor generation from anaerobic stored manure. Microbes play an important role in both production and reduction of malodors (Zhu, 2000). Microbial treatments have been extensively used in municipal wastewater to degrade organic matter (Low and Chase, 1999) and microbial treatments are emerging to treat livestock wastewater, since degradation of organic matter in wastewater relies on microorganisms (Sund et al., 2001). Microorganisms live naturally in manure and they digest solids and breakdown various components. One recent study (Rahman and Mukhtar, 2008) suggested that microbial treatment is effective in reducing solids and nutrients content in manure from anaerobic dairy lagoons. To date, limited information is available on whether microbial treatment is effective in reducing odor and pollutant gas emissions from deep pit manure systems from swine operations. Therefore, this study was designed to evaluate the effectiveness of a microbial treatment technology (Digest3+3© microbial additive) in reducing odor and pollutant gas emission from a farrowing-gestation swine operation.

2 Materials and methods

2.1 Description of facilities and management practices

This study was conducted at a commercial swine gestation-farrowing operation in North Dakota, USA. The total capacity of this facility was 5000 animals. The facility has two gestation-barns (g-barn) and two farrowing-barns (f-barn). Each g-barn (165 m × 24 m) has 2100 gestation-stalls with deep pits for manure collection and each f-barn (24 m × 12.5 m) has 15 farrowing rooms (7 rooms on one side and 8 rooms on the other side) with 60 crates per room (15 × 60 = 900 farrowing crates). The deep pit is 165 m × 24 m and the

maximum operating depth is 3 m. The two g-barns are identical in size, layout, and stocking, and so are all farrowing rooms. This facility is cross ventilated via pit fans in the winter and tunnel vented with cooling pads at the end walls and fans in the center of the side walls in the summer. The f-barns have shallow pull-plug type pits that drain manure into the corresponding g-barn pits every three weeks when the farrowing room is emptied at piglet weaning and power washed. The deep pit manure collection systems are completely separated from each other between the two g-barns and they were emptied twice in a year (May and September). In each g-barn, there are 16 pit ventilation fans and eight (8) wall ventilation fans.

2.1.1 Experimental design

The two deep pit manure collection systems in the g-barns were used in the experiment, one as treatment and one as control. The treatment pit was treated with the Digest3+3©, while the control pit was left untreated. Similarly, one side of the shallow pit of the farrowing unit was treated, while the other side of the farrowing unit was used as control. Following treatment, odorous air samples were collected once every two weeks for a month and thereafter monthly from both treated and control barns. Odor analysis schedules were slightly different to fit odor analysis schedule and funding limitation.

2.1.2 Pit treatment

Before treating pits in the g-barn and the farrowing rooms, background odorous air samples were collected monthly to obtain baseline odor detection threshold (DT) values. Thus, a total of 24 background air samples (12 samples from pit fans and 12 samples from wall fans) were collected for odor analysis. Following the background air sampling and measurement (5/21/2009 and 6/15/2009), the barn operator (producer) treated treatment pits with the Digest3+3© additive at a rate of 22.68 kg/month as per technology provider's recommendation during the study period. A typical application rate of the Digest3+3 is 454 g per 22,712–30,283 L of manure. According to the technology provider, the Digest3+3 is a blend of both aerobic and anaerobic bacteria with three natural carriers and this product works best at a pH range of 5.2 to 9.5 and temperature range of 1.7 – 57.2°C. However, pH and temperature were not measured in this study because of limited access for biosecurity reasons.

2.2 Odorous air sample collection

Because of limited resources and sample handling capacity and the large number of exhaust fans, a limited number of samples (12) were collected for odor threshold analysis during each sampling event. For sampling consistency, samples were collected from the same exhaust fans and at the same time of day (10 am - noon) each time. During each sampling event, duplicate air samples were collected from the same minimum ventilation fan of a farrowing room, whereas in the g-barn duplicate air samples were collected from the pit fans. All air samples were collected from the exhaust side of the fan due to bio-security reasons. All air samples were collected in a 10 L Tedlar bags using a vacuum chamber (SKC Inc., Eighty Four, PA) and samples were shipped overnight to an olfactometry lab at Iowa State University within 24 h of collection for determining the odor concentration (or dilution to threshold (DT) values).

2.3 Measurement

Odor DT values were analyzed using a forced-choice dynamic olfactometer (AC'Scent International Olfactometer, ST. Croix Sensory, Inc., Stillwater, Minnesota) at the Olfactory Lab at Iowa State University with eight trained panelists. During each air sampling event, duplicate NH_3 and triplicate H_2S concentrations were measured using the Dräger^{TM} Chip Measurement Systems (CMS) (SKC Inc., Eighty Four, PA) and a Jerome meter 631X (Arizona Instrument, Phoenix, Arizona), respectively. The ammonia chips (range 2 – 50 ppm) used were factory calibrated and the Jerome meter (range 0.003 – 50 ppm) used in this study was new and factory calibrated. All measurements were taken at the exhaust side of the fan. In addition, indoor temperature and relative humidity (RH) were recorded using HOBO Pro T/RH loggers (Onset Computer Corporation, Bourne, MA) with a 0.2 °C accuracy for temperature and 2.5% for RH. For the farrowing room, one HOBO logger was installed in the middle of the room. For the g-barn, two HOBO loggers were installed and data were recorded hourly.

The average air velocity rates (m/s) of all running fans were measured using a portable thermo-anemometer (Extech Instruments Corporation, Waltham, MA; range 0.4 – 30.0 m/s and accuracy ±3% + 0.20 m/s) using at least 10 – 20 locations across the radius of an exhaust fan (Zhang et al., 2007). The air flow rate (m^3/s) of each fan was calculated from the measured average air velocity and fan cross-sectional area. The measured fan airflow rate was compared with the published data from the BioEnvironmental and Structural Systems (BESS) lab fan testing data for the corresponding fan model. The total ventilation rate from each room was determined as the summation of the air flow rates of all fans.

2.4 Odor, NH_3 and H_2S emission rates calculation

Odor emission rate was calculated from the measured odor concentration and air flow rate as follows:

$$ER_{odor} = C_{odor} \times V_{rate} \quad (1)$$

where, ER_{odor} = Odor Emission rate, OU/sec; C_{odor} = Odor concentration, OU/m^3; V_{rate} = Ventilation rate through exhaust fan, m^3/sec.

Ammonia (NH_3) and H_2S emission rate was calculated using following equations:

$$ER_{P\_gas} = \left\{\left(C_{P\_gas} \times \frac{P}{RT} \times MW_{P\_gas} \times V_{rate}\right)\left(\frac{24\times3600}{10^3}\right)\right\} \Big/ AU \quad (2)$$

where, ER_{P_gas} = Pollutant gas (i.e., NH_3 or H_2S) emission rate, g day^{-1} AU^{-1}; C_{P_gas} = Pollutant gas (i.e., NH_3 or H_2S) concentration, ppm; P = Absolute pressure, atm (i.e., 1.0 atm); R = Ideal gas constant, 0.08206 1-atm/gmol-K; T = Absolute temperature, K (℃+273), (i.e., 25℃); MW_{P_gas} = Molecular weight of the pollutant gas (i.e., 17.03 for NH_3 and 34.07 for H_2S); AU = Animal unit = (N_{animal} × M_{animal})/500 (1 AU =500 kg of animal weight); N_{animal} = Number of animal; M_{animal} = Average mass of an animal, kg.

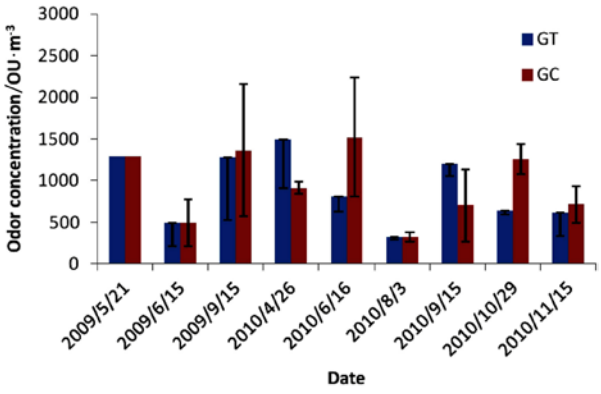
2.5 Data analysis

Analyses of variance (ANOVA) were performed using SAS and data were pooled and analyzed using the GLM statistical model. Both concentration and emissions were analyzed at P<0.05 to quantify the treatment effect and were compared between farrowing and gestation barns. The significance of the differences in concentration and emissions were examined according to Duncan's multiple range tests (Steel, Torrie and Dickey, 1997).

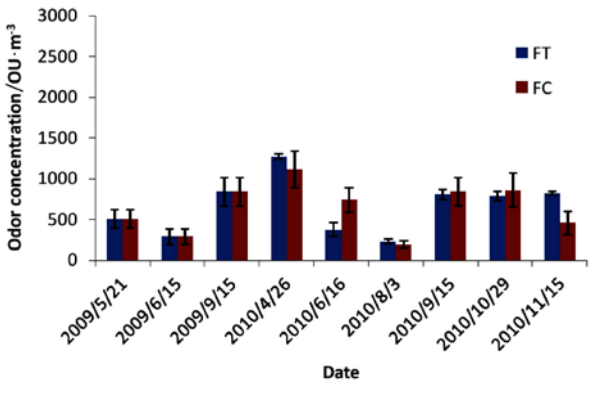
3 Results and discussion

3.1 Odor concentration and emission

Average odor concentrations of the gestation untreated (GC) and gestation treated (GT) barns were 954 ± 423 and 908 ± 416 OU/m^3, respectively, and odor concentration differences were not statistically significant (Figure 1a). Similarly, the average odor concentrations for the entire sampling period for the farrowing untreated (FC) and farrowing treated (FT) barns were 650 ± 303 and 636 ± 329 OU/m^3, respectively (Figure 1b). On average, the FT barn had slightly lower odor level than that of the FC barn, but the differences were not significant (P>0.05). Odor concentrations varied among sampling events where during colder months (October-April) the lower ventilation rates resulted in a greater concentration of odor (Figure 1). However, high odor concentration does not necessarily mean high odor emissions rate unless the ventilation rate is high too. Overall, treatment was not effective in mitigating odor.



a.



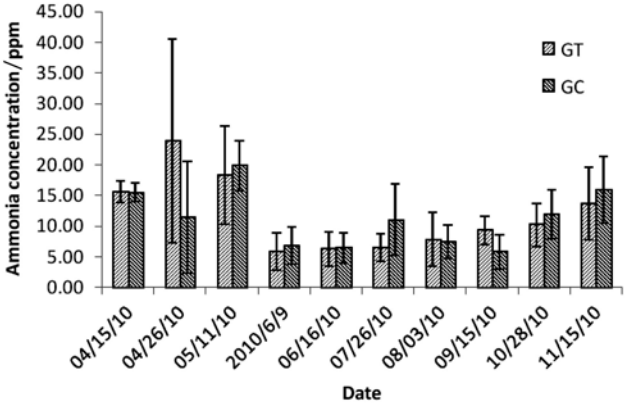
b.

Figure 1 Variation of odor concentrations a) between gestation treated (GT) and gestation untreated (GC) barn; and b) between farrowing treated (FT) and farrowing untreated (FC) barn. Error bars represent standard deviation.

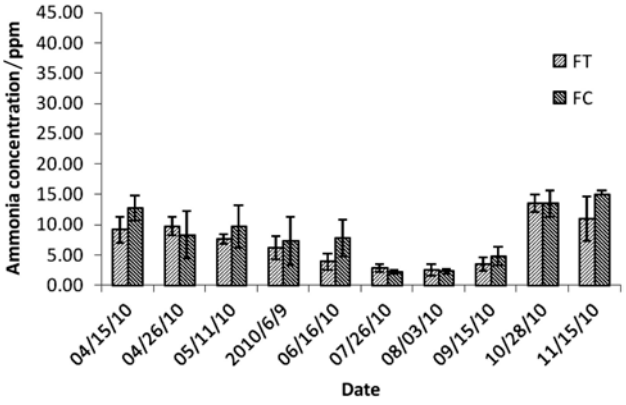
The average odor emissions varied from 8.0 to 69.7 $OUs^{-1}m^{-2}$ at the GC barn, and from 4.8 to 37.4 OU $s^{-1}m^{-2}$ at the GT barn. Similarly, the mean odor emission rates at the FC and FT barns varied from 2.4 to 6.7 OU $s^{-1}m^{-2}$ and 1.9 to 7.1 OU $s^{-1}m^{-2}$, respectively. Although the odor concentration between GC and GT was not significantly different, odor emissions varied, which was likely due to variation in the ventilation rates. Emissions results obtained in this study were within the range of 1.18 - 192 OU s^{-1} m^{-2} and 7.6 - 23.0 OU s^{-1} m^{-2} as reported by Gay et al. (2003) and Zhang et al. (2007), respectively.

3.1.1 Ammonia concentrations and emissions

The GT barn resulted in slightly higher NH_3 concentrations than the GC barn, but the differences were not significant statistically (Figure 2a). The ammonia concentration ranged from 3.0 to 27.0 ppm for the GC and from 3.1 to 43.0 ppm for the GT barn. The concentration varied from 2.0 to 15.9 ppm in the FC barn and from 2.0 to 15.2 ppm in the FT barn. The g-barns had significantly higher NH_3 concentrations (11.27 ± 4.73 ppm and 11.6 ± 6.3 ppm for the GC and GT, respectively (Figure 2a) than the farrowing barns (8.4 ± 2.2 ppm and 7.03 ± 2.6 ppm for FC and FT barn, respectively (Figure 2b).



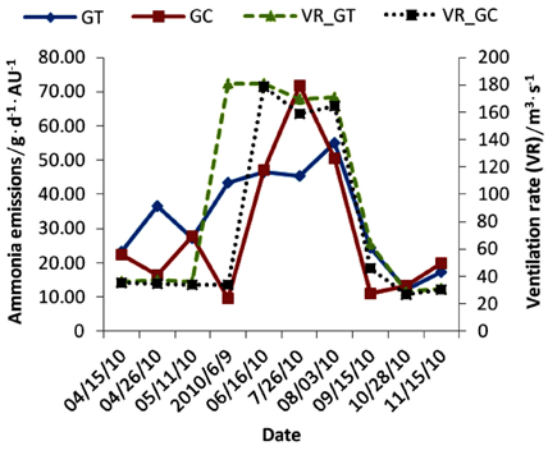
a.



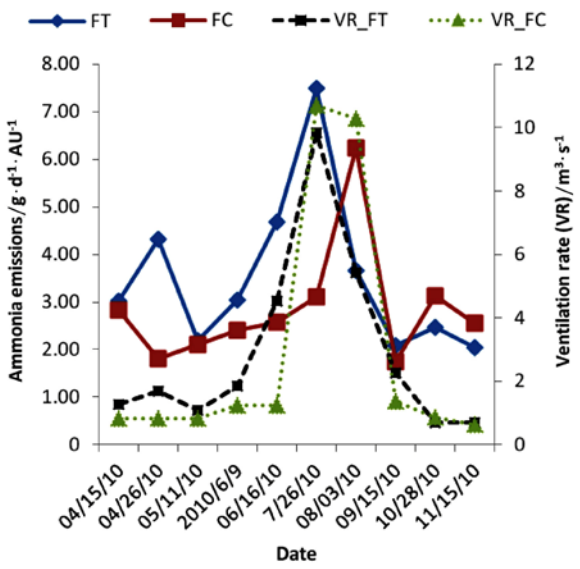
b.

Figure 2 Variation of ammonia concentration a) between gestation treated (GT) and gestation untreated (GC) barn; and b) between farrowing treated (FT) and farrowing untreated (FC) barn. Error bars represent standard deviation

The lowest NH_3 concentration was recorded during June-September and the highest concentration was found during colder months (October-April). This could be explained that during colder months mostly minimum ventilation fans were running because the ambient temperature was low (Figure 3). The low ventilation caused ammonia to accumulate inside the barns, thus resulting in high NH_3 concentrations. On the other hand, the ventilation rates were the highest during July-August (Figure 3), and more ammonia was removed from the barns, thus resulting in lower NH_3 concentrations. A similar trend was observed by other researchers (Guo et al., 2006; Sun, Guo and Peterson, 2010). Ammonia concentrations measured in both treated and untreated



a.



b.

Figure 3 Variation of ammonia emission: a) between gestation treated (GT) and gestation untreated (GC) barn; and b) between farrowing treated (FT) and farrowing untreated (FC) barn.

Ventilation rates (VR) in the barns are shown on the secondary axis

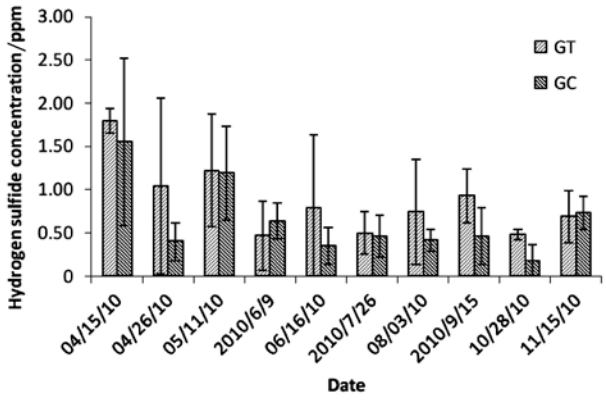
barns were within the same ranges as found in other studies. Sun, Guo and Peterson (2010) reported annual mean ammonia concentration between 14.0 and 20.0 ppm. Blunden, Aneja and Westerman (2008) reported seasonal concentrations varied between 0.58 ppm to 14.55 ppm. Zhu et al. (2000) also observed greater NH_3 concentrations in the gestation unit (between 9-15 ppm) as compared to farrowing unit (between 3-5 ppm).

Ammonia emissions varied from 9.58 to 71.74 g d^{-1} AU^{-1} in the GC barn, and from 12.19 to 55.08 g d^{-1} AU^{-1} in the GT barn (Figure 3a). The average NH_3 emissions over the entire sampling period in the GC and GT barns were 28.96 ± 20.69 and 33.10 ± 14.24 g d^{-1} AU^{-1}, respectively. Significantly lower ammonia emission was observed in the farrowing barns than the g-barns, which was likely due to manure management practices such as short and long term storage. The emission rate ranged from 1.75 to 6.23 g d^{-1} AU^{-1} for the FG room and from 2.09 to 7.49 g d^{-1} AU^{-1} in the FT room. The average rates were 2.85±1.28 and 3.51 ± 1.67 g d^{-1} AU^{-1} for the FC and FT barns, respectively (Figure 3b). For both gestation and farrowing barns, the differences in NH_3 emission rate were not statistically significant between the treatment and control.

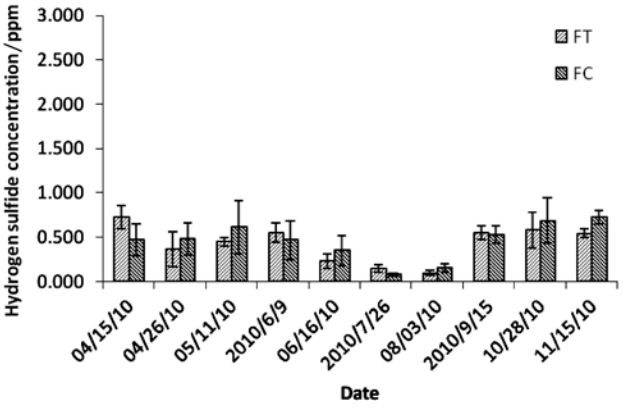
3.2 Hydrogen sulfide concentrations and emissions

The average H_2S concentration over the entire sampling period in the GC and GT barns were 0.64±0.42 ppm and 0.87 ± 0.41 ppm, respectively (Figure 4a). H_2S concentrations at the FC and FT barns were 0.45 ± 0.21 ppm and 0.42 ± 0.21 ppm (Figure 4b), respectively. Statistical analysis indicated that the differences in H_2S were not significant between the treated and untreated barns. Hydrogen sulfide emission depends on temperature, pH, and ventilation rate. However, pH and temperature were not measured in the deep pit, but pH in deep pit is about 7.8 ± 0.4 (Moody, Burns and Muhlbauer, 2009). Combination of these factors as well as treatment might have impacted H_2S emission. Although no liquid manure samples were collected from deep pit for physic-chemical analysis, but the producer noticed that the treated pit had less solids buildup compared to the untreated pit.

When the results obtained in this study were compared with other studies (Blunden, Aneja and Westerman, 2008; Zhu et al., 2000), the H_2S concentrations are within the ranges (0.148 to 0.927 ppm) as reported by Zhou and Zhang (2003) for a swine barn in Manitoba, Canada. When the H_2S concentrations were compared between f- and g-barns, the g-barn showed significantly higher H_2S concentrations than the f-barn (Figure 4).



a.

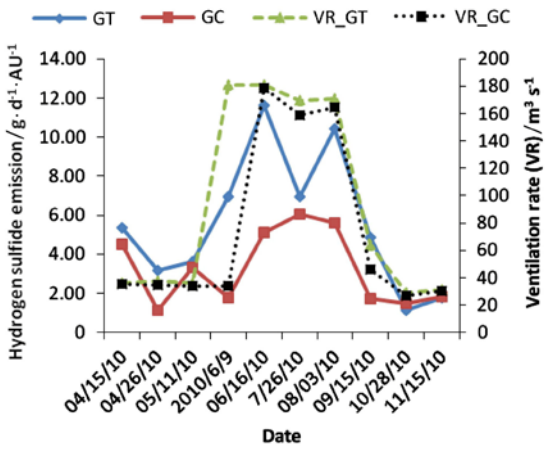


b.

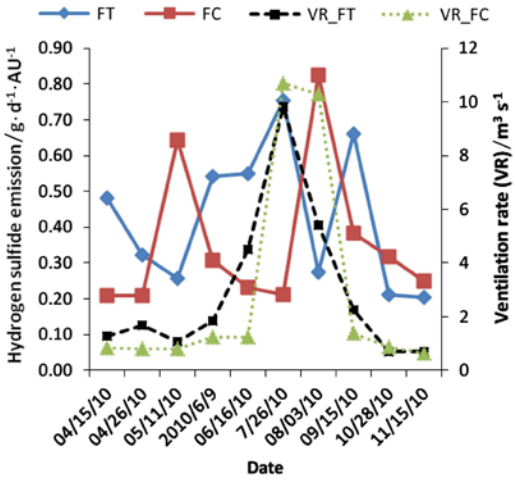
Figure 4 Variation of hydrogen sulfide concentration a) between gestation treated (GT) and gestation untreated (GC) barn; and b) between farrowing treated (FT) and farrowing untreated (FC) barn. Error bars represent standard deviation

Higher concentration in g-barn was likely due to differences in manure management systems. The g-barn had a deep pit system, whereas the farrowing had a shallow pit, and manure was removed from the shallow pit every three weeks. In a deep pit manure storage system manure is generally stored for six to nine months before pumping in May and September. As manure "ages", more H_2S is produced. Similar to the NH_3, the lowest H_2S concentration was noticed during the months of July-August and the higher concentration was noticed during the colder months (October-April).

Average H_2S emissions were 3.25 and 5.59 g d^{-1} AU^{-1} at the GC and GT barn (Figure 5a), respectively, whereas it was 0.36 and 0.43 g d^{-1} AU^{-1} at the FC and FT barn (Figure 5b), respectively. In both gestation and farrowing barns treated barn resulted in greater emissions than the control barn, which was likely due to the



a



b

Figure 5 Variation of hydrogen sulfide emission a) between gestation treated (GT) and gestation untreated (GC) barn; and b) between farrowing treated (FT) and farrowing untreated (FC) barn. Ventilation rate (VR) in the barns is shown on the secondary axis

treatment that might breakdown solids and scum in the deep pit systems and enhanced the release of H_2S. However, the differences were not statistically significant.

4 Conclusions

The effectiveness of a microbial treatment (Digest3+3©) was evaluated at a commercial swine gestation-farrowing barn in North Dakota. The following conclusions were drawn:

1) The treatment was not effective in mitigating odor;

2) The treatment was not effective in mitigating ammonia concentrations or emissions;

3) Like ammonia, the treatment was not effective in mitigating hydrogen sulfide concentrations. Instead, the treated barn had slightly higher hydrogen sulfide concentrations than the untreated barn, although the differences were not statistically significant different;

4) Higher gas concentrations and emissions in gestation barns with deep pit than the farrowing barns with shallow pits.

These results indicate that addition of microbial treatments may not be effective at reducing malodorous compounds from swine facilities at the manufacturers recommended rate. However, trends indicated that

addition of the microbial treatment studied here did influence odor and ammonia and increasing the application rate should be investigated.

Acknowledgement

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