Odor Characterization at Open-Lot Beef Cattle Feedyards Using Triangular Forced-Choice Olfactometry

D. B. Parker, M. B. Rhoades, G. L. Schuster, J. A. Koziel, Z. L. Perschbacher-Buser

Abstract. *Odor is a growing concern at concentrated animal feeding operations as residential houses encroach upon rural areas once occupied only by agriculture. A research project was conducted to determine baseline ambient odor characteristics at large open-lot beef cattle feedyards and to develop a better understanding of when and why odors occur at feedyards. Ambient odor samples were collected two to four times per month over a 12-month period in 2002-2003 at three large commercial open-lot beef cattle feedyards in the Texas panhandle. Ambient odor samples were collected upwind of the feedyard, downwind of the pens, and downwind of the runoff storage pond. Odor samples were also collected on five separate days covering four months in 2004 from a surface isolation flux chamber to estimate odor emission rates from the feedyard surface. All odor samples were collected in 10 L Tedlar bags and analyzed with trained human odor panelists for odor concentration (detection threshold, DT) by dynamic dilution forced-choice olfactometry, intensity by reference scaling, and hedonic tone. Manure moisture content and weather data were collected on-site at each of the feedyards. At two of the feedyards, mean DTs downwind of the pens and storage pond were statistically similar to upwind DTs, ranging from 33 to 45 OU m^{-3}. At the third feedyard, mean DTs downwind of the pens (69 OU m^{-3}) and pond (124 OU m^{-3}) were statistically higher than the mean upwind DT (36 OU m^{-3}) ($p < 0.05$). Odor emission rates ranged from 0.3 to 3.2 OU m^{-2} s^{-1} during a period when downwind DTs ranged from 17 to 132 OU m^{-3}. A number of elevated DTs were explained by elevated manure moisture contents from recent precipitation. These results demonstrate that odor production from open-lot beef cattle feedyards is a complex phenomenon that depends at least partially on weather conditions. Thus, odor prediction and control will likely be difficult at these facilities.*

Keywords. *Cattle, Detection threshold, Feedyard, Hedonic tone, Intensity, Manure, Odor.*

More than 7 million cattle are fed annually in Texas Panhandle feedyards, representing 30% of the nation's fed beef (TCFA, 2000). As houses encroach upon rural areas once occupied by agriculture, there is a growing concern over odor nuisances from beef cattle feedyards (Chen et al., 1999; Sweeten, 1991, 1995; Sweeten and Miner, 1993). Odors are not regulated in Texas and many other states, although some states are governing these nuisances (CAQCC, 1999; Redwine and Lacey, 2000).

Most odors from concentrated animal feeding operations (CAFOs) are caused by a group of over 200 different compounds, which are generated by the anaerobic decomposition of manure (Zhang, 2001; Mackie et al., 1998; Sweeten, 1991). Ammonia, volatile fatty acids, hydrogen sulfide, para-cresol, phenol, indole, and skatole are among the most commonly reported odorants (Zhang, 2001; Mackie et al., 1998; Sweeten, 1991).

When studying odor and its effects on people living near CAFOs, four characteristics are typically used: (1) strength or concentration of the odor, (2) frequency or how often the odor occurs, (3) duration or how long the odor is present, and (4) offensiveness or hedonic tone (Sweeten, 1995; Mackie et al., 1998; Redwine and Lacey, 2000). Odor concentration often receives the most attention in nuisance complaints (Redwine and Lacey, 2000; Mackie et al., 1998).

A standard laboratory method for quantifying odor concentration using human panelists is known as triangular forced-choice olfactometry (ASTM, 2001b). Panelists are presented with three air samples, only one of which contains the actual odor sample, and are asked to identify the sample they believe contains the odorous air. The dilution ratio of clean air to odorous air at which the panelist detects but does not recognize the odor is called the detection threshold, or DT (Mackie et al., 1998). Clanton et al. (1999) stated that the use of human panelists surpasses the combination of high-resolution gas chromatography and mass spectrometry when quantifying and identifying odorous compounds in small amounts. One of the difficulties with olfactometry is that odor DT is not a consistent number, but may vary with each panel (Sweeten et al., 1983), although this can be said of virtually every odor measurement method. Triangular forced-choice olfactometry continues to be one of the primary methods of odor assessment for swine (Bicudo et al., 2004; Gay et al., 2003; Galvin et al., 2003; Lim et al., 2001; Zhu et al., 1999) and dairy (Gay et al., 2003; Zhu et al., 1999)

Article was submitted for review in August 2004; approved for publication by the Structures & Environment Division of ASAE in May 2005.

The authors are **David B. Parker, ASAE Member Engineer,** Associate Professor, **Marty B. Rhoades, ASAE Member Engineer,** Research Associate, **Greta L. Schuster,** Associate Professor, and **Zena L. Perschbacher-Buser,** Research Associate, Division of Agriculture, West Texas A&M University, Canyon, Texas; and **Jacek A. Koziel, ASAE Member Engineer,** Assistant Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, and National Swine Research and Information Center, Ames, Iowa. **Corresponding author:** David B. Parker, West Texas A&M University, Division of Agriculture, Box 60998, Canyon, TX 79016; phone: 806-651-5281; fax: 806-651-2504; e-mail: dparker@mail.wtamu.edu.

facilities. Little information has been published on odor characteristics at open-lot beef cattle feedyards in the U.S.

Objectives

The objectives of this research were to:

- Quantify baseline odor detection thresholds at large open-lot beef cattle feedyards.
- Determine if detection threshold was correlated with intensity or hedonic tone.
- Determine if the cause of the odor could be correlated to manure moisture content and weather conditions.

Materials and Methods

Ambient Odor Sample Collection

Odor samples were collected from three commercial beef cattle feedyards (designated herein as feedyards A, B, and C) with capacities of 25,000 to 55,000 head. Odor samples were collected two to four times per month from May 2002 through April 2003. Odor samples were collected at three locations at each feedyard: (1) immediately upwind of the feedyard, (2) immediately downwind (within 20 m) of the feedyard pens, and (3) immediately downwind (within 50 m) of the runoff storage pond. Odor samples were collected in 10 L Tedlar bags at a height of 1.0 m above the ground surface. To reduce ambient bag odor, each bag was heated for 24 h at 100 °C and purged with odor-free air before the odor samples were collected (Parker et al., 2003). Samples were transported by automobile to the odor laboratory at West Texas A&M University and were analyzed within 24 h. Odor laboratory procedures followed general guidelines developed by scientists and engineers at Iowa State University and the University of Minnesota (ISU/UM, 2000). Odor samples were presented to trained panelists and analyzed for detection threshold (DT), intensity, and hedonic tone. DTs were measured throughout the 12-month study. Intensity and hedonic tone were measured only during the last three months of the study, which was the first time that these parameters had been measured at the laboratory.

Odor Emission Rate Using Flow-Through Chamber

Odor samples were collected three times in January-February 2004 and twice in September-October 2004 at feedyard C using a dynamic flow-through chamber constructed of 26.5 cm I.D. Lexan translucent tubing, 6 mm wall thickness, 47 cm high, and lined with 0.5 mm thick fluorinated ethylene propylene foil (Baek et al., 2003; Aneja et al., 2001a, 2001b). Similar chamber and wind tunnel methods have been used to measure odor emissions from lagoons and ponds (Galvin et al., 2003; Heber et al., 2002) and odor, ammonia, and hydrogen sulfide emissions from open-lot feedyard surfaces (Smith and Watts, 1994; Duysen et al., 2003; Baek et al., 2003). Odorless air generated by a zero-grade generator (model 111, Thermo Electron Corp., Franklin, Mass.) was directed into the chamber at 11 to 14 L min^{-1} using polytetrafluoroethylene (PTFE) tubing. Flow rate was controlled by a 15 L min^{-1} mass flow controller (Aalborg Instruments and Controls, Orangeburg, N.Y.). A PTFE impeller was used to mix the air inside the chamber at a constant speed of approximately 50 rpm.

The following equation was used for estimating odor emission rates:

$$E = \frac{Q[C]}{A} \tag{1}$$

where

E = odor emission rate (OU m^{-2} s^{-1})
Q = airflow rate (m^3 s^{-1})
A = surface covered by the flux chamber (m^2)
C = odor concentration (OU m^{-3}).

Upwind and downwind ambient odor samples were collected simultaneously for comparison to emission rates.

Detection Threshold

Detection threshold (DT) is a measure of the ratio of dilutions of clean air to ambient (odorous) air at which human panelists can just detect the odor when compared to clean air (Sweeten, 1995). DT was measured using triangular forced-choice olfactometry with an AC'Scent International olfactometer (St. Croix Sensory, Lake Elmo, Minn.). Panel DTs were calculated following the guidelines of ASTM (2001b). The DT for each individual panelist was calculated as the geometric mean of the concentration at which the last incorrect guess occurred and the next higher concentration at which the odor was correctly detected. The panel DT was calculated as the geometric mean of the individual panelist DTs. DT is dimensionless and commonly reported as odor units (OU), although many researchers use the units OU m^{-3} so that odor emission rates can be reported in the more meaningful form as OU m^{-2} s^{-1}. In this article, odor concentration is presented in OU m^{-3} and odor emission rates are presented as OU m^{-2} s^{-1}.

Intensity

Samples were analyzed for intensity using a static-scale method by comparison to five standard n-butanol solutions, following the general guidelines of ASTM (2001a). Solutions consisted of 0.25, 0.75, 2.25, 6.75, and 20.25 mL n-butanol per L of water, which corresponded to intensities of 1.0, 2.0, 3.0, 4.0, and 5.0, respectively. The intensity of the odor was determined by each panelist by comparing the full-strength odorous air sample from the Tedlar bag to known concentrations of n-butanol mixed with water. Scores ranged from 0.5 for an odor sample weaker than the lowest n-butanol concentration to 5.5 for an odor stronger than the highest concentration, in increments of 0.5. The average intensity was calculated for the panel using the arithmetic mean.

Hedonic Tone

Hedonic tone was determined in a similar manner by sniffing the full-strength odor sample. Panelists were asked to subjectively assign a score for hedonic tone on a scale of −4 to +4, with −4 being very unpleasant, 0 being neutral, and +4 being very pleasant. The average hedonic tone was calculated for the panel using the arithmetic mean.

Manure Samples

Manure samples were collected from within two pens near the center of each feedyard. The same two pens were utilized at each sampling event. Each pen was sampled at three locations: (1) immediately below the concrete bunk apron, (2) at the middle of the pen (or top of the mound if a mound was present), and (3) near the rear of the pen. Samples were collected at two depths at each location, the loose surface material of about 5 cm in thickness, and the hardpack subsurface manure of about 5 to 10 cm depth. Samples were oven dried at 100˚C for 24 h to determine gravimetric moisture content on a wet weight basis (weight of water divided by total weight).

WEATHER DATA

Climatic data were collected from stationary weather stations located at each feedyard (Unidata America, Lake Oswego, Ore.). The weather stations were placed at the southwest corner of the feedyard, which was typically upwind based on the predominant wind direction from the southwest. Data were collected every 2 min, stored in a Starlogger datalogger, and downloaded weekly. Data included air temperature, wind speed and direction at 2 m height, rainfall, and soil temperatures at 5 and 15 cm depths.

QUALITY ASSURANCE/QUALITY CONTROL

Prior to each odor session, 8 or 9 odor panelists were screened with an n-butanol standard gas preparation and an equipment blank on the olfactometer. An n-butanol gas sample was prepared by filling a Tedlar bag with 40 ppm n-butanol. Individual panelist DTs were determined using the n-butanol gas standard. Those panelists who were noticeably outside the target range were dismissed for the session. In all cases, panelists were dismissed because they were not sensitive enough. Ideally, a geometric mean DT for the n-butanol standard of about 500 to 2000 was targeted. This corresponds to n-butanol detection at 20 to 80 ppb, as recommended by the European Odor Standard (CEN, 2002). Most of our panelists consistently detected the n-butanol standard at DTs of about 200, which corresponds to n-butanol detection at about 200 ppb.

An equipment blank was also used at each panel session. The equipment blank was prepared by filling an aged Tedlar bag, dedicated for that purpose only, with clean air from the olfactometer outlet. The equipment blank was used to determine if there were any odors emanating from the olfactometer tubing, valves, or filters.

Odor panelists were limited to eight samples in addition to the blank and n-butanol for each session to reduce panelist fatigue and ensure the collection of quality data.

STATISTICAL ANALYSES

Pearson correlation coefficients were calculated to determine linear relationships between DT downwind of the pens and feedyard surface moisture content. The average surface moisture content for three locations in each of two pens was used in the analysis. Downwind DTs were also compared to the various climatic parameters measured at the time of sampling.

Upwind and downwind DTs were compared using paired t-tests. When performing t-tests, analyses were performed with raw data and also with log-transformed data, with no differences in results. All statistical analyses were performed using Excel (Microsoft Corp., Redmond, Wash.) and SPSS Version 10 (SPSS Inc., Chicago, Ill.).

SAFETY EMPHASIS

Odor laboratory protocols and use of human subjects in odor research was approved annually by the West Texas A&M University Institutional Review Board.

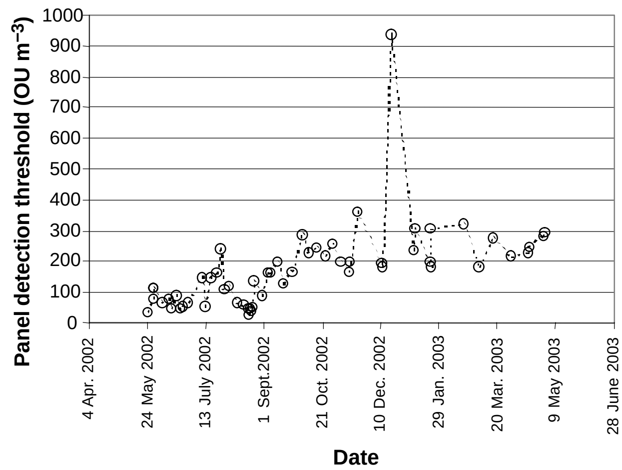

Figure 1. Panel detection thresholds determined for a bag filled with 40 ppm n-butanol standard gas.

RESULTS AND DISCUSSION

QUALITY ASSURANCE/QUALITY CONTROL

The mean panel DT over the 12-month period for the n-butanol standard was 172. Panel DTs increased slightly over the first six months before stabilizing between 200 and 300 (fig. 1). A panel DT of 200 corresponds to an n-butanol concentration of about 200 ppb, while a panel DT of 300 corresponds to a concentration of about 150 ppb. The European Odor Standard recommends that individual panelists detect the n-butanol at concentrations ranging from 20 to 80 ppb (CEN, 2002). Only a small percentage, less than 10%, of all panelists tested in our odor panel were able to routinely detect n-butanol at less than 80 ppb, even with intensive training.

The European Odor Standard recommends the use of n-butanol as a panelist evaluation and screening tool and for "quality criteria for the overall performance of the sensory measurement method" (CEN, 2002). The Standard suggests that if a panelist is sensitive to n-butanol, then that panelist will also be sensitive to other odors. Through several years of experiences gained in our odor laboratory, we have found that this is generally not the case for feedyard odors, and that n-butanol sensitivity is more often poorly correlated to feedyard odor sensitivity. For example, correlations between DT of the downwind pond and DT of the n-butanol standard for two selected days are shown in figures 2 and 3. There is little correlation between these variables in either of the figures. It is interesting that there was one panelist who was insensitive to both n-butanol (DT = 11) and feedyard odor (DT = 6) (fig. 2). This data point was removed from the calculation of the panel DT. Another panelist was sensitive to n-butanol (DT = 725) but insensitive to feedyard odor (DT = 5) (fig. 3). These results lead us to question the validity of normalizing feedyard odor data to n-butanol measurements, or for even using n-butanol as a panelist screening tool when measuring feedyard odors.

Panel DTs for the blank were generally less than 40, with a mean of 13.8 over the 12-month period (fig. 4). Two occurrences of elevated blank DTs occurred near the end of the study, although the cause is unknown.

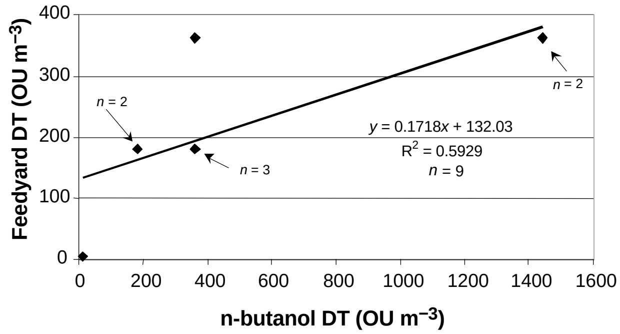

Figure 2. Relationship between feedyard and n-butanol DTs for nine panelists on a single odor sample collected downwind of the storage pond on 4 October 2003.

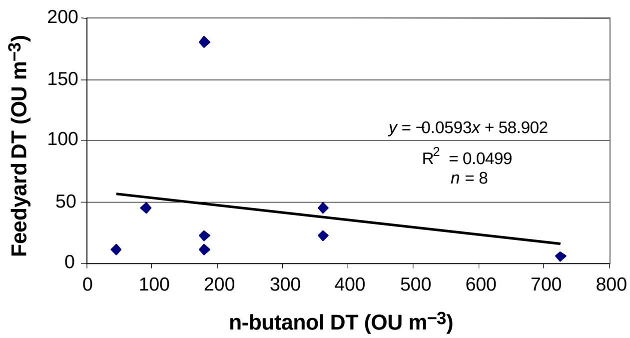

Figure 3. Relationship between feedyard and n-butanol DTs for eight panelists on a single odor sample collected downwind of the storage pond on 20 January 2003. Each data point is the value for a single panelist.

Detection Thresholds

Upwind panel DTs ranged from 7 to 362 (table 1). Panel DTs downwind of the pens ranged from 8 to 665, while DTs downwind of the pond ranged from 8 to 1223. There was no statistical difference in mean DTs upwind of the feedyard and downwind of pens or ponds at feedyards A and B, with mean panel DTs ranging from 33 to 44. For feedyard C, the mean panel DTs downwind of the pond and downwind of the pens were both statistically greater than upwind (table 1) ($p < 0.05$).

Panel DTs for the three feedyards over time are shown in figures 5 through 7. DTs are presented on a log scale to better show the values at the low DTs. There were no obvious trends or patterns observed over time. Several occurrences of elevated DTs were observed over the 12-month period at all three feedyards. Of 136 total odor observations downwind of pens, 11 were greater than 100 OU m^{-3} and six were greater than 200 OU m^{-3}, while for downwind of the pond, 20 were greater than 100 OU m^{-3} and nine were greater than 200 OU m^{-3}. In some instances, upwind DTs were higher than downwind. Elevated upwind DTs could be a result of many things, but the most likely causes were probably related to plant developmental phase (flowering) or to activities related to hay cropping. There were no other nearby feedyards or other odor sources that could have contributed to these elevated upwind DTs.

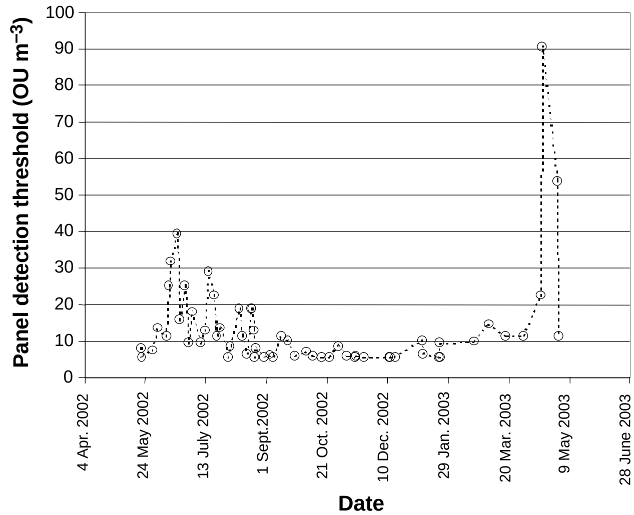

Figure 4. Panel detection thresholds for a machine blank (odorless bag filled with airstream from the olfactometer outlet) prior to each odor panel session.

Panel DTs increased at all three feedyards in March and April. However, during this same time period, the DTs for upwind samples also increased. Thus, it is probable that odor carried onto the feedyard from an upwind source was a major contributor to these elevated DTs. It could be that springtime brought more odor from offsite sources, resulting in higher DTs both upwind and downwind of the feedyards.

Table 1. Summary statistics of odor concentrations (panel detection thresholds) at three beef cattle feedyards over a 12-month period (all statistical values in OU m^{-3}).

Feedyard	Location	*n*	Minimum (OU m^{-3})	Maximum (OU m^{-3})	Median (OU m^{-3})	Mean (OU m^{-3})	Std Dev (OU m^{-3})
A	Upwind	42	8	362	23	42	58
	Downwind pens	42	8	234	23	37	41
	Downwind pond	42	8	362	23	42	63
B	Upwind	40	8	362	20	44	67
	Downwind pens	40	8	166	27	40	38
	Downwind pond	40	8	362	18	33	58
C	Upwind	54	7	256	23	36	45
	Downwind pens	54	8	665	26	69[a]	137
	Downwind pond	54	8	1223	45	124[a]	207
Overall	Upwind	136	7	362	23	40	56
	Downwind pens	136	8	665	25	59	108
	Downwind pond	136	8	1223	25	78	145

[a] Mean downwind DT is statistically greater than the corresponding mean upwind DT ($p < 0.05$) using paired t-test.

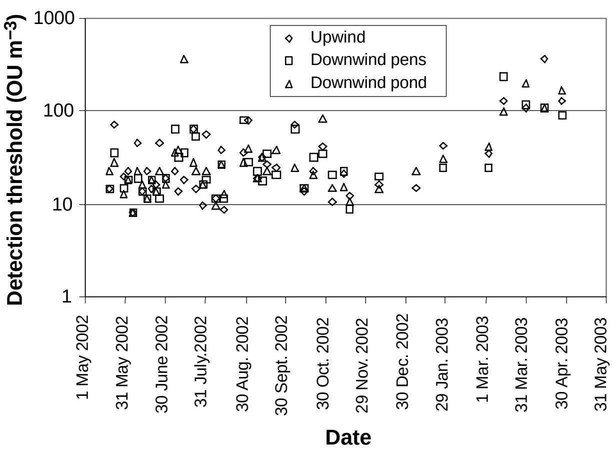

Figure 5. Detection thresholds for feedyard A over a 12-month period for upwind of the feedyard, immediately downwind of the pens, and immediately downwind of the storage pond.

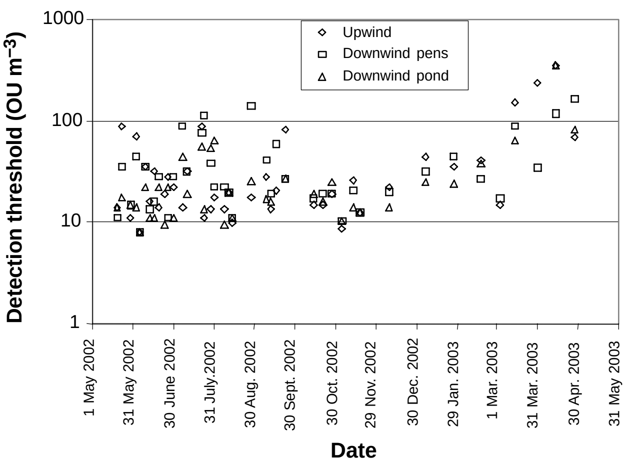

Figure 6. Detection thresholds for feedyard B over a 12-month period for upwind of the feedyard, immediately downwind of the pens, and immediately downwind of the storage pond.

Odor Emission Rates

Odor emission rates measured on five separate days in January-February and September-October 2004 ranged from 0.34 to 3.17 OU m^{-2} s^{-1}, while downwind DTs ranged from 17 to 132 OU m^{-3} during the same period (table 2). The DTs for the blank ranged from 8 to 13 for these five odor measurement times. For comparison, Duyson et al. (2003) reported odor fluxes ranging from 3.1 to 4.2 OU m^{-2} s^{-1} at a research feedyard in Nebraska in August and September. Because Nebraska experiences a wetter environment than west Texas, manure moisture content might have been a reason for the higher range of emission rates. A strong linear relationship was observed between mean downwind DTs and

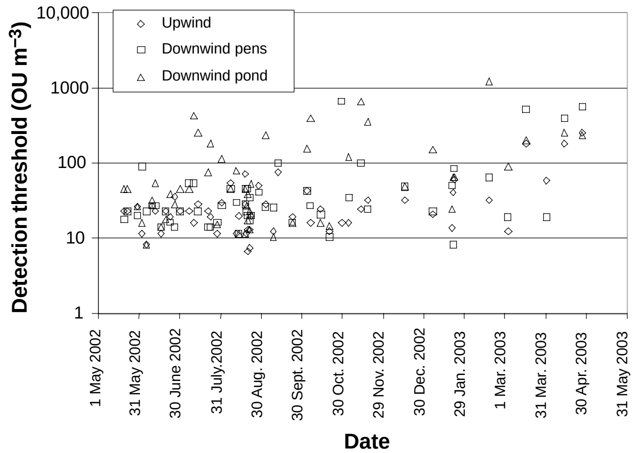

Figure 7. Detection thresholds for feedyard C over a 12-month period for upwind of the feedyard, immediately downwind of the pens, and immediately downwind of the storage pond.

odor emission rates for the January-February data, but when the September-October data were added, the overall correlation decreased significantly (fig. 8). Because the relationship between odor emission rates and downwind ambient odor concentrations will vary depending on atmospheric stability, wind speed, and other atmospheric parameters, this relationship should be viewed as preliminary at this time. Future research will focus on describing this relationship in more detail with additional sampling and modeling efforts.

Manure Moisture Content

Individual manure moisture contents measured at the time of odor sampling ranged from 5% to 80%, indicating a wide range of moisture conditions throughout the year. Mean manure moisture contents ranged from 17% to 37% depending on the feedyard and location in the feedyard (table 3). Mean manure moisture contents were 1.2% to 10.6% lower in the loose surface manure than the hardpack subsurface manure, with an overall average of 6.1%. In general, the middle of the pen was dryer than either the front or rear. Feedyard C had mounds in the pens, while the other two feedyards did not. Other than the mounds, the feedyards had similar management, stocking densities, and pen slopes.

Correlation Between DT, Manure MC, and Weather Parameters

DT was not significantly correlated to moisture content for any of the three feedyards (table 4). Figures 9 through 11 show how panel DTs relate to feedyard surface moisture content. This finding is particularly important because in the past there has been a common misconception that odor and moisture content were highly correlated. DT was negatively correlated with air temperature, indicating that DT decreased

Table 2. Odor emission rates as compared to upwind and downwind DTs.

Date	Detection Threshold (OU m^{-3})			Odor Emission Rate (OU m^{-2} s^{-1})		
	Upwind	Downwind 1	Downwind 2	Chamber 1	Chamber 2	Chamber 3
29 Jan. 2004	43	56	47	1.57	2.07	3.17
2 Feb. 2004	37	24	52	1.16	0.82	0.75
5 Feb. 2004	27	17	35	0.40	0.34	0.39
27 Sept. 2004	28	72	73	1.11	0.94	NA[a]
4 Oct. 2004	55	132	NA[a]	0.74	1.11	NA[a]

[a] NA = not analyzed.

with increasing air temperature. This does not necessarily mean that there is a cause-effect relationship between DT and air temperature, as air temperature was also negatively correlated to moisture content (r = −0.4 to −0.6). There was a significant negative correlation between wind speed and DT in feedyard A only, an indication that the DT decreased as wind speed increased, presumably from increased dilution and turbulence. Correlations were not significant for the other two feedyards, an indication that wind speed is a poor predictor of detection threshold.

Relationship Between DT, Intensity, and Hedonic Tone

There was a small positive correlation between panel detection threshold and intensity (r = 0.36) (fig. 12). There was no correlation between detection threshold and hedonic tone (fig. 13). There was a negative correlation between intensity and hedonic tone (r = −0.68) (fig. 14), indicating that hedonic tone increased as intensity decreased. There were no patterns associated with the upwind, downwind, or downwind pond samples. All of these data appear to be evenly distributed throughout the graphs, indicating no indication of trends within any of these three sampling locations.

Investigating the Cause of Elevated DTs

One of the long-term goals of our odor research is to make strides toward understanding odors so that they can be reduced or eliminated. We used a variety of statistical and logical means in an attempt to better understand the causes of the elevated DTs (i.e., those DTs > 100 OU m^{-3}). The elevated DTs were first examined in detail to determine if they were really from the feedyard source, or if they could possibly have been an artifact of machine contamination, bag contamination, or an upwind source. Using the decision tree shown in figure 15, we determined that of the 31 total DTs greater than 100, 14 of these were suspect because of elevated upwind DTs (>100 OU m^{-3}) and one was suspect because of an elevated machine blank DT of 54. Of the remaining 17 DTs definitely attributable to odor from the feedyard, 13 were from downwind of the pond and four were from downwind of the pens.

We observed no distinguishable relationships between weather conditions and DTs downwind of the pond, so efforts were focused on DTs downwind of the pens. One of the downwind of the pens samples had an elevated DT from the hot feed that had just been delivered to the pens, which was characterized as "strong but pleasant." The remaining three elevated DTs downwind of the pens were evaluated in detail to determine if they could be explained in any way with manure moisture content and weather conditions at the time of sampling, or with weather conditions during the previous week (table 5). All three outliers had between 2 and 6 cm of precipitation during the previous seven days, with manure

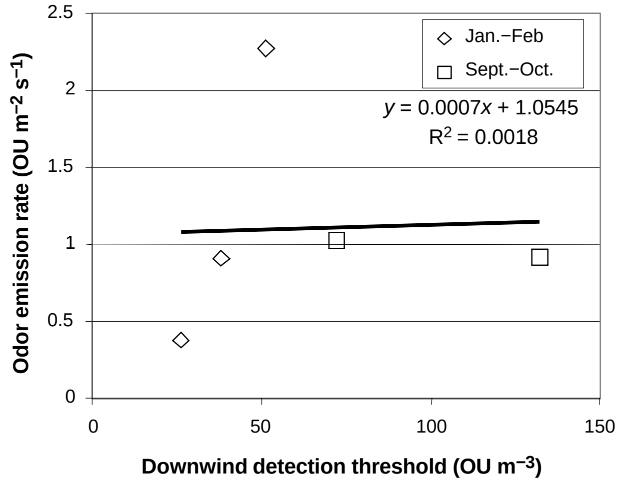

Figure 8. Relationship between odor emission rates measured with a flux chamber and downwind detection thresholds, measured on five separate days in 2004. Each data point is the average of two to three odor emission rates and two downwind detection threshold measurements.

moisture contents ranging from 46% to 69% on the day of odor sampling. These three outliers also had a characteristic "strong feedyard manure" odor. This is in line with our observations that feedyards often have a distinguishable odor a few days after a rainfall event. These findings are also in general agreement with those of Watts et al. (1994), who found little correlation between moisture content and odor emissions when looking at grouped data, but found a definitive increase in odor emissions two days after a precipitation event. Contrarily, Koelsch et al. (2004) found no increase in total reduced sulfur (hydrogen sulfide) concentrations following precipitation events.

This analysis suggests that, although DT is not strongly correlated with manure moisture content when all data are grouped, the highest characteristic "feedyard odor" DTs do appear to be associated with elevated moisture contents following recent precipitation events.

Because all odor samples were filtered before presentation to panelists, these observations are limited to measurement of volatile odors and not particulate odors. The relationship between odor and dust-related transport is a complicated topic that may be studied in the future.

Conclusions

The following conclusions were drawn from this research:

- Over a 12-month period, DTs downwind of feedyard pens ranged from 8 to 665 OU m^{-3}, with a mean of 59 and median of 25. DTs downwind of feedyards ponds ranged from 8 to 1223 OU m^{-3}, with a mean of 78 and median of 25. Two of three feedyards had mean upwind

Table 3. Summary of mean manure moisture contents (percent wet weight basis) measured over a 12−month period at three feedyards.

	Pen 1						Pen 2					
	Bunk		Middle		Rear		Bunk		Middle		Rear	
Feedyard	0-5 cm depth	5-10 cm depth	0-5 cm depth	5-10 cm depth	0-5 cm depth	5-10 cm depth	0-5 cm depth	5-10 cm depth	0-5 cm depth	5-10 cm depth	0-5 cm depth	5-10 cm depth
A	20.3	25.6	18.1	23.4	21.2	26.2	21.1	25.0	16.7	19.7	22.4	23.6
B	31.4	36.9	27.0	33.8	22.4	31.6	24.4	32.8	19.8	30.4	23.3	33.8
C	25.5	32.7	20.2	26.2	24.0	30.6	24.6	29.1	19.7	28.0	24.9	28.4

Table 4. Pearson correlation coefficients relating panel detection threshold to manure moisture content and various weather parameters.

Feedyard	Moisture Content: Surface	Moisture Content: Subsurface	Air Temp.	Soil Temp.: 5 cm	Soil Temp.: 15 cm	Wind Speed
A	−0.023	−0.027	−0.05	0.02	0.04	−0.33[a]
B	0.166	−0.054	−0.002	0.10	0.19	−0.028
C	0.007	0.002	−0.34[a]	−0.24	−0.21	0.06

[a] Correlation is significant at the 0.05 level.

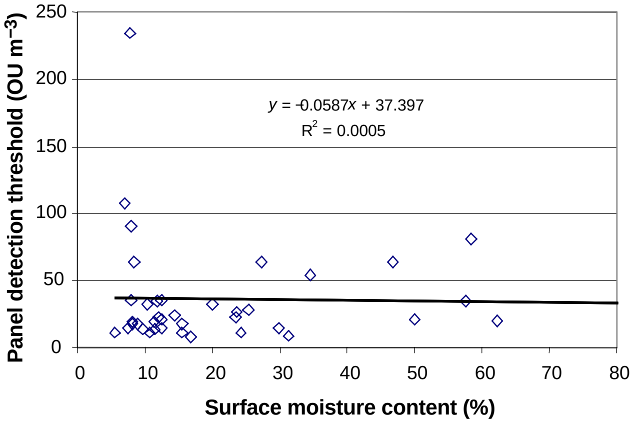

Figure 9. Relationship between panel detection threshold immediately downwind of pens and feedyard surface moisture content (wet weight basis) for feedyard A.

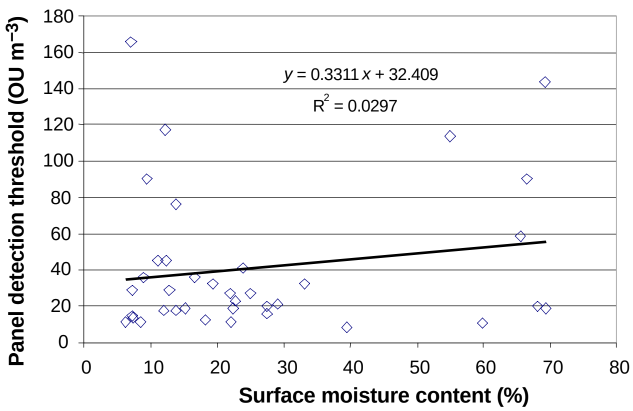

Figure 10. Relationship between panel detection threshold immediately downwind of pens and feedyard surface moisture content (wet weight basis) for feedyard B.

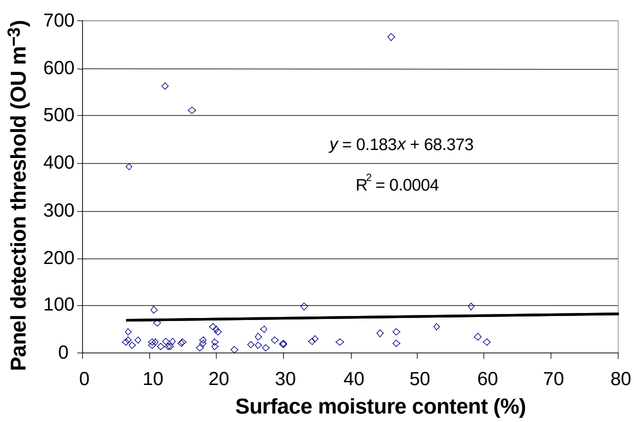

Figure 11. Relationship between panel detection threshold immediately downwind of pens and feedyard surface moisture content (wet weight basis) for feedyard C.

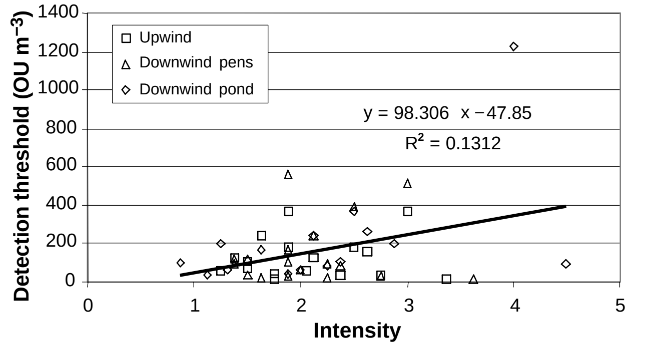

Figure 12. Relationship between panel detection threshold and intensity for all three feedyards and three locations per feedyard.

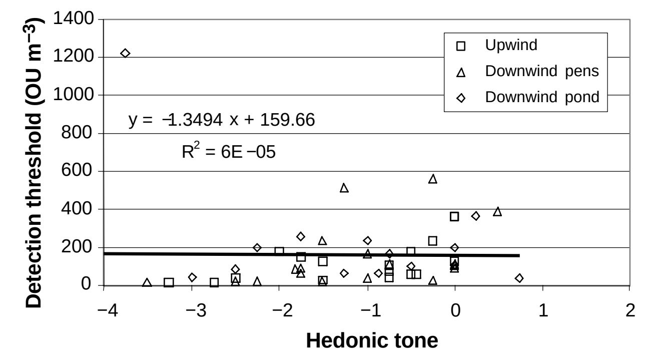

Figure 13. Relationship between panel detection threshold and hedonic tone for all three feedyards and three locations per feedyard.

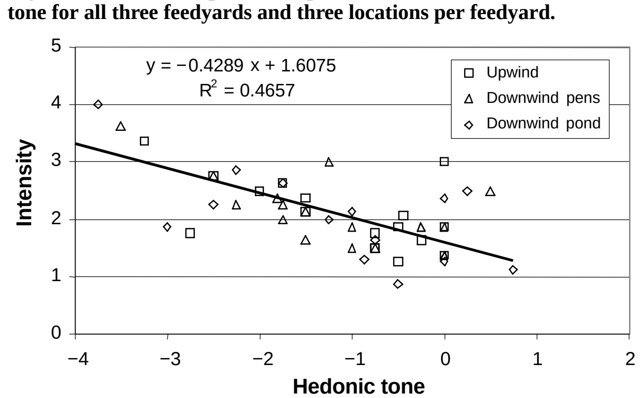

Figure 14. Relationship between intensity and hedonic tone for all three feedyards and three locations per feedyard.

DTs similar to downwind DTs. Odor emission rates ranged from 0.34 to 3.17 OU m^{-2} s^{-1} during a period when downwind DTs ranged from 17 to 56 OU m^{-3}.

- DT was positively correlated with intensity (r = 0.36), with little to no correlation with hedonic tone (r = 0.008). Intensity was negatively correlated with hedonic tone (r = −0.68).
- Although DT was not significantly correlated with manure moisture content when all odor data were grouped, the outliers (high DTs) with corresponding characteristic "strong feedyard manure" odor appeared to all be associated with elevated manure moisture contents following recent precipitation events.
- These results demonstrate that odor production from open-lot beef cattle feedyards is a complex phenomenon that depends at least partially on weather conditions, thus odor prediction and control will likely be difficult at these facilities.

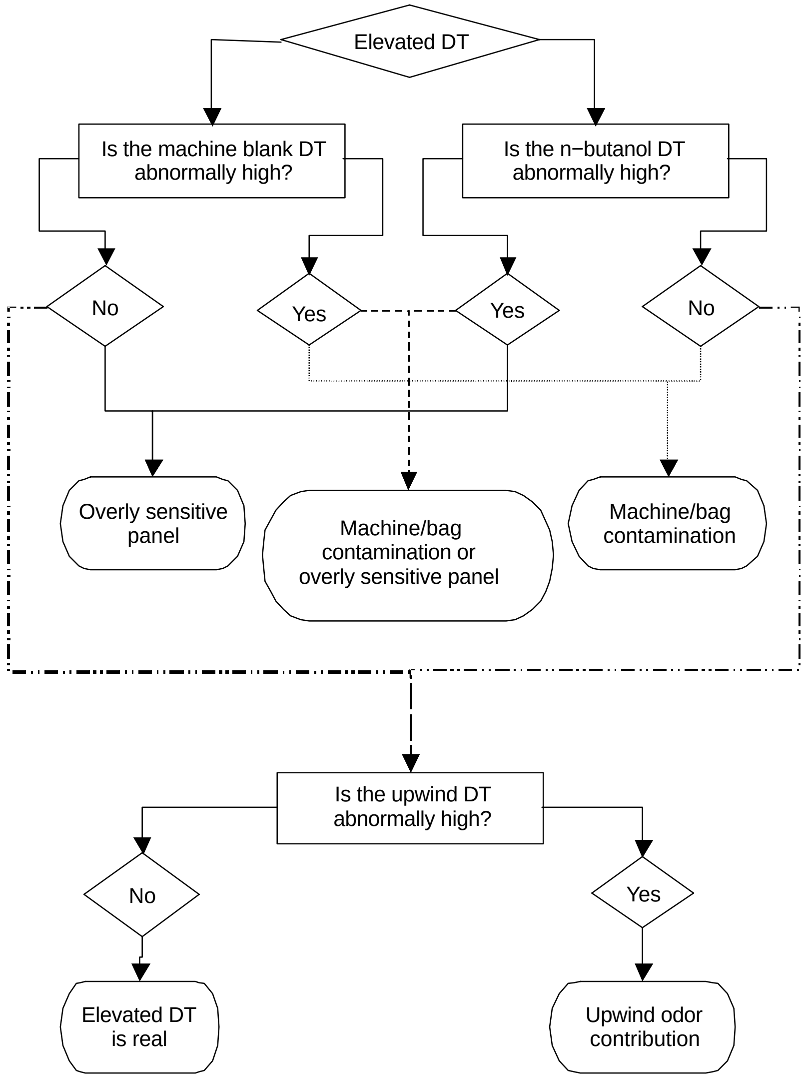

Figure 15. Decision tree used to evaluate the potential cause of elevated DTs.

Table 5. Summary of odor and weather conditions for four outliers with elevated DTs downwind of feedyard pens.

Outlier	Feedyard and Date	DT ($OU\ m^{-3}$) Upwind	DT ($OU\ m^{-3}$) Downwind	Hydrogen Sulfide (ppm) Upwind	Hydrogen Sulfide (ppm) Downwind	Manure Surface MC (%)	Air Temp. (°C)	Soil Temp. (°C)	Wind Speed ($m\ s^{-1}$)	7-day Precip. (cm)	Odor Character
1	B 24 July 2002	11	114	0.004	0.025	55.0	28.0	30.1	6.0	2.1	Feedyard (wet manure)
2	B 29 Aug. 2002	18	144	0.004	0.050	69.3	13.9	26.8	4.0	3.7	Feedyard (wet manure)
3	B 28 Apr 2003	70	166	0.008	0.034	7.0	27.0	27.1	4.5	0.15	Hot feed (pleasant)
4	C 30 Oct. 2002	16	665	0.002	0.050	46.1	2.0	8.4	5.8	6.2	Feedyard (wet manure)

Acknowledgements

This was a collaborative project supported by the Cooperative Research, Education, and Extension Team (CREET). Funding for this project was provided by the State of Texas Advanced Technology/Advanced Research Program (ATP/ARP) and the USDA-CSREES Air Quality-Texas special research project "Air Quality: Odor, Dust, and Gaseous Emissions from Concentrated Animal Feeding Operations in the Southern Great Plains."

References

Aneja, V. P., J. M. Overton, B. P. Malik, Q. Tong, and D. Kang. 2001a. Measurement and modeling of ammonia emissions at waste treatment lagoon atmospheric interface. *J. Water, Air, and Soil Pollution* 1: 177-188.

Aneja, V. P., B. J. Bunton, J. T. Walker, and B. P. Malik. 2001b. Measurements and analysis of atmospheric ammonia emissions from anaerobic lagoons. *Atmospheric Environ.* 35(11): 1949-1958.

ASTM. 2001a. E544-99: Standard practices for referencing suprathreshold odor intensity: Procedure B, static-scale method. In *Annual Book of ASTM Standards*. Philadelphia, Pa.: American Society of Testing and Materials.

ASTM. 2001b. E697-91: Standard practice for determining odor and taste thresholds by force-choice concentration series method of limits. In *Annual Book of ASTM Standards*. Philadelphia, Pa.: American Society of Testing and Materials.

Baek, B. H., A. J. Koziel, L. Kiehl, and J. P. Spinhirne. 2003. Estimation of ammonia and hydrogen sulfide fluxes and rates from cattle feedlots in Texas. ASAE Paper No. 034111. St. Joseph, Mich.: ASAE.

Bicudo, J. R., C. J. Clanton, D. R. Schmidt, W. Powers, L. D. Jacobson, and C. L. Tengman. 2004. Geotextile covers to reduce odor and gas emissions from swine manure storage ponds. *Applied Eng. in Agric.* 20(1): 65-75.

CAQCC. 1999. Regulation No. 2 (30 March 1999). Denver, Colo.: Colorado Air Quality Control Commission.

CEN. 2002. EN 13725: Air quality - Determination of odour concentration by dynamic olfactometry. Brussels, Belgium: European Committee for Standardization.

Chen, Y., D. S. Bundy, S. Hoff, and J. Steven. 1999. Using olfactometry to measure intensity and threshold dilution ratio for evaluating swine odor. *J. Air and Waste Management Assoc.* 49(7): 847-853.

Clanton, C. J., D. R. Schmidt, R. E. Nicolai, P. R. Goodrich, L. D. Jacobson, K. A. Janni, S. Weisberg, and J. A. Buckel. 1999. Dynamic olfactometry variability in determining odor dilutions-to-threshold. *Trans. ASAE* 42(4): 1103-1112.

Duyson, R., G. Erickson, D. Schulte, and R. Stowell. 2003. Ammonia, hydrogen sulfide, and odor emissions from a beef cattle feedlot. ASAE Paper No. 034109. St. Joseph, Mich.: ASAE.

Galvin, G., K. D. Casey, S. A. Lowe, N. A. Hudson, M. A. Atzeni, and E. J. McGahan. 2003. Spatial variability of odor emissions from anaerobic piggery lagoons in Queensland. In *Air Pollution from Agricultural Operations III: Proc. 3rd Int. Conf.* St. Joseph, Mich.: ASAE.

Gay, S. W., D. R. Schidt, C. J. Clanton, K. A. Janni, L. D. Jacobson, and S. Weisberg. 2003. Odor, total reduced sulfur, and ammonia emissions from animal housing facilities and manure storage units in Minnesota. *Applied Eng. in Agric.* 19(3): 347-360.

Heber, A. J., J. Q. Ni, and T. T. Lim. 2002. Odor flux measurements at a facultative swine lagoon stratified by surface aeration. *Applied Eng. in Agric.* 18(5): 593-602.

ISU/UM. 2000. Odor laboratory operating procedure. Revised September 2000. Ames, Iowa: Iowa State University, and Minneapolis, Minn.: University of Minnesota.

Koelsch, R. K., B. L. Woodbury, D. E. Stenberg, D. N. Miller, and D. D. Schulte. 2004. Total reduced sulfur concentrations in the vicinity of beef cattle feedlots. *Applied Eng. in Agric.* 20(1): 77-85.

Lim, T. T., A. J. Heber, J. Q. Ni, A. L. Sutton, and D. T. Kelly. 2001. Characteristics and emission rates of odor from commercial swine nurseries. *Trans. ASAE* 44(5): 1275-1282.

Mackie, R. I., P. G. Stroot, and V. H. Varel. 1998. Biochemical identification and biological origin of key odor components in livestock waste. *J. Animal Sci.* 76(5): 1331-1342.

Parker, D. B., M. B. Rhoades, J. Koziel, and J. Spinhirne. 2003. Background odors in Tedlar bags used for CAFO odor sampling. ASAE Paper No. 034144. St. Joseph, Mich.: ASAE.

Redwine, J., and R. Lacey. 2000. A summary of state odor regulations pertaining to confined animal feeding operations. In *Proc. Air Pollution from Agricultural Operations*, 33-41. St. Joseph, Mich.: ASAE.

Smith, R. J., and P. J. Watts. 1994. Determination of odour emission rates from cattle feedlots: Part 2. Evaluation of two wind tunnels of different size. *J. Agric. Eng. Research* 58(4): 231-240.

Sweeten, J. M. 1991. Odor and dust from livestock feedlots. Bulletin No. B-5011. College Station, Texas: Texas A&M University, Texas Agricultural Extension Service.

Sweeten, J. M. 1995. Odor measurement technology and applications: A state-of-the-art review. In *Proc. 7th International Symposium on Agricultural and Food Processing Wastes*, 214-229. C. C. Ross, ed. St. Joseph, Mich.: ASAE.

Sweeten, J. M., and J. R. Miner. 1993. Odor intensities at cattle feedlots in nuisance litigation. *Bioresource Tech.* 45(3): 177-188.

Sweeten, J. M., D. L. Reddell, A. R. McFarland, R. O. Gauntt, and J. E. Sorel. 1983. Field measurement of ambient odors with a butanol olfactometer. *Trans. ASAE* 26(4): 1206-1216.

TCFA. 2000. The impact of cattle feeding on the TCFA area economy. Amarillo, Texas: Texas Cattle Feeders Association. Available at: www.tcfa.org/impact.html. Accessed 12 January 2000.

Watts, P. J., M. Jones, S. C. Lott, R. W. Tucker, and R. J. Smith. 1994. Feedlot odor emissions following heavy rainfall. *Trans. ASAE* 37(2): 629-636.

Zhang, Q. 2001. Odour emissions from confined swine production. Winnipeg, Manitoba: University of Manitoba, Department of Biosystems Engineering. Available at: www.gov.mb.ca/agriculture/livestock/livestockopt/papers/zhang.pdf. Accessed 12 April 2003.

Zhu, J., L. D. Jacobson, D. R. Schmidt, and R. E. Nicolai. 1999. Daily variations in odor and gas emissions from animal facilities. ASAE Paper No. 994146. St. Joseph, Mich.: ASAE.