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Total Reduced Sulfur Concentrations in the Vicinity of Beef Cattle Feedlots

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TOTAL REDUCED SULFUR CONCENTRATIONS IN THE VICINITY OF BEEF CATTLE FEEDLOTS

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ABSTRACT. *A field survey of total reduced sulfur (TRS) concentrations in the vicinity of beef cattle feedlots was conducted to compare field observations against current regulatory thresholds. In addition, environmental factors that may contribute to increased TRS emissions were evaluated. It was observed that TRS levels in the vicinity of beef cattle feedlots are not likely to exceed current regulatory thresholds used by midwestern states. It was further noted that concentration of TRS varies with air temperature and time of day. However, wet feedlot surface conditions and wind speed had almost no impact upon observed concentrations.*

Keywords. *Hydrogen sulfide, Total reduced sulfur, Beef cattle feedlots, Air quality.*

Hydrogen sulfide (H_2S) and total reduced sulfur (TRS) emissions from livestock systems are increasingly being implicated with community health related concerns. Occupational health hazards for H_2S for those people working in totally confined animal housing and confined spaces associated with manure storage have long been recognized. The American Conference of Governmental Industrial Hygienists (ACGIH) has established occupational exposure limits for H_2S at 10 parts per million (ppm) time weighted average concentration for a conventional 8-h work day and 15 ppm for any 15-min period. However, community exposure to ambient levels of H_2S has gained increasing scrutiny in recent years. The Agency for Toxic Substances and Disease Registry, the federal agency charged with evaluating possible general public health risks from chemicals released at wastes sites has recently published recommended Minimal Risk Levels for H_2S in the range of 0.03 to 0.07 ppm corresponding to 15- to 364- and 1- to 14-day durations of exposure, respectively.

In 1997, the Nebraska Department of Environmental Quality amended its Title 129 Air Quality Regulations to establish a regulatory threshold for Total Reduced Sulfur (TRS) concentrations under ambient conditions. Two noncompliance thresholds were set by these rules. Observations exceeding 1) 10.0-ppm maximum 1-min average concentration or 2) 0.10-ppm maximum 30-min rolling average are out of compliance. Following the adoption of these rules, two agricultural regions of Nebraska with significant cattle finishing in open feedlots came under scrutiny for possible rule violations. In one situation, area feedlots were asked to prepare and implement a TRS control plan. The development of air quality standards in Nebraska and other states and their application to animal agriculture has prompted the need for understanding TRS concentrations in the vicinity of livestock facilities.

OBJECTIVES

The intent of this research is to:

- compare field observations from the vicinity of beef cattle feedlots against current regulatory thresholds for Nebraska (0.1 ppm TRS ½-h average), Minnesota (0.05 ppm H_2S ½-h average), and Iowa (proposed to be 0.07 ppm H_2S 1-h average);
- identify environmental factors that influence TRS concentration.

This article summarizes field observations of average TRS concentrations, number of observations exceeding regulatory threshold values, and observed relationships between TRS levels and time of day, air temperature, and feedlot surface moisture conditions.

LITERATURE REVIEW

Hydrogen sulfide is colorless, heavier than air, and has a characteristic rotten egg odor. High concentrations of H_2S are toxic to humans and animals. Concentrations of 50 ppm cause dizziness and other health while levels of instantaneous 1,000 ppm cause respiratory paralysis and death with little or no warning. Historically, workplace threshold limits are set at 10 ppm (ACGIH, 1996) over an 8-h day.

More recently, concerns are being raised about long-term exposure of neighbors of confined livestock operations to substantially lower rates. Schiffman et al. (2001) reported that a low concentration of H_2S and other gases and bio-aerosols associated with animal agriculture can potentially impact human health. The odor detection threshold of H_2S is 30 ppb or less for 83% of the population and concentrations of less than 40 ppb annoy 50% of the population (Collins and Lewis, 2000). Increased self-re-

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ported health symptoms have been observed for ambient air containing H_2S between 7- and 27-ppb annual average (Legator et al., 2001). To minimize these health concerns, the Agency for Toxic Substances and Disease Registry (ASTDR) has established an intermediate (15- to 364-day exposure) and an acute (1- to 15-day exposure) inhalation minimum risk level of 30- and 70-ppb daily average exposure, respectively (ATSDR, 1999).

Exposure to low H_2S concentrations has been the basis for property line or ambient air based H_2S regulation. Janni et al. (2001) identified 27 states that regulate H_2S or TRS levels. A property line concentration in the range of 30 and 100 ppb over a 30- to 60-min averaging time is a common regulatory threshold (Janni et al., 2001).

Methionine, a common amino acid in many feedstuffs, is the origin of many sulfur-related odors (Hobbs and Pain, 1995). Sulfate compounds in the urine originate from degradation of protein sources such as methionine. Degradation of sulfate in the urine by sulfate reducing bacteria produces the odorous sulfides and mercaptans (Spoelstra, 1980). A reduced crude protein diet supplemented with synthetic amino acids, including methionine, to meet but not exceed animal protein needs reduces room aerial H_2S concentrations by 40% (Kendall et al., 1998). Arogo et al. (2000) observed that initial sulfate concentration in the manure impacted H_2S production and suggested that reducing sulfate concentration in the water supply would also reduce sulfide production.

In addition, many environmental and management factors affect the release or concentration of H_2S. Heber and Heyne (1999) observed that H_2S levels as measured at a property line for a wean-to-finish swine facility were twice as high at night as during the day and that high wind speeds (greater than 29 km/h) increased emission rates from a lagoon surface. Installation of a geotextile/straw cover reduced H_2S levels to 13% of mean concentrations observed prior to installation (Heber and Heyne, 1999). Average H_2S emissions from manure storage facilities for swine finishing operations was reported to range from less than 5 to 30 $\mu g/(m^2\text{-}s)$ for a storage surface with a natural crust to 20 to almost 100 $\mu g/(m^2\text{-}s)$ for a storage surface lacking a natural crust (Bicudo et al., 2001). Agitation of pit swine manure causes substantial short-term increases in H_2S emissions concentrations (Tengman, 2001).

A growing database on H_2S concentration and emission rates for swine facilities is available (Ni et al., 2000; Zhu et al., 2000; Zahn et al., 2001; Parbst et al., 2000; Wood et al., 2001). A limited database is available for cattle facilities. Zhu et al. (2000) reported H_2S concentrations in dairy buildings ranging from 8 to 26 ppb as compared to levels in swine nursery and gestation buildings ranging from 500 to 3400 ppb. A mean H_2S emission rate of 1.72 $\mu g/(m^2\text{-}s)$ was reported for open lot beef facilities as compared to 14 $\mu g/(m^2\text{-}s)$ for swine finishing barns in Minnesota (Wood et al., 2001). Carlisle (1998) observed H_2S measurement at the property line of one Texas cattle feeding operation and reported a maximum 30-min concentration of 6 ppb as compared to a maximum of 10 to 43 ppb for six swine operations.

Measurement of H_2S is possible with an indicator or diffusion tube (1000 ppb and greater), Jerome meter (3 ppb and greater), or MDA Scientific single-point monitors (2 to 90 ppb) (Jacobson et al., 2001). Winegar and Schmidt (1998) observed that the Jerome 631-X portable H_2S unit's 'gold film sensor is affected by sulfides other than H_2S.' They further suggest 'field testing for mixed sulfides by collecting field data with the Jerome 631-X (and reporting) as total sulfides.' The study further reported a reliable detection level of 1 ppb and excellent agreement between the Jerome meter and GC standard methods over a range of 0 to 40,000 ppb ($R^2 = 0.9998$, slope = 0.9832).

A single gas, as an indicator of odors, is a common pursuit of recent research. O'Neill and Phillips (1992) list 15 sulfide compounds and 9 mercaptans that are among the 160 compounds identified in animal waste or air around livestock buildings. This reports further notes that six of the 10 compounds with the lowest odor detection threshold contain sulfur. Guo et al. (2000) identified a correlation coefficient of $r^2 = 0.569$ (1152 air samples from 260 sources on 80 Minnesota livestock and poultry farms) and concluded that H_2S is a generally a poor odor indicator but has value for species and facility specific situations. Jacobson et al. (1997) and Fakhoury (2000) also noted low correlation coefficients between H_2S concentration and odor. Williams (1984) suggests that sulfide is a misleading indicator of offensiveness of odor from pig slurry during anaerobic treatment but is a useful indicator during post-treatment storage.

PROCEDURES

A field study was implemented to provide an understanding of TRS concentrations in the vicinity of feedlots. Two Jerome 631-S analyzers with memory modules and a dynamic range of 1 ppb to 50 ppm were used to measure TRS concentrations at 15-min intervals approximately 1 m from the ground surface. An on-site meteorological weather station (MicroMet Station) was used to measure wind speed, wind direction, air temperature, barometric pressure, and relative humidity at 15-min intervals.

The data presented in this article are described as TRS concentration and represented as an H_2S equivalent measure. The Jerome meter measures H_2S, alkyl sulfides, disulfides, mercaptans, and cyclic sulfur compounds. Winegar and Schmidt (1988) reported that the response of the Jerome 631-X meter was 100% to H_2S and 0% to 45% to 11 other reduced sulfur gases when exposed to calibrated mixtures. They further suggested that the meter response is expressed as an H_2S equivalent. A comparison of a Jerome meter reading (measuring an H_2S equivalent) against a TRS based regulatory standard produces a conservative (high) estimate if most of the TRS is in the form of H_2S. TRS, reported as elemental sulfur, has a molecular weight of 32.050 while H_2S has a molecular weight of 34.076 (Bolz and Tuve, 1973). In situations where H_2S is the dominant TRS, this overestimate is small or negligible.

A field study was conducted on three feedlots for one-week periods each under spring, summer, and fall conditions during 2000. During this investigation, sampling was completed at the following locations:

- Perimeter observations were conducted with the Jerome meter upon arrival, departure, and at equipment checks during the one-week sampling period (fig. 1). Single TRS measurements were taken at 0.2-mile intervals on all four township mile lines surrounding the feedlot during each visit. This data was typically collected during daylight hours. A total of 14 or 15 independent measures of TRS concentration were made at each 0.2-mile interval location.

- Within the feedlot, data were collected near the center of the feedlot among the animal pens and at the downwind edge of the feedlot and the runoff holding pond. The downwind feedlot and holding pond edge locations were selected based upon prevailing wind conditions for the nearest local weather station. All data from a downwind measurement location were included in the analysis, not just the data collected when the wind was blowing from the facility toward the meter. Typically, one Jerome meter was located at the center of the feedlot for the entire week and the second meter was moved among the three locations at two-to three-day intervals. Measurements were made at 15-min intervals at these three locations.

A second survey was conducted in 2001 to identify environmental factors that increased the emission of TRS. Two 9-week surveys were conducted during the spring

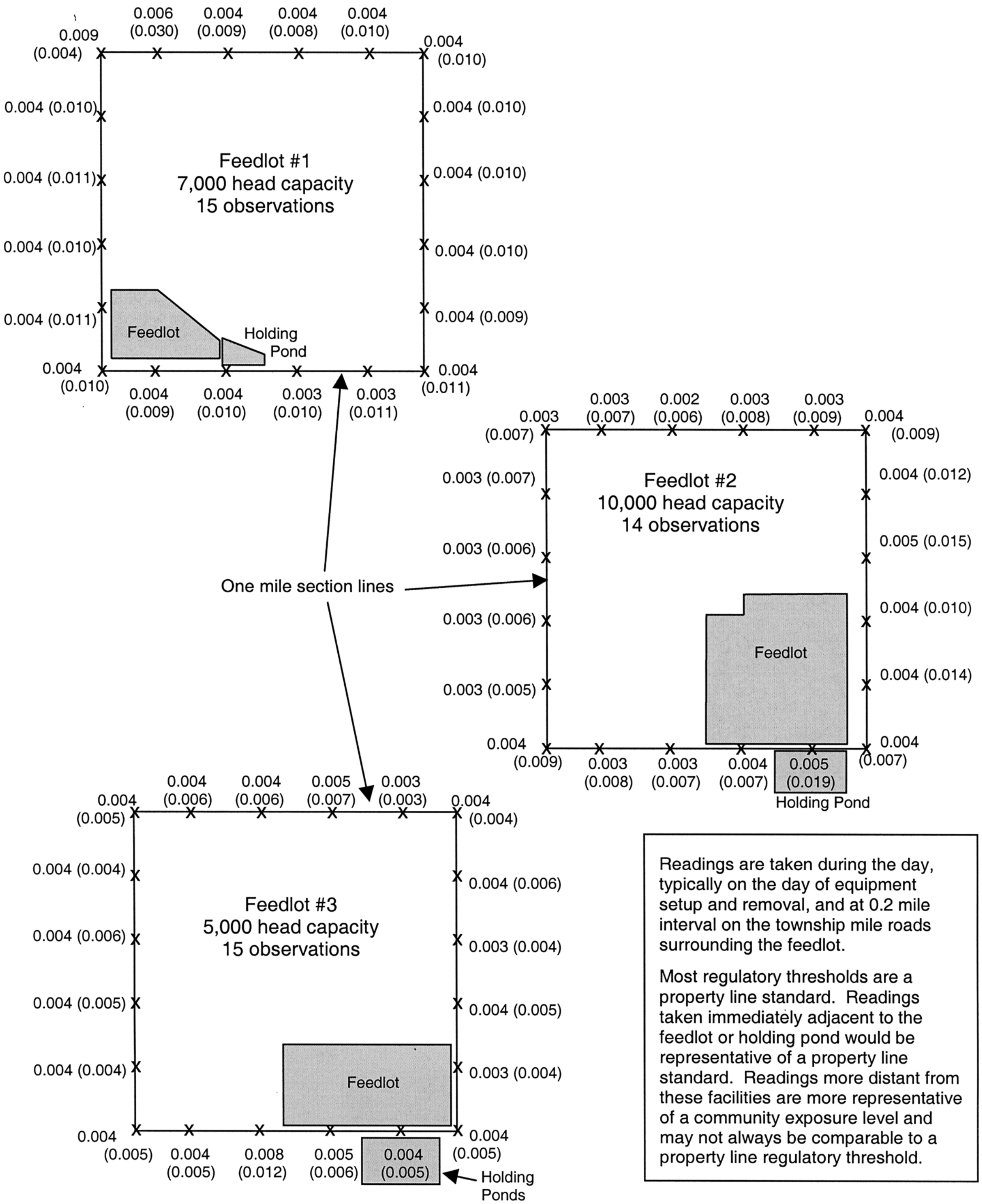

Figure 1. Summary of average (and maximum) TRS observations at perimeter of feedlots (ppm). Each observation represents a single point in time. TRS is expressed as an equivalent H_2S concentration.

(4 April through 9 June) and summer (9 July through 12 September) of 2001 at a single location at the center of one feedlot with one Jerome meter. During the sampling period, on-site weather data were collected at 15-min intervals and were matched with TRS observations collected at similar time intervals.

To evaluate field observations against regulatory thresholds, three state regulations were used:

- Nebraska: Property line TRS concentrations shall not exceed 10.0-ppm maximum, 1-min average concentration or 0.10-ppm maximum, 30-min rolling average. A single Jerome meter reading was compared against the 1-min average threshold. A rolling average of three consecutive Jerome meter readings taken at 15-min intervals and compared against the 30-min threshold. The rolling average was recalculated every 15 min using the new data value and the two previous data values.
- Minnesota: H_2S concentrations shall not exceed 0.03 ppm for a 30-min average concentration (twice in 5 days) or a 0.05 ppm for a 30-min average concentration (twice per year). The second standard (0.05 ppm) was used for comparisons following the same procedure as used for the Nebraska 30-min threshold.
- Iowa (proposed rule): Property line H_2S concentrations shall not exceed 0.07 ppm for a 1-h time weighted average (Merchant and Ross, 2002). A rolling average of five consecutive Jerome meter readings taken at 15-min intervals was compared against the 1-h time weighted average threshold. It is important to note the difference in time for calculating a weighted average for the Iowa standard versus the Minnesota and Nebraska standard and the potential for those time differences to cause perceived irregularities in results.

Results

Perimeter Observations

To determine the impact of feedlot TRS emissions on the community, a survey of neighborhood concentrations was completed on the township mile lines surrounding the feedlot. Those observations are summarized in figure 1. The average TRS levels at these locations ranged from 0.002 to 0.006 ppm (average of 14 to 15 single point observation) for all three feedlots. The peak observation was 0.030 ppm. The 0.030-ppm reading was observed at a location approximately 1 mile from the feedlot and based upon other observations and readings at nearby locations, it appeared to be an isolated observation not related to the feedlot. Other higher than normal values were from locations directly adjacent to the feedlot facilities. Two cautions should be noted when comparing these perimeter values against regulatory standards. First, all readings were taken during daylight hours. Higher concentrations are more likely during the night. Second, all perimeter observations represent single points in time measures while most regulatory thresholds are for 30- to 60-min running averages. Although the perimeter observations provide an incomplete understanding of community exposure to TRS, none of the observations made would suggest non-compliance with regulatory thresholds of the three states.

Very little variation in average TRS levels was observed for perimeter measurements more distant from the feedlot compared to those immediately adjacent to the feedlot. Average TRS levels on locations immediately adjacent to the feedlots was within 0.002 ppm of the averages observed at more distant locations. Although no specific measures of background TRS levels were made, the lack of variation on the 1-mile perimeter roads around the feedlots would suggest that these observations are near a background level. The perimeter observations provided no indications of TRS levels that might exceed regulatory thresholds.

Downwind monitoring at the edge of the feedlot and holding pond (total of 3900 observations collected - table 1) provides a worst-case estimate of potential property line TRS concentrations. Only two observations exceeded Nebraska's 10 ppm, 1-min standard, both at the edge of the holding pond. The 30-min running averages exceeded Nebraska's 0.1 ppm, 30-min standard on 36 occasions (15 and 21 occurrences at the edge of the feedlot and holding pond, respectively). The proposed Iowa (0.070 ppm, 60-min average) and the Minnesota standard (0.030 ppm, 30-min average) were exceeded by the calculated 30- or 60-min running averages for the feedlot and holding pond down wind edges 47 and 88 times, respectively. Few differences were observed among the three feedlots. Average TRS concentrations were similar among feedlots with most averages being less than 0.01 ppm. Frequency of observations exceeding regulatory thresholds was also similar.

The calculated running average from this study was based upon only three (for Minnesota and Nebraska comparisons) and five data points (for Iowa comparison) allowing a single large TRS value to heavily influenced the computed running averages. No situations were observed where three or five consecutive readings exceeded any of the regulatory standards (see three or five consecutive observations > threshold in table 1). Single uniquely high TRS data points caused the running average values to often surpass regulatory threshold values although sustained high TRS levels were very uncommon.

Feedlot Center Observations

At the center of the feedlot, spikes in TRS concentration that exceeds a property line threshold were common, but sustained TRS levels in excess of the three regulatory standards were extremely rare. More than 17,800 instantaneous observations were made at the center of all feedlots (table 1). Sixty-two single point observations exceeded a 0.1-ppm level. However, even at the center of the feedlot, sustained TRS levels exceeding the 0.1-ppm (30-min time averaging) and 0.07-ppm (60-min time averaging) regulatory thresholds were very infrequent (two and six occurrences, respectively). However, the Minnesota standard (0.5 ppm for 30-min time average) was more commonly surpassed. Sustained concentrations exceeding the 0.1 and 0.07 ppm standard (see three or five consecutive observations section in table 1) were extremely rare while 20 periods of sustained concentrations above the Minnesota standard were observed (0.1% of observations). All occurrences were from feedlot 2. The feedlot surface would not appear to be a sustained source of TRS that might lead to property line regulatory concerns.

Several environmental factors have the potential to impact TRS concentrations. TRS levels increased linearly with air temperature between 0°C and 35°C (fig. 2). Increased soil temperatures should contribute to increased soil microbial activity and greater production of volatile sulfur compounds. Soil temperature, not measured in this experiment, would be expected to track changes in air temperature.

Wind speed generally impacts gas emissions concentrations. With increased wind speed causing increased atmospheric instability and greater mixing of feedlot emissions with fresh air, lower concentrations of TRS would be

Table 1. Summary of TRS[a] observations within three Nebraska feedlots.

	Feedlot No. 1			Feedlot No. 2			Feedlot No. 3					
	Spring 2000	Summer 2000	Fall[b] 2000	Spring 2000	Summer 2000	Fall 2000	Spring 2000	Summer 2000	Fall 2000	Spring 2001	Summer 2001	Total
Center of Feedlot												
Single observations:												
> 10 ppm	0	0	0	0	0	0	0	0	0	0	0	0
> 0.1 ppm	6	3	0	17	3	10	1	13	3	3	3	62
> 0.07 ppm	7	3	0	25	3	21	1	13	3	3	3	82
> 0.05 ppm	9	3	0	46	3	40	1	14	3	3	3	125
Running average[c]:												
> 0.1 ppm (30-min)	6	0	0	21	1	2	0	8	3	0	0	41
> 0.07 ppm (60-min)	5	0	0	3	3	11	0	16	5	0	0	43
> 0.05 ppm (30-min)	16	6	0	51	8	34	3	33	3	6	3	153
Consecutive observations (3 or 5):												
> 0.1 ppm (3)	0	0	0	2	0	0	0	0	0	0	0	2
> 0.07 ppm (5)	0	0	0	0	0	0	0	0	0	0	0	6
> 0.05 ppm (3)	0	0	0	14	0	6	0	0	0	0	0	20
Average TRS concentration[a]	0.012	0.012	0.001	0.028	0.015	0.009	0.007	0.014	0.002	0.006	0.008	
Number of observations	907	320	187	911	253	640	1246	558	854	5803	6117	17,796
Feedlot Downwind Edge												
Single observations:												
> 10 ppm	0	0	0	0	0		0	0				0
> 0.1 ppm	9	1	0	1	4		0	4				19
> 0.07 ppm	9	1	0	1	4		0	4				19
> 0.05 ppm	12	3	0	1	4		0	4				24
Running average[c]:												
> 0.1 ppm (30-min)	9	0	0	0	0		0	6				15
> 0.07 ppm (60-min)	10	0	0	0	14		0	5				29
> 0.05 ppm (30-min)	24	3	0	0	10		0	10				47
Consecutive observations (3 or 5):												
> 0.1 ppm (3)	0	0	0	0	0		0	0				0
> 0.07 ppm (5)	0	0	0	0	0		0	0				0
> 0.05 ppm (3)	0	0	0	0	0		0	0				0
Average TRS concentration[a]	0.013	0.009	0.000	0.007	0.006		0.008	0.008				
Number of observations	251	343	462	184	459		188	180				2067
Holding Pond Downwind Edge												
Single observations:												
> 10 ppm	1	0		0	1	0	0	0				2
> 0.1 ppm	2	2		1	0	0	1	3				9
> 0.07 ppm	2	2		2	0	0	1	3				10
> 0.05 ppm	2	2		4	0	0	18	6				30
Running average[c]:												
> 0.1 ppm (30-min)	6	3		0	9	0	3	0				21
> 0.07 ppm (60-min)	10	5		0	0	0	3	0				18
> 0.05 ppm (30-min)	6	3		3	10	0	10	9				41
Consecutive observations (3 or 5):												
> 0.1 ppm (3)	0	0		0	0	0	0	0				0
> 0.07 ppm (5)	0	0		0	0	0	0	0				0
> 0.05 ppm (3)	0	0		0	0	0	0	0				0
Average TRS concentration[a]	0.010	0.009		0.009	0.014	0.002	0.012	0.008				
Number of observations	228	255		355	229	353	283	185				1,888

[a] TRS is reported as parts per million H_2S equivalent .
[b] Most observations occurred after a six-inch blowing snow.
[c] A running average of three consecutive observations at 15-min intervals were compared against the 30-min rolling average threshold for Nebraska and Minnesota. A running average of five consecutive readings were used to approximate the 60-min rolling average threshold of Iowa.

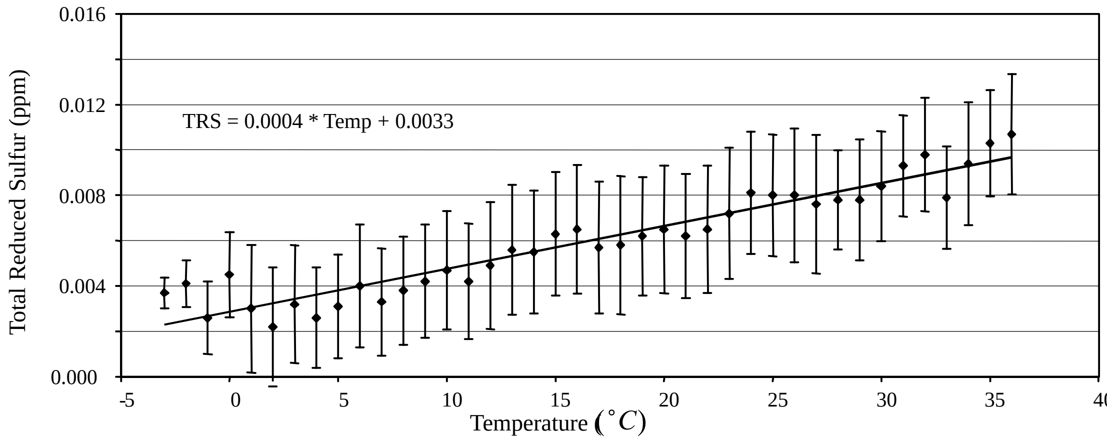

Figure 2. Average TRS concentration (± 1 standard deviation) vs. air temperature for feedlot no. 3 during spring 2001. TRS is reported as H_2S equivalent.

anticipated. However, mean TRS concentrations at the center of the feedlot showed little variation with increases in wind speed measured at 1 m above the feedlot surface (fig. 3).

A strong diurnal pattern was observed for TRS concentration (fig. 4). Peak concentrations were observed during mid-afternoon and the lowest concentrations occurred during early morning hours. Afternoon concentrations were approximately twice those concentrations observed during the early morning. Several factors would likely impact daily TRS concentrations. Typically, wind speed and stability of the air influences dilution of gas emissions. However, timing of conditions that produce the least (evening conditions) and greatest (mid-day condition) dilution did not match with the timing of the high and low TRS concentrations observed. Other factors as opposed to air mass stability must be influencing the observed diurnal pattern.

Soil temperature and animal activity may provide a more plausible explanation of this diurnal pattern. Soil surface temperature, which impacts microbial action and TRS production, would increase during daylight and decline during the night similar to the pattern observed for TRS. Figures 1 and 5 provide additional indications that TRS level are related to air temperature. Animal activity would tend to increase during the morning hours as a result of feeding practices and during late afternoon and evening hours as evening temperatures cool. The late afternoon TRS peak is at a similar time to the late afternoon peak in animal activity. Peaks in animal activity are commonly correlated with feedlot dust emissions (Auvermann, 2001). Thus, soil temperature and animal activity are more likely factors contributing to the observed diurnal TRS levels at the feedlot's center.

It was anticipated that feedlot surface moisture level would influence TRS concentration. Wet feedlot conditions, conducive to bacterial activity, and anaerobic conditions should result in greater TRS production. Feedlot surface conditions in Nebraska vary dramatically based upon weather conditions. The extended sampling during the spring and summer of 2001 was conducted in hopes of capturing the effects of volatile sulfur production under muddy feedlot surface conditions.

Six rainfall events occurred during the spring and summer 2001 sampling periods. TRS levels between 3 days before and 6 days after significant (>15 mm) rainfall events are summarized in table 2. For much of the early spring 2001, wet feedlot conditions were common. Summer feedlot surface conditions were typically very dry with short wet periods following a rainfall event. The TRS concentration for the

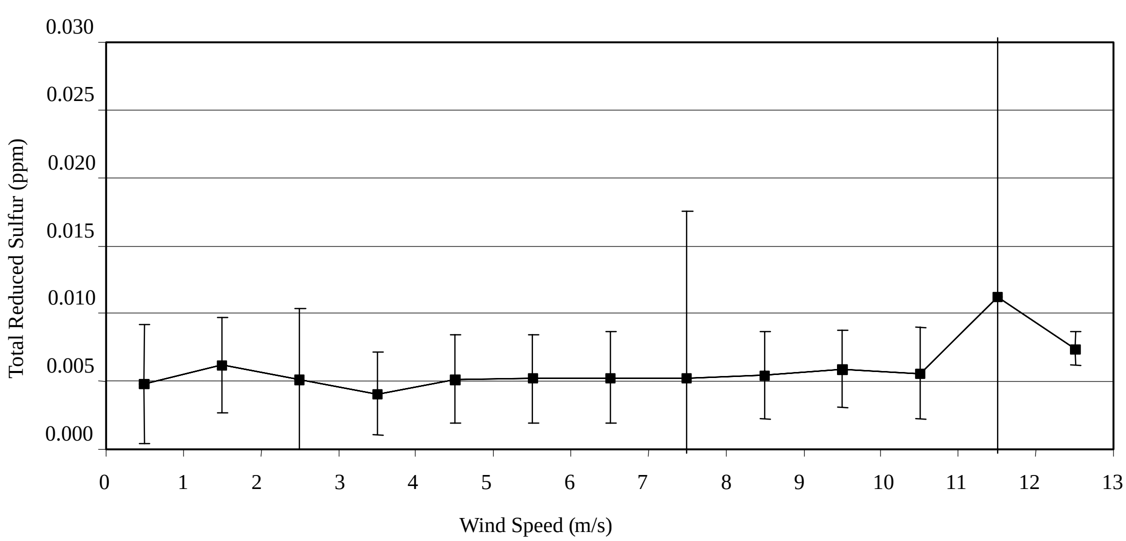

Figure 3. TRS concentration (reported as an H_2S equivalent) at various wind speeds on feedlot no. 3 during spring 2001.

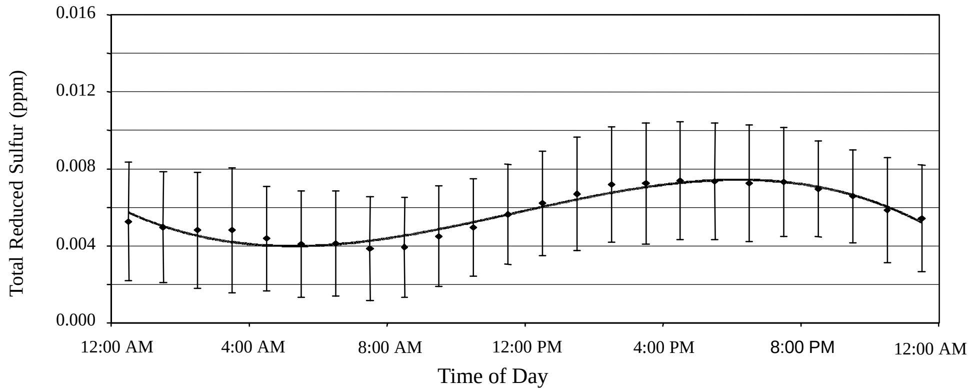

Figure 4. Average TRS concentration (reported as an H_2S equivalent) vs. time of day for feedlot no. 3 during spring 2001.

days following rainfall events did not rise above the levels observed prior to or on the day of rainfall events (see fig. 5 and table 2). No increase in TRS levels could be attributed to wet feedlot conditions.

Discussion

Based upon TRS observations at the prevailing downwind edge of the feedlot and holding pond as well as those on the one-mile lines surrounding the feedlots, it appears unlikely that feedlots produce sufficient TRS to exceed regulatory thresholds for Nebraska, Iowa, or Minnesota. However, peak concentrations occasionally exceeded regulatory levels for these states where the feedlot or holding pond facilities are located at a property line. These peak concentrations produced several 30- or 60-min running averages that exceeded these regulatory thresholds. However, this study's computation of a 30- or 60-min running average based upon only three or five data points, allowed a single peak reading to produce a running average in excess of a regulatory threshold. With extremely few exceptions, these peak concentrations are not sustained over a 30- or 60-min period. Sustained levels of TRS at the perimeter of the feedlot and holding pond above any of the three state regulatory thresholds were rare, including the more stringent Minnesota regulation.

A comparison of TRS observations at the perimeter (downwind feedlot and holding pond edge) and within the community (1-mile township roads) with established health risk levels reveals little reason for concern. The minimum risk levels for intermediate (0.030 ppm for 15 to 364 day) and acute exposures (0.07 ppm for 1 to 15 day) defined by ATSDR were not exceeded at any of the three feedlots.

One weakness of this study is that community concentrations of TRS (made on the mile lines surrounding the feedlot) represent a limited number of observations made during the day. Typically, the atmospheric conditions are least stable during daytime conditions resulting in greater dispersion of any gaseous emissions and lower concentration. Higher nighttime concentrations would be anticipated. However, observations at the edge of the feedlot and holding pond which were made continuously at 15-min intervals provided no indication of a sufficient source of TRS to cause significant changes in TRS observations in the community.

Emissions from the feedlot surface where cattle are contained appear to be a minor source of TRS. Single high observations (above 0.1 ppm) were commonly observed at the center of the feedlot, but these elevated levels were not sustained. It may be possible that short bursts of TRS are

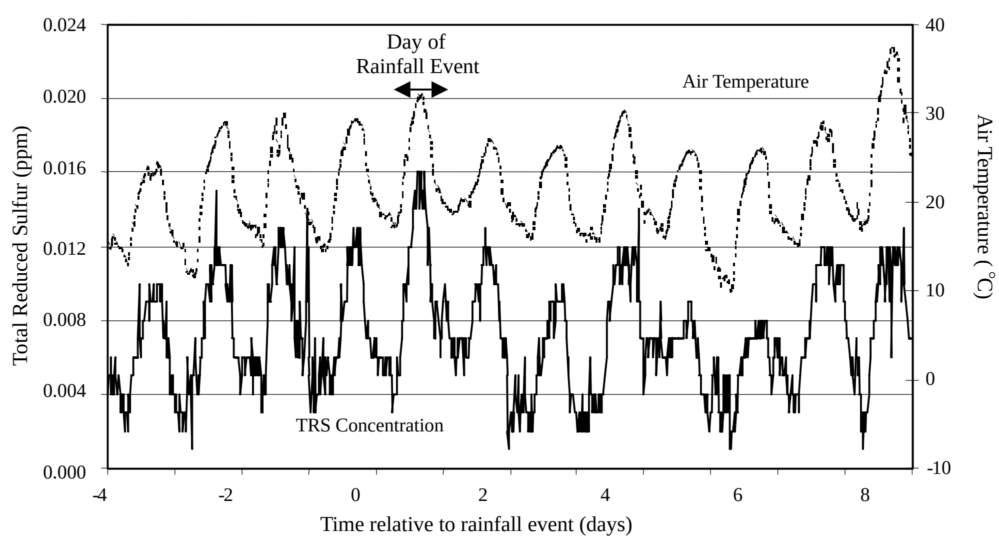

Figure 5. Impact of rainfall on TRS concentration (reported as an H_2S equivalent) for feedlot no. 3 (Event 5, 10-21 August).

Table 2. Summary of daily TRS[a] level relative to rainfall events at feedlot no. 3 in 2001.

Day Relative to Rainfall Event	Event 1		Event 2		Event 3		Event 4		Event 5		Event 6	
	7 to 16 April		1 to 10 May		17 to 26 May		27 May to 5 June		11 to 20 Aug.		20 to 29 Aug.	
	Rainfall (mm)	Average TRS (ppm)	Rainfall (mm)	Average TRS (ppm)	Rainfall (mm)	Average TRS (ppm)	Rainfall (mm)	Average TRS (ppm)	Rainfall (mm)	Average TRS (ppm)	Rainfall (mm)	Average TRS (ppm)
-3	0.4	0.004	0.8	0.007		0.008		0.008		0.007		0.008
-2	0.1	0.003	14.9	0.006		0.007		0.007		0.008		0.008
-1		0.004	5.2	0.006	1.2	0.007	9.6	0.006		0.007		0.007
0	16.0	0.002	72.9	0.004	17.7	0.007	40.4	0.007	26.0	0.009	20.0	0.007
1	5.8	0.003	9.1	0.007		0.007		0.007		0.008		0.007
2		0.003		0.007	0.7	0.007	0.1	0.006		0.005		0.006
3		0.002		0.004		0.006		0.006		0.007		0.006
4		0.003			0.2	0.005	17.9	0.007		0.006		0.007
5						0.007	2.2	0.003		0.005		0.007
6	0.2	0.007				0.008	1.2	0.006		0.008		0.006

[a] TRS concentrations are reported as an H_2S equivalent. See Procedures section.

emitted from the feedlot surface, but that these bursts are not sustained. As a result, average TRS levels even at the center of the feedlot were fairly low, ranging from 0.006 to 0.037 ppm. The cause of these short periods of high TRS levels is unknown. Variation in animal activity in the vicinity of measurement point might be one explanation for these high short-term TRS levels. If true, future efforts to measure emissions rate for various gases from the feedlot surface should attempt to capture the animal activity factor as part of the emission measurement. Animal activity is known to be a critical factor in dust emissions (Auvermann, 2001).

Air temperature was the only observed environmental factor to which TRS concentration was correlated based upon observations at the center of the feedlot. Increases in temperature produced an increased TRS level. Daily TRS patterns also closely followed daily air temperature patterns. Future efforts to measure emissions rate for various gases from the feedlot surface should also measure feedlot surface or soil temperatures.

A strong diurnal pattern in TRS concentration was observed. It follows a similar pattern as air temperature. It is anticipated that increased soil temperature enhances fermentation processes, thus impacting the production and release of what little TRS there was. Animal activity level may also provide some explanation for higher afternoon TRS levels. If other gaseous and odor emissions follow similar patterns to TRS, it will be important to recognize this diurnal pattern in emission rate measurements.

TRS levels were scrutinized during the periods immediately following rainfall events for increased TRS concentrations, but no measurable increase in TRS was observed. Rainfall events should have stimulated anaerobic decomposition and produced fermentation products that sulfate-reducing bacteria (SRB) utilize. It is likely that a combination of environmental factors limit the abundance and activity of SRB at cattle feedlots, which accounts for the low H_2S concentrations after rainfall events. The feedlot soil is a very dynamic environment experiencing extremes in moisture, temperature, and substrate availability, which likely select against SRB. In general, SRB are strictly anaerobic microorganisms that require relatively simple substrates, such as lactate, short-chain VFA, and alcohols (Widdel, 1988), but are unable to compete with faster-growing fermentative microorganisms for more complex substrates (polysaccharides and proteins) that comprise manure (Miller and Varel, 2001). A combination of factors including substrate availability, oxygen intolerance, and moisture and temperature extremes would limit SRB activity and control sulfate reduction in the cattle feedlot soils thus explaining the lack of increase in TRS concentrations following rainfall events.

CONCLUSIONS

Based upon the observations made in this study of total reduced sulfur (TRS) concentrations (expressed as a hydrogen sulfide equivalent) in the vicinity of cattle finishing feedlots, the following conclusions were drawn:

- Sustained levels of TRS at the township mile lines and prevailing downwind edge of the feedlot and holding pond above the regulatory thresholds for Nebraska, Iowa (proposed), and Minnesota, were extremely rare. TRS concentrations in the vicinity of beef cattle feedlots are unlikely to exceed common regulatory thresholds or health risk levels identified by ATSDR.
- TRS levels increase linearly with increasing air temperature. It is anticipated that warming of feedlot surface is partially responsible for the increased production of TRS.
- A diurnal pattern was observed for TRS concentrations with peak levels occurring in mid-afternoon. This pattern is also likely attributable to varying feedlot surface temperature and possibly animal activity.
- TRS level was not influenced by rainfall events or wind speed. Transiently wet feedlot surface conditions do not appear to increase TRS emissions.

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