Potentially hazardous sulfur conditions on beef cattle ranches in the United States

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Objective—To analyze the sulfur content of water and forage samples from a geographically diverse sample of beef cow-calf operations in the United States and to estimate frequency and distribution of premises where forage and water resources could result in consumption of hazardous amounts of sulfur by cattle.

Design—Cross-sectional study.

Sample Population—709 forage samples from 678 beef cow-calf operations and individual water samples from 498 operations in 23 states.

Procedure—Sulfur content of forage samples and sulfate concentration of water samples were measured. Total sulfur intake was estimated for pairs of forage and water samples.

Results—Total sulfur intake was estimated for 454 pairs of forage and water samples. In general, highest forage sulfur contents did not coincide with highest water sulfate concentrations. Overall, 52 of the 454 (11.5%) sample pairs were estimated to yield total sulfur intake (as a percentage of dry matter) ≥ 0.4%, assuming water intake during conditions of high ambient temperature. Most of these premises were in north-central (n = 19) or western (19) states.

Conclusions and Clinical Relevance—Results suggest that on numerous beef cow-calf operations throughout the United States, consumption of forage and water could result in excessively high sulfur intake. All water sources and dietary components should be evaluated when assessing total sulfur intake. Knowledge of total sulfur intake may be useful in reducing the risk of sulfur-associated health and performance problems in beef cattle. (*J Am Vet Med Assoc* 2002;221:673–677)

Economically viable ranching in the United States depends on optimal use of available resources to promote reproduction, growth, and maintenance of ruminant livestock. The forage base of a ranching operation is a core resource that determines the overall success of the nutrition program. Inadequate nutrition and overnutrition can both negatively affect reproduction of livestock, whereas an inappropriate nutrient balance, nutrient deficiencies, and various toxicoses can adversely affect health and performance. To optimize the use of resources, it is necessary to exploit those that are advantageous and avoid those that have adverse effects. Ultimately, such an approach promotes long-term profitability and sustainability. Because approximately two thirds of annual maintenance costs for beef cows are attributable to nutrition,[1] this is a key area for production efficiency and profitability.

High sulfur intake can adversely affect ruminants in 2 ways. First, ruminal reduction of sulfur produces intermediates that complex with copper and result in decreased absorption and use of copper.[2] This secondary copper deficiency results in impaired reproduction and performance. Second, sulfate and other nontoxic forms of sulfur are reduced by ruminal microbes to hydrogen sulfide and its ionic forms, which are highly toxic substances that interfere with cell respiration.[3-5] The capacity of ruminal microbes to generate hydrogen sulfide increases under conditions of high dietary sulfate intake, and sulfate-reducing microorganisms are associated with this conversion process.[6,7]

In previous studies,[8-10] steers fed a high-sulfate diet (≥ 0.38% sulfur on a dry matter basis) developed polioencephalomalacia, an important neurologic disorder of ruminants.[11] The onset of polioencephalomalacia was associated with episodes of excessive ruminal hydrogen sulfide production,[8,9,12] which led to the general hypothesis that under conditions of high total sulfur intake, regardless of the source (eg, water, forage, and feed ingredients or additives), excessive ruminal production of hydrogen sulfide is a hazard to ruminants.[13]

Overall, it appears that many sulfur sources may be important in ruminal hydrogen sulfide production and development of polioencephalomalacia. For instance, polioencephalomalacia has been associated with ingestion of water with a high sulfate content,[14-18] with ingestion of molasses[19] or gypsum,[20] and with addition of sulfate to concentrate diets.[21,22] Cruciferous feedstuffs[23] and certain corn processing by-products[24] can also be high in sulfur content and have been implicated in outbreaks of polioencephalomalacia. In the western part of the United States, polioencephalomalacia has been associated with ingestion of water with a naturally high sulfate content,[25] and polioencephalomalacia was recently observed in calves consuming hay with a high sulfate content along with water containing moderate concentrations of sulfate.[26] When feedlot cattle consumed water with various concentrations of sulfate, average daily gain and feed efficiency decreased linearly with increasing water sulfate concentration.[27]

In general, the maximum tolerable sulfur intake in ruminants is estimated to be 0.4% of total dry matter consumption.[24] In evaluating potential sulfur sources in outbreaks of polioencephalomalacia, it is necessary

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to assess all dietary sources of sulfur, including the water. The present study was designed to evaluate the number and geographic distribution of beef cattle ranches in the United States where cattle could potentially be exposed to excessive sulfur intake as a result of high sulfur content of forage, water, or both. Specifically, the purposes of the study reported here were to analyze the sulfur content of water and forage samples from a geographically diverse sample of beef cow-calf operations in the United States and to estimate frequency and distribution of premises where forage and water resources could result in consumption of hazardous amounts of sulfur by cattle.

Materials and Methods

The study was conducted as part of the USDA:APHIS:VS National Animal Health Monitoring System Beef '97 study, which was designed to provide information on health, productivity, management practices, and nutritional resources of beef cow-calf operations throughout the United States.[28] For the Beef '97 study, a stratified random sample of producers with ≥ 1 beef cows in 23 states was selected by the USDA's National Agricultural Statistics Service. Producers were contacted in person by National Agricultural Statistics Service enumerators to enlist their participation in the study and collect basic management information. Producers who elected to participate in the study and had at least 5 beef cows were visited by a veterinarian or animal health technician who collected additional data on management practices. In addition, if the producer was amenable, the visiting veterinarian or animal health technician collected forage and water samples for analysis. In most instances, forage samples (excluding silage) that were collected from each operation were pooled to create a composite sample. A water sample was collected only if the producer had a subsurface water source for the cattle; a single water sample was collected from each operation. When possible, water samples were collected from the faucet, hose, or pipe supplying water to the cattle, after letting the water run for at least 1 minute. Otherwise, water samples were collected from the vessel holding the water for the animals to drink.

Forage samples were classified as to forage type at the time of collection. Forage types that were used included alfalfa, brome, Bermuda, fescue, Sudan, cereal, native grass, unspecified grass, silage, orchard grass, and other. Forage samples were tested for energy, protein, phosphorus, calcium, copper, zinc, molybdenum, manganese, cobalt, iron, and sulfur contents at a commercial laboratory.[a] Sequential inductively coupled plasma spectrophotometry was used to determine forage sulfur content. One forage sample per operation was tested without charge; additional samples were tested at a reduced cost.

Water samples were tested for nitrate, nitrite, sulfate, and total solids concentrations and for hardness (in general, the magnesium and calcium ion concentrations) at the USDA:APHIS:VS National Veterinary Services Laboratories. Water sulfate concentration was determined turbidimetrically.[29] The limit of detection was 200 mg of sulfate/L. Samples with values less than the detection limit were assigned a concentration of 100 mg/L for inclusion in analyses.

Amount of sulfur consumed in the forage was estimated with a standard formula[24] (0.025 × body weight) for forage intake on a dry matter basis. Amount of sulfur consumed in the water was estimated with a standard formula[24] (0.18 × body weight) for expected water intake during conditions of high ambient temperature (32 C [90 F]). Estimated total sulfur intake was then calculated by adding amount of sulfur consumed in the forage to amount of sulfur consumed in the water; estimated total sulfur intake was expressed as a percentage of total dry matter intake. When multiple forage samples were collected from a single operation, estimated total sulfur intake was calculated separately for each forage sample.

Data analysis—Mean forage sulfur content and mean water sulfate concentration were calculated for 5 regions of the United States. The central region consisted of Arkansas, Illinois, Iowa, and Missouri; the north-central region consisted of Kansas, Nebraska, North Dakota, and South Dakota; the south-central region consisted of Oklahoma and Texas; the southeast region consisted of Alabama, Florida, Georgia, Kentucky, Mississippi, Tennessee, and Virginia; and the west region consisted of California, Colorado, Montana, New Mexico, Oregon, and Wyoming. Mean forage sulfur content was also calculated for each forage type. A mixed ANOVA procedure that accounted for the nonindependence of forage samples from some operations was used to compare mean sulfur content by forage type and region. Because a multiple comparisons test is not available for this procedure, a conservative *P* value (< 0.001) was used to assign statistical significance to differences between pairs of means. Mean water sulfate concentrations were compared among regions with a general linear models procedure; the Tukey Studentized range test was used to test for differences between pairs of means.

Results

Forage and water samples—A total of 1,190 cow-calf operations participated in the Beef '97 study. Producers representing 678 premises elected to submit at least 1 forage sample for analysis. Because some producers submitted > 1 forage sample, a total of 709 forage samples were analyzed. Producers representing 498 premises with subsurface water sources for cattle elected to submit a single water sample for analysis.

Forage sulfur content—Forage sulfur content (expressed as a percentage of dry matter) ranged from 0.03 to 0.49% (mean ± SE, 0.20 ± 0.003%). Although there was some variation in sulfur content by forage type, there was more variation within forage type (**Table 1**). Similarly, although there was some variation in forage sulfur content by region, there was more variation within region (**Table 2**). Fourteen of the 709 (2%) forage samples had a sulfur content ≥ 0.4%, indicating that these dietary components, if fed by themselves, could cause excessive total sulfur intake. Ninety-one (12.8%) forage samples had a sulfur content ≥ 0.3%, suggesting that these dietary components, if fed in combination with water with a high sulfate concentration, could cause excessive total sulfur intake.

Table 1—Mean sulfur content of various forages collected from beef cow-calf operations in the United States

Forage type	No. of samples	Sulfur content (%)
Alfalfa	196	0.23 ± 0.005 (0.09–0.46)[b]
Brome	20	0.15 ± 0.015 (0.09–0.23)[c,d]
Bermuda	112	0.27 ± 0.006 (0.08–0.49)[a]
Fescue	73	0.19 ± 0.008 (0.03–0.31)[c]
Sudan	61	0.12 ± 0.009 (0.06–0.37)[d]
Cereal	46	0.17 ± 0.010 (0.08–0.38)[c,d]
Native grass	38	0.17 ± 0.011 (0.07–0.46)[c]
Grass	70	0.19 ± 0.008 (0.06–0.35)[c]
Silage	31	0.14 ± 0.012 (0.08–0.32)[c,d]
Orchard grass	34	0.18 ± 0.011 (0.09–0.34)[c]
Other	28	0.16 ± 0.013 (0.08–0.30)[c,d]

Data are given as mean ± SE (range). Sulfur content is expressed on a dry matter basis.

[a-d]Values without a common letter superscript were significantly ($P <$ 0.001) different.

Table 2—Mean sulfur content of forages for beef cow-calf operations in the United States classified by region

Region	No. of samples	Sulfur content (%)
Central	95	0.18 ± 0.008 (0.08–0.35)[b,c]
North-central	150	0.18 ± 0.007 (0.06–0.36)[b,c]
South-central	128	0.20 ± 0.007 (0.06–0.49)[a,c]
Southeast	185	0.22 ± 0.006 (0.08–0.49)[a]
West	151	0.21 ± 0.007 (0.03–0.46)[a,b]

The central region consisted of Arkansas, Illinois, Iowa, and Missouri; the north-central region consisted of Kansas, Nebraska, North Dakota, and South Dakota; the south-central region consisted of Oklahoma and Texas; the southeast region consisted of Alabama, Florida, Georgia, Kentucky, Mississippi, Tennessee, and Virginia; and the west region consisted of California, Colorado, Montana, New Mexico, Oregon, and Wyoming.

[a–c]Values without a common letter superscript were significantly ($P < 0.001$) different.

See Table 1 for remainder of key.

Table 3—Mean sulfate concentration of water samples from beef cow-calf operations in the United States classified by region

Region	No. of samples	Sulfate (mg/L)
Central	63	200 ± 30 (100–1,400)[a,b]
North-central	134	417 ± 70 (100–7,600)[a]
South-central	66	308 ± 75 (100–3,800)[a]
Southeast	92	102 ± 2.8 (100–360)[b]
West	143	285 ± 36 (100–2,500)[a,b]

The lower limit of detection for sulfate concentration was 200 mg/L; for purposes of analysis, samples with concentrations less than the lower limit of detection were assigned a concentration of 100 mg/L.

[a,b]Values without a common letter superscript were significantly ($P < 0.05$) different.

See Tables 1 and 2 for remainder of key.

Figure 1—Locations of beef cow-calf operations in the United States for which estimated total sulfur intake was ≥ 0.4% on a dry matter (DM) basis, calculated on the basis of water intake expected during conditions of high ambient temperature. Some premises submitted > 1 pair of forage and water samples for analysis.

Water sulfate concentration—Water sulfate concentration ranged from undetectable (< 200 mg/L) to 7,600 mg/L. A few significant differences in mean water sulfate concentration were found between regions (**Table 3**). Nine of the 498 (1.8%) water samples had sulfate concentrations ≥ 2,000 mg/L, including 4 from the north-central region, 3 from the south-central region, and 2 from the west region. Thirty (6.0%) water samples had sulfate concentrations ≥ 1,000 mg/L. Of these, 15 (50%) were from operations in the north-central region, and 10 (33%) were from operations in the west region.

Estimated total sulfur intake—Water samples were not collected from all operations that submitted forage samples, and forage samples were not collected from all operations that submitted water samples. Therefore, total sulfur intake could be estimated for only 435 operations. Because some of these operations submitted > 1 forage samples, total sulfur intake was estimated for 454 pairs of forage and water samples. Overall, 52 of the 454 (11.5%) pairs of forage and water samples were estimated to yield total sulfur intake, expressed as a percentage of dry matter, ≥ 0.4% (assuming water intake during conditions of high ambient temperature). Nineteen of these 52 (37%) sample pairs were from the north-central region, and another 19 were from the west region (**Fig 1**). For 27 of the 52 (52%) sample pairs expected to yield total sulfur intake ≥ 0.4%, the forage type included alfalfa.

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Table 4—Source of sulfur for pairs of forage and water samples potentially associated with high total sulfur intake on beef cattle ranches in the United States

	No. of samples		
Estimated total sulfur intake	High forage content and low water content	Low forage content and high water content	High forage content and high water content
0.4 to 0.5%	20	5	0
> 0.5%	1	21	5

High forage content was defined as > 0.25% sulfur on a dry matter basis; low forage content was defined as < 0.25% sulfur on a dry matter basis. High water content was defined as sulfate concentration > 1,000 mg/L; low water content was defined as sulfate concentration < 1,000 mg/L.

Twenty-five sample pairs were estimated to yield total sulfur intake between 0.4 and 0.5% (**Table 4**); for most of these pairs, the forage provided the bulk of the sulfur intake. Twenty-seven sample pairs were estimated to yield total sulfur intake > 0.5%. High water sulfate concentration (> 1,000 mg/L) played an important role in 26 of these 27 pairs.

Discussion

Results of the present study suggest that on numerous beef cow-calf operations throughout the United States, consumption of forage and water could result in sulfur intake high enough to potentially cause polioencephalomalacia, poor performance, or copper antagonism. These results further illustrate the importance of evaluating sulfur content of all available nutrient sources, including water, to estimate total intake. For example, in a few instances in the present study, forage sulfur content alone was high enough to result in excessive sulfur intake, but in most instances, it was the combination of forage sulfur content and water sulfate concentration that was important.

The National Research Council's recommended sulfur requirement for beef cattle is 0.15% on a dry matter basis, with a maximum tolerable intake of 0.4%.[24] High sulfur intake in feedlot and range cattle has been associated with polioencephalomalacia and with decreased average daily gain and feed efficiency.[27] A water sulfate concentration > 583 mg/L (equivalent to sulfur intake of 0.22% on a dry matter basis) also decreased performance of feedlot cattle.[27]

For purposes of estimating total sulfur intake in the present study, sulfur intake from water was calculated on the basis of water intake expected during conditions of high ambient temperature (32 C [90 F]). Because water intake of cattle increases as ambient temperature increases, more sulfate will be consumed during hot weather if the water source has high sulfate concentration. In a previous study[25] of feedlot cattle consuming water with a sulfate concentration of 2,400 mg/L, for instance, polioencephalomalacia was most common in hot weather, and in pastured cattle, polioencephalomalacia has been shown to be more common during the summer months.[30]

A potential for selection bias existed in the present study, because participating producers decided whether to allow collection of forage and water samples. However, it is not clear what effects, if any, this bias might have had on our results. At the time this study was conducted, the influence of sulfur on cattle health was not widely known, and producers were more likely to allow collection of forage samples to obtain information on protein and energy contents, rather than on sulfur content. Producers may have allowed water samples to be collected because of suspicions about water quality problems, but high nitrogen content was likely to have been of more concern than high sulfate concentration. Because the purpose of the present study was to obtain a general overview of the geographic distribution of conditions that could potentially be associated with high total sulfur intake, we do not believe that selection bias affected the conclusions of the study.

The incidence of polioencephalomalacia on operations with water sulfate concentration and forage sulfur content that could result in high sulfur intake was not determined in this study, and more detailed studies are required to make an association. Nevertheless, identification of a substantial number of premises with conditions that could result in high sulfur intake in cattle indicates this is a problem the industry should address to avoid potential adverse effects. Management strategies should be directed at analyzing forage sulfur content and water sulfate concentration to detect combinations that might put animals at risk of excessive sulfur intake.

The relative potential for ruminal hydrogen sulfide production from various sulfur substrates has not been studied in detail. Most cases of polioencephalomalacia associated with excessive sulfur intake involved 1 or more identifiable sources with high sulfur concentration. Sulfate is readily reduced by sulfate-reducing bacteria in the rumen,[4,6] but how or whether protein sulfur is metabolized to sulfide is less well understood. It has been shown in vitro that cysteine can serve as a source of sulfur for sulfide generation when added to fresh rumen fluid.[6]

Results of the present study suggest that cattle producers in the north-central and west regions of the United States are more likely to have problems with high sulfur intake, compared with other regions. Several circumstances could possibly be considered indicative of high sulfur intake in these regions. For instance, development of polioencephalomalacia or of clinical signs suggestive of "blind staggers" should raise concerns about high sulfur intake. In addition, evidence of precipitated salts around surface water sources and use of water sources known colloquially as alkali areas or saline sloughs should also raise concerns. Cruciferous plants are constitutively high in sulfur,[23] and some weeds and grasses[14,26] can accumulate sulfur under certain conditions. When such situations exist, it would likely be useful for individual operations to periodically analyze feed and water resources for sulfur content as part of an overall nutrition management program. Naturally occurring sulfur contents of water and forage can vary even within relatively small geographic areas; thus, it is important to measure sulfur content at individual sites. Knowledge of total sulfur intake can be used to reduce the risk of sulfur-associated health and performance problems in beef cattle. If the potential for excessive total sulfur intake is detected, various strategies to decrease sulfur intake can be employed. For instance, it may be possible to bring in water with a low sulfate concentration as a substitute for water with a high sulfate concentration, but this may not be practical for the long term. Water sulfate concentration may be decreased with various water purification technologies, but costs may be excessive. If dietary components are the cause of high total sulfur intake, alternative sources should be substituted or mixed with the regular ration to provide a dilution effect.

[a]Petersen Labs, Hutchinson, Kan.

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