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Effect of Total Dissolved Solids and Sulfates in Drinking Water for Growing Steers

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Summary

Previous results showed that water with elevated total dissolved solids (TDS) and sulfates was detrimental to performance and health of growing steers. The objective of this study was to determine the level of TDS or sulfates where reductions in performance and health occur. Eighty-four crossbred steers (640 lb) were blocked by weight and randomly assigned to one of 12 pens (7 steers/pen). Pens were randomly assigned to one of four water treatments (3 pens/treatment) based on targeted TDS concentrations (ppm): 1) 1,000 (average = 1,226 TDS; 441 sulfates); 2) 3,000 (average = 2,933 TDS; 1,725 sulfates); 3) 5,000 (average = 4,720 TDS; 2,919 sulfates); and 4) 7,000 (average = 7,268 TDS; 4,654 sulfates). All water was obtained from natural sources and constituted the only available water source. Steers were fed a diet (0.44 Mcal/lb NEg) of ground grass hay and wheat middlings from May 23 to September 4 (104 days). Average daily gain, dry matter intake, and gain to feed ratio declined quadratically ($P < 0.05$) with both increasing TDS and sulfate levels in water. Water intake declined linearly with increasing TDS and sulfates ($P < 0.01$). Incidence of polioencephalomalacia was 48% (10 of 21) in the 7,000 ppm TDS treatment with no cases in any other treatment ($P < 0.01$), and 33% (7 of 21) of steers on the 7,000 ppm TDS treatment died of polioencephalomalacia ($P < 0.01$). Water with 4,720 ppm TDS and 2,919 ppm sulfates tended to cause performance reductions in growing steers, whereas water with 7,268 ppm TDS and 4,654 ppm sulfates caused marked reductions in steer performance and health. We hypothesize that water sulfates were responsible for performance and health reductions.

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Introduction

Field observations made from our laboratory since 1999 have shown both surface and subsurface water in South Dakota often exhibit high levels of total dissolved solids (TDS) and sulfates. Gould et al. (2002) reported that in multiple locations in South Dakota, sulfur intake from water and forage exceeded the NRC (1996) maximum tolerable level of dietary sulfur (0.4% of DM). Drought conditions in 2002 further exacerbated water quality problems in South Dakota.

We recently reported data that showed growing steers receiving water with over 4,800 ppm total dissolved solids (TDS) and 3,000 ppm sulfates had reduced average daily gain, DM intake, water intake, and gain to feed ratio (Patterson et al., 2003). Steers receiving high TDS/sulfate water had over a 12% incidence of polioencephalomalacia (PEM) and a 5.0% mortality rate. Since sulfates made up the majority of TDS, we hypothesized daily sulfur intake likely resulted in the observed rates of PEM. An interesting aspect of that research was that performance and health were not further reduced when water sulfates increased from an average 3,000 to 4,000 ppm. We were unable to determine from the research if levels of TDS and sulfates less than 4,800 and 3,000, respectively, decrease performance and health. Therefore, the objective of this study was to determine the level of TDS and sulfates where reductions in performance and health occur.

Materials and Methods

The study was conducted from May 23 to September 4, 2002, at South Dakota State University Cottonwood Range and Livestock Research Station, near Philip, SD. Eighty-four crossbred steers (640 lb) were blocked by weight and randomly assigned to one of 12 pens (7 steers/pen). Pens were randomly assigned to one of four water treatments (3 pens/treatment) based on targeted TDS concentrations (ppm): 1)

1,000 (average = 1,226 TDS; 441 sulfates); 2) 3,000 (average = 2,933 TDS; 1,725 sulfates); 3) 5,000 (average = 4,720 TDS; 2,919 sulfates); and 4) 7,000 (average = 7,268 TDS; 4,654 sulfates). All water was obtained from one of three natural sources, and various levels were created by mixing water to form the desired TDS level. The use of natural water sources was important in creating water with ratios of sulfate to TDS commonly found in cattle drinking water in western South Dakota. The average analyses of water samples collected throughout the trial for each treatment are shown in Table 1. Since we were working with natural water sources, exact target levels were not achieved. The ranges in TDS (ppm) of samples taken from the treatments were: 1) 915-1,532 (1,226 average); 2) 2,408-3,226 (2,933 average); 3) 4,620-4,902 (4,720 average); and 4) 6,500-7,730 (7,268 average). The water described in Table 1 constituted the only water source provided to cattle in each respective treatment.

Steers were housed in dry-lot pens and fed a diet of grass hay and wheat middlings (DM basis: 15.65% CP, 52.29% NDF, 0.44 Mcal/lb NEg, 0.17% S). Limestone (36% Ca) was top-dressed at a rate of 0.15 lb/d, and salt was offered free choice. No trace minerals were supplemented. Rations were fed in concrete bunks at approximately 8:00 am daily. Bunks were managed to be clean just prior to feeding, and any orts were weighed and recorded. Water was supplied in aluminum tanks. Water consumption was measured by the daily change in water depth adjusted for evaporation and precipitation (measurements of evaporation and precipitation taken from a weather station located adjacent to the research feedlot). Animal health was monitored daily. Cattle were diagnosed with PEM when showing clinical symptoms. Necropsies were performed on all mortalities.

Steer weights were taken in the morning on three consecutive days at the beginning and end of the experiment. Access to water was denied 12 hours prior to weight measurements. At the end of the experiment all cattle were placed on the lowest TDS water (1,226 ppm TDS, 441ppm sulfate) and limit fed the ration at approximately 2.0% of BW (DM basis) for 4 days prior to final weight measurements to alleviate rumen fill differences. Steer ADG was calculated for each experimental unit (pen) from data with dead cattle removed. Due to mortality during the experiment, two of three pens on the highest level of TDS had less than the initial 7 steers (one pen had two steers and another had five steers). Gain efficiency (G:F) was calculated as ADG divided by average daily DMI.

The relationships between steer final weights, ADG, DMI, G:F, and water intake to TDS and sulfate concentrations were analyzed by regression implemented using PROC GLM of SAS (SAS Inst. Inc., Cary, NC). Linear and quadratic regressions were tested for each variable across both TDS and sulfate concentration in water. The influence of water treatments on morbidity, mortality, and incidence of PEM was analyzed by Chi-Square analysis (PROC GENMOD of SAS).

Results and Discussion

Final weight, ADG, DM intake, and G:F declined quadratically ($P < 0.05$) with increasing TDS and sulfate concentration in water (Table 2). Water intake declined linearly ($P < 0.01$) with increasing TDS and sulfate concentration in water (Table 2). Average daily gain, DM intake and water intake were reduced by 65%, 37%, and 37%, respectively, from the 1,226 ppm TDS water to the 7,268 ppm TDS water treatments. Patterson et al. (2003) reported a reduction in ADG, DM intake, and water intake of 27%, 6.3%, and 12.9% when water TDS increased from 1,019 ppm to 4,835 ppm, with no further reductions for water with an average TDS of 6,191 ppm. Loneragan et al. (2001) reported linear decreases in ADG and G:F with increasing sulfates in water for finishing steers, where the maximum water sulfate was 2,400 ppm.

Steers consuming water with the highest TDS/sulfate level (7,268 ppm TDS and 4,654 ppm sulfates) had a 52.4% incidence of morbidity, 47.6% incidence of PEM, and a 33% mortality rate compared to no PEM or mortality in the other treatments (Table 3; $P < 0.01$ for all traits). All mortalities were confirmed by necropsy to be associated with PEM. Two steers on the highest level of sulfate water had PEM at the end of the experiment. These steers did not respond to treatment for PEM and were subsequently euthanized (not included in 33% death loss reported). Patterson et al. (2003) reported a 15% incidence of PEM with 3,087 ppm sulfate water (the same source of water as the 2,919 ppm sulfate treatment in this study), with no further increase in PEM with dietary sulfates up to 3,947 ppm. It was unexpected that steers in this study on the 2,919 ppm sulfate water exhibited no PEM whereas those on the 4,654 ppm sulfates exhibited near a 50% incidence.

Observed reductions in performance of steers receiving water with elevated TDS and sulfates was likely due to reduced water and feed consumption and PEM (sulfur toxicity). It is impossible to separate effects of elevated TDS from that of elevated sulfates on water intake, as all sources of water in this experiment had substantial sulfate concentrations (Table 1). Effects of water quality on water intake are important due to the correlation between water intake and DM intake (NRC, 1996). Sulfates may have been important in the observed reductions in water and feed intake encountered in this study. Weeth and Hunter (1971) reported that sodium sulfate addition to drinking water of heifers reduced water intake and feed intake, but the addition of sodium chloride to the water did not cause reductions. Clinical PEM in cattle on the highest sulfate level likely caused a marked reduction in performance of cattle on that treatment, and thus likely contributed substantially to the quadratic effect on production traits. The linear reduction in water intake across treatments, combined with the 0.0% incidence of diagnosed PEM in all treatments except the highest sulfate level, indicates the effects of poor quality water on ADG and DM intake were not solely related to cattle exhibiting PEM.

Ingestion of high levels of sulfur from water can cause PEM (McAllister et al., 1997). This is potentially due to the reduction of sulfur in the rumen to hydrogen sulfide gas (Loneragan et al., 1998), a toxic compound that can be inhaled following eructation from the rumen (Kandylis, 1984). Dietary sulfur levels of 0.9% of DM have been associated with PEM (Loneragan et al., 1998), and the NRC (1996) reports the maximum tolerable level of dietary sulfur to be 0.4%. Average dietary sulfur in this experiment was 0.26, 0.48, 0.68, and 1.1% of DM, for treatments with water sulfate levels of 441, 1,725, 2,919, and 4,654, respectively (corresponding to average daily sulfur intake of 24, 45, 58, and 66 g of S). Water deprivation is another cause of PEM (Gould, 1998). The steers in the 4,654 ppm sulfate treatment had markedly reduced water intake. It is not clear whether water intake was deprived to a level to induce PEM.

We conclude that water with 7,268 ppm TDS and 4,654 ppm sulfates markedly reduced animal health and performance. Water intake declined linearly with increased water sulfate concentration.

Implications

These data, combined with field observations, suggest that water quality in a significant portion of South Dakota may be inadequate for optimal production. Animal performance may be expected to decline quadratically with increased sulfates in water. Water greater than 3,000 ppm sulfates is potentially lethal.

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Tables

Table. 1. Average analyses (ppm) of water provided to growing steers across target total dissolved solid levels

	Target Total Dissolved Solid Level, ppm			
Item	1,000	3,000	5,000	7,000
TDS	1,226	2,933	4,720	7,268
Sulfate	441	1,725	2,919	4,654
Calcium	10	147	322	299
Magnesium	3	49	94	236
Sodium	430	726	1,002	1,628
Potassium	4	7	10	19
Chloride	18	33	44	140

Table 2. Intake and performance of growing steers supplied water with various total dissolved solid and sulfate levels in western South Dakota (Least Squares Mean)[a]

	Total Dissolved Solid/Sulfate Level, ppm				
Item	1,226/441	2,933/1,725	4,720/2,919	7,268/4,654	SEM
Initial Weight, lb	642	640	640	639	2
Final Weight, lb[b]	827	812	794	710	5
ADG, lb/d[b]	1.78	1.65	1.48	0.61	0.11
DM Intake, lb/d[b]	20.79	20.62	18.95	13.18	0.95
Gain/Feed[b]	0.086	0.080	0.078	0.045	0.005
Water Intake, gallons/d[c]	15.04	13.43	11.97	9.53	0.62

[a]Cattle fed a consistent diet (0.97 Mcal/kg NEg) and provided various water for 104 days during the summer.
[b]Measurements declined quadratically with increasing total dissolved solids and with increasing sulfates ($P < 0.05$).
[c]Measurements declined linearly with increasing total dissolved solids and with increasing sulfates ($P < 0.01$).

Table 3. Health of steers supplied water with various total dissolved solid and sulfate levels in western South Dakota [a]

	Total Dissolved Solid/Sulfate Level, ppm			
Item	1,226/441	2,933/1,725	4,720/2,919	7,268/4,654
Morbidity, %[b]	4.8	4.8	0.0	52.4
Mortality, %[b]	0.0	0.0	0.0	33.3
Polioencephalomalacia, %[b]	0.0	0.0	0.0	47.6

[a]Data analyzed by Chi-Square analysis (observations = 12; events = 84).
[b]$P = 0.0001$.