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INTRODUCTION

Producers often invest a great deal of time and money in developing nutrition and grazing strategies for their cattle. It is often taken for granted that if water is available, cattle productivity can be maintained. This is not always the case. The quality of water available to cattle can have substantial impacts on productivity. Much of the water available to cattle in South Dakota, and other parts of the United States, is not sufficient in quality to sustain performance and health of cattle.

Field observations from our laboratory since 1999 have shown both surface and subsurface water to be high in total dissolved solids (TDS, an estimate of total salts) and sulfates. In the midst of drought conditions in 2002, we observed surface water with sulfates as high as 10,000 parts per million (ppm). Data from the USDA's National Animal Health Monitoring System (APHIS, 2000) showed samples collected in South Dakota feedlots averaged over 1000 ppm in sulfates. Gould et al. (2002) concluded that 6% of 498 subsurface water samples taken in regions across the United States had sulfates greater than 1000 ppm, with 50% of those coming from water in the North-Central Region (SD, ND, NE, and KS). The authors 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 dry matter). Drought conditions not only compromise the quantity of water available to cattle, but the lack of moisture re-charge exacerbates water quality problems.

EFFECTS OF HIGH-SALT WATER ON BEEF CATTLE

Water high in salt content can compromise performance and health of cattle in three ways: 1) reduced water and feed intake; 2) toxic levels of sulfur ingestion; and 3) induced trace mineral deficiencies. Beef cattle may voluntarily consume less poor quality water, which in turn results in reduced consumption of dry matter (NRC, 1996). Reduced consumption of dry matter and thus nutrient intake has direct and obvious impacts on cattle productivity. The degree by which poor quality water impacts water intake and productivity may be dependent upon water requirements. Factors that affect water requirements include size, dry matter intake, physical exertion, lactation, and temperature. The effects of temperature are especially important, as water requirements can double as temperatures increase from 40 to 90 degrees F (NRC, 1996). Since water is required to regulate body temperature, reduced water consumption can have substantial impacts when temperatures are elevated.

In South Dakota, we commonly observe sodium sulfate as the primary salt causing elevated water TDS. Sulfates may have greater effects on water intake and performance than other salts. Research in Nevada (Weeth and Hunter, 1971) found the addition of sodium sulfate to heifer drinking water reduced water consumption by 35%, feed consumption by 30%, and caused more weight loss in heifers compared to controls. In that study, the addition of sodium chloride to heifers' water did not reduce water intake or performance. We hypothesize that sulfates are the primary cause of many water quality-related problems observed in cattle in South Dakota and neighboring areas.

Toxic ingestion of sulfur can occur when cattle consume water high in sulfates. Sulfur is a necessary mineral for rumen microorganisms. The NRC (1996) gives the requirement and maximum tolerable level of sulfur to be 0.15 and 0.40% of dry matter, respectively. Diets greater than 0.2% sulfur have been shown to reduce performance of finishing steers (Zinn et al., 1997). In addition, ingestion of high levels of sulfur from water can cause polioencephalomalacia (PEM). Symptoms noticed in animals with PEM include lethargy, anorexia, blindness, muscle tremors, gastrointestinal stasis, incoordination, staggering, weakness, convulsions, and death. Dietary sulfur levels of 0.9% of dry matter have been associated with PEM (Loneragan et al., 1998). Indeed, increased water intake (i.e. during periods of high temperature or lactation) results in elevated sulfur ingestion when sulfates are present in the water.

Polioencephalomalacia has often been associated with a thiamin deficiency (McDowell, 1989). Thiamin is often recommended as an effective treatment for cattle exhibiting symptoms of PEM. Recent evidence has shown sulfur induced PEM to be associated with hydrogen sulfide production in the rumen, and not with blood thiamin levels (McAllister et al., 1997; Loneragan et al., 1998). Hydrogen sulfide is a toxic gas that can be inhaled following eructation from the rumen (Kandylis, 1984). Hydrogen sulfide leads to a disruption in energy metabolism in brain cells, subsequently causing the necrotic lesions characterizing PEM. It is important to note that thiamin may be therapeutic to PEM, even if a deficiency is not the cause of the disorder (Gould, 1998).

Minerals in water can be antagonistic to trace mineral availability, especially copper. Elevated iron and sulfur in the diet can impair copper utilization (McDowell, 1992). Perhaps of greater significance is the reduction in copper utilization in the presence of both sulfur (commonly found in water) and molybdenum (commonly found in forages). Copper status has been shown to be related to reproduction and immune function in cattle (Spears, 1995). Supplementation with elevated levels of copper from available sources may be advantageous when sulfates are high in water.

WATER QUALITY RESEARCH

We recently conducted experiments at South Dakota State University's Cottonwood Range and Livestock Research Station (near Philip, SD) to evaluate the impacts of water quality on animal health and performance. Two studies were conducted with cattle in confinement. In 2001 (Patterson et al., 2002), steers were placed on a growing diet consisting of grass hay and wheat middlings from June 20 to September 12. Steers were housed in confinement pens, and each pen was supplied with one of three sources of water based on sulfate levels (approximate levels, ppm) 1) 400 sulfate (1000 TDS); 2) 3100 sulfates (4800 TDS); 3) 3900 sulfates (6200 TDS). The lowest sulfate water was from a local rural water system (deep well), the intermediate water was from a well (80 feet deep) located on the research station, and water with the highest sulfates was hauled to cattle from a local stock dam. The stock dam water decreased in quality as the summer progressed, ranging in sulfates from 3167 ppm in June to 4603 ppm in September (average 3900 ppm).

Steer average daily gain declined from 1.39 to 1.01 lb/day as the sulfates in drinking water increased from 400 to 3100. Gain was not further reduced with the highest water sulfate level (Table 1). In addition, steers receiving the 3100 and 3900 sulfate water had reduced water intake, dry matter intake, and gain/feed compared to cattle receiving the 400 sulfate water (Table 1). There was no morbidity or mortality in steers receiving the 400 sulfate water, but we observed a 15.0 and 12.5% incidence of PEM in cattle on the 3100 and 3900 sulfate treatments, respectively. Five percent of the cattle on the 3100 and 3900 sulfate treatments died from PEM. When accounting for sulfur in water, average dietary sulfur was 0.27, 0.74, and 0.93% of dry matter for cattle receiving the 400, 3100, and 3900 sulfate treatments, respectively.

In order to further investigate the effects of sulfate levels on performance, a similar study was conducted in 2002 (Patterson et al., 2003). Steers were supplied with one of four water sources based on sulfate concentration (approximate levels, ppm): 1) 400 sulfates (1000 TDS); 2) 1700 sulfates (3000 TDS); 3) 2900 sulfates (5000 TDS); and 4) 4600 sulfates (7000 TDS). Water for each treatment was created by mixing water from one of three natural sources to maintain consistent salt levels. Dry matter intake and water intake declined with increasing water sulfate concentration (Table 2). Steer average daily gains were 1.79, 1.65, 1.48, 0.62 lb/day for the 400, 1700, 2900, and 4600 sulfate treatments, respectively. Feed efficiency was reduced by 48% as water sulfate concentrations increased from 400 to 4600 ppm (Table 2). Steers on the 4600 ppm sulfate water had a 47.6% incidence of PEM and a 33% mortality (due to PEM), compared to no PEM or mortality in other treatments. The high rate of PEM in the 4600 sulfate treatment likely contributed to pronounced performance reductions in that group of cattle. Average dietary sulfur intake was 0.26, 0.48, 0.68, and 1.1% of dry matter for cattle receiving water with 400, 1700, 2900, and 4600 ppm sulfates, respectively.

The results of the 2002 study brought out a few interesting points. First, performance was reduced with sulfate levels as low as 1700 ppm. It is very common to see sulfate levels in water at least at this level in the northern Great Plains. It is also important to note that performance was reduced in situations where no clinical signs of PEM were diagnosed. It is not clear why cattle receiving water with approximately 3000 ppm sulfates experienced significant PEM cases in 2001 but not 2002. We are in the process of conducting further evaluations to see if factors such as temperature were related to the various results across years. We do not know if there is any adaptation, physiological or behavioral, associated with cattle drinking water with elevated sulfate levels. There have been a few other studies to evaluate the effect of sulfate level on performance of growing cattle. Working in Colorado, Loneragan et al. (2001) reported a linear decrease in average daily gain and gain/feed with increasing sulfates in the water for finishing steers (maximum water sulfate level was 2400 ppm). Working with heifers in Nevada, Weeth and Capps (1972) found a 12.4% reduction in hay intake when water sulfate levels increased from 110 to 2814 ppm, but water sulfate levels of 1462 ppm did not impact intake.

We also evaluated the effects of high sulfate water on steers grazing native range during the summer in western South Dakota. In 2001, steers grazing range from May to September that received water with an average sulfate level of 3900 ppm gained 0.2 lb per day less than steers that received water with 400 ppm sulfate. In 2002, steers grazing range from May to July that received water with an average sulfate level of 4600 ppm gained 0.6 lb per day less that steers receiving water with 400 ppm sulfates. Across both years, we documented a few cases of PEM in the stocker steers receiving the high sulfate water, but no steers died from the disorder.

In 2003, we evaluated the impacts of sulfates in water to cow-calf pairs. Ninety-six May-calving cows grazed in one of six pastures from June 3 to August 26. Cows in each pasture were provided with either low or high sulfate water (3 pastures for each water treatment) in aluminum stock tanks. The low sulfate water was from the local rural water system and averaged 400 ppm sulfates. The high sulfate water was created by adding sodium sulfate to rural water, and it averaged 2600 ppm sulfates (individual pasture averages ranged from 2380 to 2860 ppm sulfates). Cows on the high sulfate water lost 36 pounds whereas those on the low sulfate water gained 10 pounds. Calf average daily gain was not different between treatments (2.33 lb/d versus 2.38 lb/d for low and high sulfate, respectively). Milk production, estimated by the weigh-suckle-weigh technique in July and August, was not different between treatments. Pregnancy rates were not different between treatments (94 and 95% for low and high sulfate, respectively), and no cases of PEM were observed.

Water with elevated sulfates reduced performance in grazing steers and cows, but the effects of poor water on performance and health were not as severe as documented with cattle in confinement. Cattle grazing range may experience less detriment to the high sulfates due to: 1) more moisture in forage than dry feed, 2) less heat stress (lower surface temperatures and more shade), and 3) the ability to consume standing water in low areas after precipitation events. It is important to note, however, that the effects of high sulfate water on foraging yearlings were substantial. The sulfate level tested with the cows was not enough to reduce calf weights or reproduction. It is possible that a threshold exists where cow/calf performance would be substantially reduced. Indeed, we have documented cases of PEM for foraging cattle consuming high sulfate water throughout the state of South Dakota. In addition, it is important to remember the impacts that sulfates can have on the copper status of cattle. Our research program will continue to evaluate the critical levels of sulfates in water where reductions in performance and health occur.

CONCLUSIONS AND RECOMMENDATIONS

Water high in salt content, especially sulfate salts, has negative impacts on production and health of growing cattle. Water high in sulfates can reduce water intake, dry matter intake, feed efficiency, and may induce sporadic cases of PEM. Dietary sulfur levels of 0.7%

of DM and greater may cause PEM in growing cattle. Based on a review of the literature and results from our research in South Dakota, we have modified previous estimates of maximum tolerable levels of TDS (Table 3) and sulfates (Table 4) in drinking water for beef cattle. We use TDS as a screen because we can easily estimate TDS with an electroconductivity meter. These rather inexpensive meters can be used to determine if a sample needs to be submitted to the laboratory for a livestock suitability test (especially sulfate). Extension offices in South Dakota will screen water for free using the meters. We recommend sending water with greater than an estimated 3000 ppm in TDS to the laboratory for testing. It is important to note that the critical levels of TDS in water may change, depending on how much of the salts are made up of sulfates. Water with greater than 3000 ppm sulfates is considered poor, and water with greater than 4000 ppm sulfates is considered dangerous.

We recommend that producers test water sources on their operation. It is important to document seasonal and annual trends (at least across a few years). With these data, a water management plan can be developed. Surface water that is marginal in quality (see Tables 3 and 4) would be more appropriately used in spring or early summer, as evaporation during the summer may increase salt concentrations to toxic levels. Reductions in cattle performance may occur when water is marginal in quality, especially when temperatures are elevated. Weaning calves from cows may reduce water requirements and may decrease the deleterious effects of water with elevated salt levels. The use of poor water should be minimized, and poor water should not be provided to cattle in confinement. Development of alternative water sources is the only option in some situations. If producers are forced to run cattle on marginal to poor quality water, they should work with their veterinarian to develop a PEM treatment plan (usually thiamin and an anti-inflammatory). In addition, producers should work with a nutritionist to develop a trace mineral supplementation regimen if sulfates are at appreciable levels in water. Sulfur contributions from the diet should also be considered when sulfates are present in water. The bottom line is that it is important to know your water quality and to develop a plan to manage it.

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Table 1. Intake and performance of growing steers supplied water from various sulfate levels in western South Dakota in 2001 (Least squares means ± SEM)[a]

	Water Sulfate Level, ppm		
Item	400	3100	3900
Observations	3	3	6
Initial wt, lb	701 ± 4	695 ± 4	699 ± 2
Final wt, lb	816 ± 9[b]	783 ± 9[c]	785 ± 7[c]
ADG, lb/d	1.39 ± 0.07[b]	1.01 ± 0.07[c]	1.01 ± 0.04[c]
DMI, lb/d	17.6 ± 0.4[d]	16.5 ± 0.4[e]	16.8 ± 0.2[e]
Gain/Feed	0.078 ± 0.004[b]	0.061 ± 0.004[c]	0.061 ± 0.003[c]
Water intake, gal/d	12.5 ± 0.5[d]	10.9 ± 0.5[e]	11.1 ± 0.3[e]

[a]Patterson et al., 2002.
[bc]Within a row, means without a common superscript letter differ, ($P < 0.05$).
[de]Within a row, means without a common superscript letter differ, ($P < 0.10$).

Table 2. Intake and performance of growing steers supplied water with various sulfate levels in western South Dakota in 2002 (Least Squares Mean)[a]

	Water Sulfate Level, ppm				
Item	400	1700	2900	4600	SEM
Initial Weight, lb	642	640	640	640	2
Final Weight, lb[b]	827	811	794	710	11
ADG, lb/d[b]	1.79	1.65	1.48	0.62	0.11
DM Intake, lb/d[b]	20.8	20.6	18.9	13.2	1.0
Gain/Feed[b]	0.086	0.080	0.078	0.045	0.005
Water Intake, gal/d[c]	15.0	13.4	11.9	9.5	0.6

[a]Patterson et al., 2003.

[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. Interpretation of Water Quality Based on TDS for Cattle in areas where Sulfates are prevalent

TDS (ppm)	**Interpretation**	**Suggested Action**
Less than 2000	Safe. Levels greater than 1000 may have some laxative effect and may reduce availability of trace minerals	None required
2000-3000	Generally safe. May reduce performance, should not affect health	Monitor water, especially as weather gets hot
3000-5000	Marginal. May reduce performance and affect health	Test water for sulfates. Monitor water.
5000-7000	Poor water. Performance and health depression expected in times of high temperatures	Test for sulfates. Use for low producing stock
7000-10,000	Dangerous. Performance and health depression expected.	Do not use for pregnant or lactating cattle. Sulfates likely to be high.
Greater than 10,000	Extremely Dangerous. Not suitable for livestock	Do not use

Table 4. Interpretation of Water Sulfate Levels for Cattle

Sulfate level (ppm)	**Interpretation**
< 500	Safe
500-1500	Generally safe. Trace mineral availability may begin to be reduced. May decrease performance in confined cattle.
1500-3000	Marginal. May be considered poor for confined cattle during hot weather. Sporadic cases of polio may be seen in confined cattle. Performance may be reduced.
3000-4000	Poor water. Sporadic cases of polio are probable, especially in confined cattle. Performance of grazing cattle may be affected.
> 4000	Dangerous. Health problems expected. Substantial reductions in performance expected.