A DEFENSIBLE MAXIMUM FOR INORGANIC SULFATE IN DRINKING WATER OF CATTLE[1,2]

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1976

SUMMARY

Twelve Hereford-Angus weanling heifers were used in a split-plot design incorporating a randomized complete block to determine physiological effects of subtoxic concentrations of inorganic sulfate in drinking water. Treatments were tap-water (110 mg/liter sulfate), 1,250 mg/liter sulfate and 2,500 mg/liter surface. The sulfate was added to the tap water as sodium sulfate. The sulfate-waters did not affect feed consumption, water consumption or growth during the 90-day experiment. No overt toxicity was observed. Heifers drinking sulfate-water had tendencies to accumulate methemoglobin and sulfhemoglobin without affecting total hemoglobin. Sulfate loading did not induce diuresis although heifers drinking 2,500 mg/liter sulfate-water increased renal filtration of sulfate by 37.7% and decreased renal reabsorption of this ion by 23.7%. Therefore, in these animals the percentage of filtered sulfate reabsorbed was decreased by 44.8%. The heifers were subsequently used in a taste response experiment in which they were offered either sodium chloride or sodium sulfate in a two-choice preference situation. The choice was the salt solution or tap-water. The salts were added to tap-water in increasing but estimated equal anionic concentrations in six increments from 275 to 4,400 mg/liter of anion. The animals discriminated against drinking water containing 1,620 mg/liter chloride or 2,018 mg/liter sulfate. Concentrations at the estimated rejection threshold were 5,524 and 3,317 mg/liter for chloride and sulfate, respectively. On a molar basis, discrimination and rejection thresholds for sulfate were 21.0 and 34.5 mM, respectively. Those for chloride were 45.6 and 155.6 mMolar. Apparently, sulfate was more unpalatable than chloride when compared on an equimolar basis. It appears that these heifers were able to tolerate 2,500 mg/liter sulfate in their drinking water without adverse effects, and that this concentration of sulfate represents a safe tolerance concentration.

(Key Words: Water, Sulfate, Maximum, Taste Response.)

INTRODUCTION

It has been shown previously that ingestion of inorganic sulfate *via* drinking water produced quantitative changes in blood composition and *renal function* of cattle. Heifers showed a 63.1% and a 50.0% increase in serum sulfate when drinking 3,493 mg/liter sulfate (Weeth and Hunter, 1971) and 2,814 mg/liter sulfate (Weeth and Capps, 1972), respectively. Also observed were increases in methemoglobin and sulfhemoglobin concentrations without alteration of total hemoglobin. A relative diuresis was noted in both of the above citations with a higher percentage of ingested water being excreted through the urine. On the basis of these studies, it was suggested that growing cattle could tolerate at least 1,450 mg/liter sulfate in their drinking water for at least 30 days and that this concentration was probably near their taste discrimination threshold (Weeth and Capps, 1972). Reported herein is an attempt which was made to define a defensible limit for the concentration of inorganic sulfate in the drinking water of cattle by evaluating physiological effects and taste response.

EXPERIMENTAL PROCEDURE

Twelve Hereford-Angus weanling heifers (four per treatment) were offered either tap-water (110 mg/liter sulfate), 1,250 mg/liter sulfate-water or 2,500 mg/liter sulfate-water in a 90-day experiment conducted
Sodium sulfate was the source o
sulfate-waters. The animals were
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grass hay and 14% protein pell
Proximate analysis of the grass
tein, 12.06%; sulfate, .60%;
2.07%; ash, 11.20%; and, fiber
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dairy pellets was: protein, 20
.47%; ether extract, 3.88%; ash
fiber, 11.54% on a dry matter
initial body weight was 165 kilog

On days 0, 45 and 90 a
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TABLE 1. EFFECTS OF DRI
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Item	M
Water intake, kg/day	
Hay intake, kg/day	
Concentrate intake, kg/day	
Sulfate intake, g/day	
Weight gain, kg/day	
Plasma osmolality, mOsm/kg	2
Total hemoglobin, g/100 ml	
Methemoglobin, mg/100 ml	
Sulfhemoglobin, mg/100 ml	
Serum sulfate, mEq/liter	
Plasma sodium, mEq/liter	1

[a]Four observations per item mean,
[b,c,d]Means on same line bearing di

[1]Conducted in cooperation with Western Region Research Project W-46, The Effects of Environmental Stresses on Range Cattle and Sheep Production.

[2]Journal Paper No. 300.

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SULFATE IN DRINKING

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Water, Sulfate, Maximum, Taste

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RIMENTAL PROCEDURE

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a 90-day experiment conducted during summer. Sodium sulfate was the source of sulfate in the sulfate-waters. The animals were managed individually in partially shaded pens. They were fed grass hay and 14% protein pellets *ad libitum*. Proximate analysis of the grass hay was: protein, 12.06%; sulfate, .60%; ether extract, 2.07%; ash, 11.20%; and, fiber, 29.29% on a dry matter basis. Proximate analysis of the dairy pellets was: protein, 20.06%; sulfate, .47%; ether extract, 3.88%; ash, 7.57%; and, fiber, 11.54% on a dry matter basis. Average initial body weight was 165 kilograms.

On days 0, 45 and 90 a renal clearance observation was made on each heifer using techniques previously described (Weeth and Lesperance, 1965). Total hemoglobin, methemoglobin and sulfhemoglobin were determined by the technique of Hainline (1965) on freshly collected blood. For other determinations, samples of plasma, serum and urine were stored frozen until analyzed. Analytical procedures were as noted by Weeth and Hunter (1971). Since repeated observations were made on the same animals, data were analyzed statistically as suggested by Gill and Hafs (1971). Differences among treatment means were evaluated by Duncan's multiple range test (1955).

The weather during the experiment was warm and dry, average maximum and minimum temperatures being 33.2 and 9.2 C. Evaporation from a U.S. Weather Bureau pan was 7.6 mm/day.

Following the sulfate tolerance study, the heifers were used in a two-choice taste response experiment (Goatcher and Church, 1970a) in which the treatments were tap-water and either sodium sulfate or sodium chloride. Six animals were offered each salt solution. The tap-water contained 370 mg/liter total dissolved solids with 75 mg/liter sodium, 10 mg/liter chloride and 110 mg/liter sulfate. The salts were added to the tap-water in increasing, estimated equal anionic concentrations in six increments ranging from 275 to 4,400 mg/liter of the anion. The test period for each concentration was 2 days. The datum collected was the percent consumption of salt solution to total fluid consumption. An animal's two water containers were rotated daily. To establish a zone of nondiscriminate or random drinking each salt solution test period was preceded by a tap-water *vs* tap-water 2-day period. Linear regressions, confidence intervals and differences between regression lines were calculated as suggested by Steel and Torrie (1960).

The weather was cooler during the taste response study with maximum and minimum temperatures averaging 22.0 and −1.0 C. Evaporation was 4.0 mm/day.

RESULTS AND DISCUSSION

No overt toxicity was observed in any of the heifers. All animals appeared to be in good condition throughout the experiment. The sulfate-water treatments did not affect feed or water consumption (table 1). All heifers gained

TABLE 1. EFFECTS OF DRINKING TAP-WATER, 1,250 MG/LITER SULFATE-WATER AND 2,500 MG/LITER SULFATE-WATER ON HEIFERS DURING A 90-DAY PERIOD[a]

	Sulfate added to tap-water, mg/liter					
	0		1,250		2,500	
Item	Mean	SE	Mean	SE	Mean	SE
Water intake, kg/day	38.5	1.41	31.5	1.47	33.1	1.59
Hay intake, kg/day	4.1	.28	3.9	.28	3.9	.24
Concentrate intake, kg/day	3.1	.07	3.2	.05	3.1	.11
Sulfate intake, g/day	42.6[b]	2.17	81.4[c]	3.91	124.9[d]	12.89
Weight gain, kg/day	.9	.08	.8	.05	.8	.10
Plasma osmolality, mOsm/kg	277	3.9	278	3.7	281	1.3
Total hemoglobin, g/100 ml	13.3	.22	12.7	.22	12.5	.22
Methemoglobin, mg/100 ml	62.1[b]	41.01	206.7[c]	190.50	132.2[bc]	27.64
Sulfhemoglobin, mg/100 ml	5.5	3.80	98.6	39.41	111.4	31.39
Serum sulfate, mEq/liter	3.2[b]	.10	3.9[cd]	.23	4.5[d]	.13
Plasma sodium, mEq/liter	139.5[b]	1.36	141.6[cd]	.63	145.2[d]	2.92

[a]Four observations per item mean, except eight observations on blood related items.

[b,c,d]Means on same line bearing different superscripts are different (P<.05).

weight during the study, there being no apparent treatment effects. No evidence of dehydration was observed, plasma osmotic pressure remaining constant regardless of treatment.

Although there was much variation, heifers drinking sulfate-water showed evidence of increased production of methemoglobin, the increase seen in the 1,250 mg/liter group being significant (table 1). Weeth and Capps (1972) also noted increased methemoglobin concentration in heifers drinking 1,462 and 2,814 mg/liter sulfate-water. It is known that methemoglobin formation induced by sodium nitrite provides prophylaxis against toxic concentrations of sulfide (Smith, 1969). Sulfide produced by the reduction of ingested sulfate by ruminal micro-organisms (Lewis, 1954) is rapidly absorbed in the upper alimentary tract (Hansard and Mohammed, 1969). In the blood stream, some of the sulfide is trapped by methemoglobin, thereby preventing inhibition of cytochrome oxidase (Smith and Gosselin, 1964). The bovine apparently readily oxidizes hemoglobin to methemoglobin (Smith and Beutler, 1966). Fortunately the reverse reaction, catalyzed by a methemoglobinase, is also rapid.

Drabkin and Austin (1935) also observed that absorbed sulfide can convert functional hemoglobin to sulfhemoglobin. In the present study, heifers consuming 1,250 and 2,500 mg sulfate per liter of water had mean sulfhemoglobin concentrations of 98.6 and 111.4 mg/100 ml, respectively. The mean concentration for heifers drinking tap-water was 5.5 mg/100 ml, with sulfhemoglobin being detected in only 25% of the blood samples. Although not statistically significant, these values do indicate that cattle produce increased amounts of sulfhemoglobin when ingesting large quantities of sulfate. This observation has been made previously by Weeth and Hunter (1971).

Serum sulfate concentrations of heifers consuming 1,250 and 2,500 mg/liter sulfate-water increased by 22.8 and 40.5%, respectively (table 1). This is consistent with earlier observations (Heller and Paul, 1934; Weeth and Hunter, 1971) and reflects the increased dietary intake of sulfate by animals (Weir and Rendig, 1954). Plasma sodium concentrations were also increased ($P<.05$) in the heifers consuming the larger quantities of sulfate as sodium sulfate (table 1).

The sulfate-water treatments resulted in increased ($P<.05$) urinary excretion of sulfate and sodium but renal clearances of creatinine, osmolalities and free water were unaffected (table 2). Urine osmotic pressure was unchanged; therefore, although urine was collected for only a 2 hr period, it appears that these concentrations of sulfate caused no diuresis. This is supported by the lack of polydipsia in heifers drinking sulfate-water (table 1).

As indicated in table 2, heifers drinking both

TABLE 2. EFFECTS OF DRINKING TAP-WATER, 1,250 MG/LITER SULFATE-WATER AND 2,500 MG/LITER SULFATE-WATER ON RENAL FUNCTION OF HEIFERS DURING A 90-DAY PERIOD[a]

	Sulfate added to tap-water, mg/liter					
	0		1,250		2,500	
Item	Mean	SE	Mean	SE	Mean	SE
Urine sulfate, mEq/liter	39.8[b]	3.89	101.8[bc]	18.96	141.2[c]	5.4
Urine sodium, mEq/liter	176.1[b]	7.69	216.6[bc]	9.55	236.5[c]	20.58
Creatinine clearance, liter/hr/m^2	9.9	.45	8.5	.44	9.5	.42
Free water clearance, liter/hr/m^2	-.26	.001	-.29	.001	-.28	.001
Urine osmolality, mOsm/kg	772	62.6	760	71.4	806	45.9
Sulfate filtered, mEq/hr	101.5[b]	3.82	114.8[bc]	5.89	139.9[c]	10.29
Sulfate reabsorbed, mEq/hr	83.7[b]	1.98	60.4[c]	3.36	63.9[c]	5.66
Filtered sulfate reabsorbed, %	83.2[b]	1.02	52.6[c]	.93	45.9[d]	2.03
Sodium filtered, mEq/hr	4431.1	251.20	3830.2	208.30	4402.8	331.81
Sodium reabsorbed, mEq/hr	4351.4	243.72	3751.8	255.08	4273.2	302.48

[a]Eight observations per treatment mean.

[b,c,d]Means on same line bearing different superscripts are different ($P<.05$).

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Since the mean percentage of
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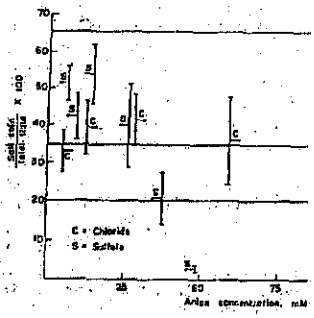

Figure 1. Taste responses of heife
concentrations of chloride and su
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SULFATE-WATER AND
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ter, mg/liter		
-	2,500	
	Mean	SE
8.96	141.2[c]	5.4
9.55	236.5[c]	20.58
.44	9.5	.42
.001	-.28	.001
1.4	806	45.9
3.89	139.9[c]	10.79
1.36	63.9[c]	5.66
.93	45.9[d]	2.03
1.30	4402.8	331.81
1.08	4273.2	309.48

concentrations of sulfate-water actually reabsorbed less sulfate from the glomerular filtrate (27.8 and 23.7% less for the 1,250 and 2,500 mg/liter treatments, respectively). Weeth and Hunter (1971) made similar observations with heifers offered 3,493 mg/liter sulfate-water. Because of the decreased actual reabsorption and increased filtration, the percentage of filtered sulfate which was reabsorbed was markedly decreased by the sulfate-water treatments. These observations support the theory of Lotspeich (1947) of a renal transport maximum for sulfate, but additionally with these heifers it appears that exceeding the transport maximum depressed reabsorption. Such depressed reabsorption might provide some protection to animals consuming large amounts of sulfate.

In the subsequent taste response experiment, the nondiscrimination zone (figure 1) was found to lie between 65.4 and 34.6% ($P<.05$). This zone is slightly wider than that established by Goatcher and Church (1970a), but narrower than that observed by Weeth and Capps (1972). Johnson *et al.* (1958) recorded only three to four drinking per day by cattle at 10 C ambient temperature. It is possible that such infrequent drinking results in the wide zone for nondiscriminate drinking.

Since the mean percentage of salt solution to total water consumption did not deviate significantly above 50 (figure 1), it can be concluded that no preference was shown for any of the salt solutions offered. Goatcher and Church (1971a) found no preference by cattle for 1,400 to 12,500 mg/liter sodium chloride. Goats showed preference for 800 to 6,300 mg/liter sodium chloride (Bell, 1959). Richter and MacLean (1939) found that humans could recognize about 160 mg/liter sodium chloride and that a solution could be identified as being salty at about 870 mg/liter.

It has been observed that afferent impulses could be generated on the chorda tympani of calves with 292 mg/liter sodium chloride applied to the tongue (Bell and Kitchell, 1966). Moncrieff (1967) suggested, without reference to species, that the detectable minimum for sodium chloride was near 550 mg/liter. Goatcher and Church (1970a) observed that cattle can recognize as little as 1,600 mg/liter sodium chloride. The results of the present study indicate that the lowest concentration of sodium chloride tested (434 mg/liter) would be below the detectable minimum.

As shown in figure 2, the regression line for chloride ($Y=40.66-.0037X$) crosses the lower discrimination threshold (salt solution consumption <34.6% of total fluid consumption) at 1,620 mg/liter (45.6 mM). That for sulfate ion ($Y=57.26-.0011X$) crosses at 2,018 mg/liter (21.0 mM). The concentrations at the rejection thresholds (salt solution <20.0% of total consumption) are 5,524 mg/liter (155.6 mM) and 3,317 mg/liter (34.5 mM) for chloride and sulfate, respectively. Only the rejection thresholds differ significantly. The regression lines are significantly different, that for sulfate being steeper.

Beidler (1963) observed that a taste receptor is stimulated by a molecule or an ion. Therefore, the two salt solutions might best be compared on a molar basis (figure 3). This results in a marked difference between the

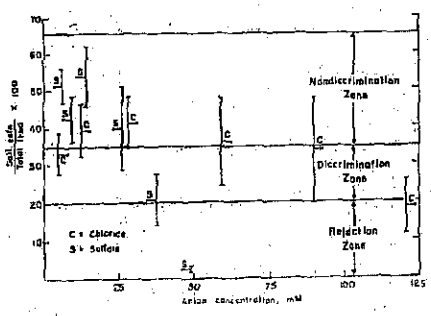

Figure 1. Taste responses of heifers to increasing concentrations of chloride and sulfate added to drinking water as the sodium salts. Observations within the figure are means ± standard errors.

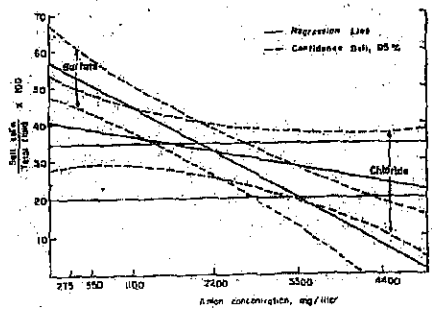

Figure 2. Effects of increasing anion (w/v) concentrations on percent of salt solution drunk by heifers. Parallel lines at 34.6 and 20.0% indicate discrimination and rejection levels, respectively.

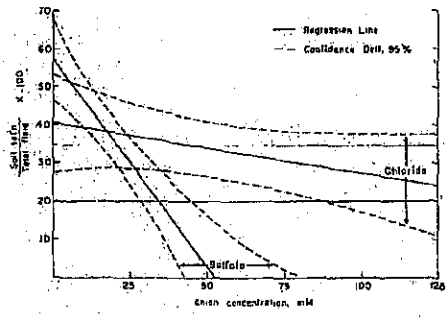

Figure 3. Effects of increasing millimolar concentrations of anion on percent salt solution to total water drunk. Parallel lines at 34.6 and 20.0% indicate discrimination and rejection levels, respectively.

anions. The lower discrimination threshold for sulfate is 21.0 mM with a confidence limit of 15.2 to 27.0 mM ($P<.05$). That for chloride is 45.6 mMolar. The rejection threshold for sulfate is 34.5 mM with a confidence limit of 27.9 to 44.6 mMolar. The chloride rejection threshold is 155.6 mMolar. Both thresholds are now significantly lower for the sulfate ion.

Moncrieff (1967) states that both chloride and sulfate are effective in producing a saline taste and that bitterness of a salt increases as its molecular weight increases. Goatcher and Church (1970b) concluded that cattle are more sensitive to bitter than salty. This may be why the sulfate salt was rejected at a lower anionic concentration than the chloride salt.

From this study it appears that growing cattle were able to tolerate 2,500 mg/liter sulfate without over toxic effects. It has been shown previously (Weeth and Capps, 1972) that concentrations of 2,814 mg/liter caused some deleterious effects in cattle. According to the discrimination threshold observed in the present study, this concentration of sulfate would be discriminated against if water containing a lower concentration of sulfate was available to the animal. It is not feasible to set an exact safe tolerance concentration for sulfate in water since tolerance is dependent on total intake and the turnover rate of sulfate in the individual animal. However, 2,500 mg/liter may be close to the safe tolerance limit for the concentration of inorganic sulfate in the drinking water of cattle.

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SUMMARY

The nutritive values of pang
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and cellulose digestibility (CD).
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Significant differences ($P<$
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[1] Journal Series No. 1881 of t
tural Experiment Station.
[2] Department of Animal Sciences

High Levels of Inorganic Sulfate Cause Diarrhea in Neonatal Piglets[1,2,3]

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ABSTRACT Artificially reared neonatal piglets were used to study the effect of inorganic sulfate on bowel function in human infants. Two experiments were conducted to evaluate the effect of high levels of inorganic sulfate on the growth, feed intake and feces consistency of artificially reared piglets, and to determine the dose at which at least 50% of piglets develop nonpathogenic diarrhea. The effect of sulfate level on kidney weight and concentration of inorganic sulfate in urine was also assessed. In each experiment, 40 pigs with an average initial age of 5 d were individually caged and reared with an automatic feeding device. Ten pigs per dietary treatment were fed one of four diets containing the following levels of added inorganic sulfate (mg/L of diet), as anhydrous sodium sulfate (USP): 0, 1200, 1600 and 2000 for Experiment 1 (18-d study), and 0, 1800, 2000 and 2200 for Experiment 2 (16-d study). The levels of added sulfate did not affect ($P > 0.05$) the growth of piglets, or their feed intake. Whereas 1200 mg added sulfate/L had essentially no effect on feces consistency, levels >1800 mg/L of diet resulted in a persistent, nonpathogenic diarrhea in neonatal piglets. Added sulfate did not affect ($P > 0.05$) relative kidney weight. Inorganic sulfate in urine reached maximum concentration ($P < 0.05$) in pigs fed diets with 1600 and 1800 mg added sulfate/L in Experiments 1 and 2, respectively, but declined at higher levels. The results suggest that the level of added dietary inorganic sulfate at which 50% of piglets develop nonpathogenic diarrhea is between 1600 and 1800 mg/L. J. Nutr. 125: 2325–2332, 1995.

INDEXING KEY WORDS:

- *inorganic sulfate* • *neonatal piglets*
- *gastrointestinal effects* • *liquid diets* • *swine*

Sulfate is a common divalent anion found in the environment, mainly in natural waters, in concentrations ranging from a few tenths of a milligram per liter to several thousand milligrams per liter (NRC 1977). In a survey of the 100 largest cities in the United States (Durfor and Becker 1964), the median sulfate concentration of all samples was 26 mg/L, with a range of 0 to 572 mg/L, and more than 90% of the samples contained <100 mg sulfate/L. McCabe et al. (1970) examined a total of 2595 water samples that included a large variety of drinking water sources in the United States, and reported that only 3% of the samples had sulfate concentrations exceeding the recommended National Secondary Drinking Water Standard (NSDWS) of 250 mg/L, with a maximum concentration of 770 mg/L. A study of 248 private wells in North Dakota reported that 197 had dissolved solids content >1000 mg/L, 125 had >2000, 63 had >3000, 33 had 4000 mg dissolved solids/L and in the majority of the waters the sulfate ion constituted the major proportion of the dissolved solids (cited by Moore 1952).

The lowest dose of sulfate that causes diarrhea in humans is not certain. Moore (1952) reported that 62% of people experienced a laxative effect when the sulfate concentration in well water exceeded 1 g/L. Survey data collected from ground water users in North Dakota (Peterson 1951) indicated that waters

[1]Presented in part at the 1994 Joint Annual Meeting of the American Dairy Science Association and the American Society of Animal Science, July 11–15, 1994, Minneapolis, MN (Gomez, G. (1994) Effects of sulfate in liquid diets for artificially-reared piglets. J. Anim. Sci. 72 (suppl. 1): 164 (abs.)).

[2]This study was conducted at the NCSU Piglet Core with a grant from the U.S. Environmental Protection Agency through the Center for Gastrointestinal Biology and Disease. Although the research described in this article has been supported by the U.S. EPA, it has not been subjected to agency review and therefore does not necessarily reflect the views of the agency. No official endorsement should be inferred. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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0022-3166/95 $3.00
Manuscript received 17 November 1994. Initial review completed 3 January 1995. Revision accepted 6 March 1995.

with 600 to 750 mg sulfate/L had a laxative effect. Chien et al. (1968) reported on three infants who developed diarrhea when given formula made with water containing 620–1150 mg sulfate/L.

Young weanling pigs (3 to 4 wk of age) having access to saline drinking water (6000 mg total solids/L) high in sulfates (2392 mg/L) showed increased prevalence of diarrhea as well as higher water consumption during the first week after weaning compared with controls drinking low sulfate water, but there was no difference in rate of growth, food consumption and gain to feed ratios (Anderson and Stothers 1978). Patterson et al. (1979) observed that when pigs consumed water with a sulfate concentration of 3000 mg/L, there was no effect on reproduction or weight gain, but there was an increase in fecal moisture content and water consumption. Recently, Veenhuizen et al. (1992) reported that weanling pigs tended to have better weight gain over a 4-wk period when provided water with a sulfate concentration of 600 or 1800 mg/L compared with controls receiving water with 54 mg sulfate/L. The prevalence of diarrhea was higher in pigs given sulfate in the water than in the controls.

No report has been found on the effects of high sulfate levels in liquid diets fed to baby pigs in a manner that would mimic situations encountered with human infant formula feeding. Limited information is available with respect to infants and children. Because of the obvious limitations of using infants as experimental subjects, this study used artificially reared neonatal piglets as a model to evaluate the effect of inorganic sulfate on bowel function in human infants.

Thus, the purpose of the present study was to determine the dose of sulfate, as sodium sulfate, at which diarrhea develops in neonatal pigs and to ascertain the dose at which 50% of pigs had diarrhea. The experiments herein reported assessed the influence of sulfate on weight gain, feed intake and feces consistency throughout the entire trial under strictly controlled conditions. The effect of sulfate on kidney weight as well as on sulfate concentration in urine of pigs at the end of the experiment was also measured.

MATERIALS AND METHODS

Experimental animals. Gestating sows were obtained from the North Carolina State University Swine Farm and transferred to an isolated farrowing facility, 5 d before farrowing. Crossbred pigs carrying no known or defined pathogens were farrowed in an antiseptically clean (washed three times daily) stall after 4 to 5 d of repeated bathing and sanitizing of the sows, before delivery, with an iodinated detergent (Wescodyne®, American Sterilizer Company, Medical Products Division, Erie, PA). Piglets farrowed by five third-parity and five first-parity sows were used in Experiments 1 and 2, respectively. Forty crossbred piglets were used in each experiment. Piglets were left with their dams for ~48 h after farrowing and then transferred to an isolated room containing an automatic feeding device (Autosow). The temperature of the room was maintained at 32°C during the first week and lowered to 27–29°C throughout the remainder of each experimental period. The ambient relative humidity in the room varied between 55 and 75%. Lights were on at all times. The protocol of this research was approved by the NCSU Institutional Animal Care and Use Committee.

Feeding protocol and basal diet. The Autosow is a machine containing individual cages (length, 0.50 m; width, 0.30 m; and height, 0.40 m) and regularly dispensing, aseptically, small volumes of liquid diet according to the weight of each piglet. Piglets were fed liquid diets only and did not have access to drinking water. The diet reservoir was refrigerated, and therefore, bacterial growth in the diets, if any, was minimal. The feeding pans were washed under pressure after each feeding with a warm chlorinated detergent (Tri-Foam™, Diversey Corp., Wyandotte, MI). Details of the characteristics of this device have been previously reported (Coalson and Lecce 1973). Piglets were fed a daily volume of diet that was ~30% of their body weight, i.e., a 1-kg piglet was fed 300 mL of diet/d. Previous studies (Coalson and Lecce 1973, Lecce 1969) have shown that this daily volume to weight ratio is near optimum with regard to weight gain and feed efficiency when diets are made from milk solids and have a dry weight of ~20%. The feeding interval used in both experiments was 1.5 h. In Experiment 1, the daily volume of diet was divided into 16 equal portions during the first 8 d of the trial and 13 portions thereafter (feeding schedule was from 0600 to 2400 h). In Experiment 2, piglets were fed 13 times per day throughout the entire trial. The calculated feed intake per pig is expressed as kilograms of dry matter consumed per experimental period.

Once piglets were housed in the Autosow, they were fed a basal diet (**Table 1**) with no added sulfate and adapted to the new environment throughout a 3- to 4-d period. At the end of the adaptation period (at an average age of 5 d), piglets were weighed and distributed according to body weight, sex and litter origin to four groups of 10 pigs each. Piglets used in Experiment 2 had lower initial body weights, at a similar age, than those in Experiment 1 because they were from first-parity litters compared with third-parity litters in Experiment 1.

Experimental diets. The experimental diets were randomly assigned to each one of the groups. In each experiment four levels of added sulfate, expressed as milligram per liter of diet, were evaluated as follows:

TABLE 1

Composition of the basal diet[1]

Ingredient	Amount
	per L of diet
Deionized, distilled water	840 mL
8/50-SPL[2]	80 g
Nonfat dry milk	143 g
Trace mineral premix[3]	5 mL
Vitamin premix[4]	1.6 g

[1]Calculated analysis (dry matter basis): dry matter, 20%; crude protein, 28%; lactose, 50%; ether extract, 20%; total energy, 4.1 MJ.
[2]A product supplying 8% crude protein and 50% ether extract (Milk Specialties Company, Dundee, IL).
[3]Trace mineral premix supplied the following (mg/L of diet): $CuSO_4 \cdot 5H_2O$, 5.1; $FeSO_4 \cdot 7H_2O$, 78; ZnO, 12.
[4]Vitamin premix (MasterMix Miscible Poultry Vitamins, Central Soya, Fort Wayne, IN) supplied the following (mg/L of diet): retinyl acetate, 3.6; cholecalciferol, 0.070; all-*rac*-α-tocopheryl acetate, 8.75; menadione sodium bisulfite complex, 1.87; thiamine, 2.1; riboflavin, 4.2; *d*-calcium pantothenate, 10.5; pyridoxine HCl, 2.1; nicotinic acid, 42; folic acid, 1.1; cyanocobalamin, 0.035; biotin, 0.175; ascorbic acid, 35.

0, 1200, 1600 and 2000; and 0, 1800, 2000 and 2200, for Experiments 1 and 2, respectively. Inorganic sulfate, as anhydrous sodium sulfate, was dissolved in the deionized, distilled water before adding and mixing the other ingredients. Water and liquid diets were analyzed for inorganic sulfate by a private laboratory (Roche Analytics Laboratory, Richmond, VA) using an analytical technique based on ion chromatography. The deionized, distilled water contained <1 mg inorganic sulfate/L (n = 4); the basal diets of Experiments 1 and 2 contained 277 and 261 mg inorganic sulfate/L (n = 2 each), respectively. Analytical values corrected for the supply of inorganic sulfate in the basal diet were 1283, 1663, and 1903 (n = 2 each) for expected sulfate contents of 1200, 1600 and 2000 mg/L, respectively, for Experiment 1. In Experiment 2, the corrected analytical values were 1689, 1989 and 1999 (n = 1 each) for expected sulfate contents of 1800, 2000 and 2200 mg/L, respectively. Results of total inorganic sulfate analyses in the diets indicated that values were within a range of ±9% of the expected sulfate contents.

Experimental protocol. Pigs were weighed daily and volume of diet for each pig was adjusted according to its body weight. Feed scores were recorded according to the following scale: 1 = eating normally, 2 = off feed, and 3 = not eating. Feces consistency or diarrhea scores were based on the following scale: 1 = normal, solid feces; 2 = soft, looser than normal stools; and 3 = liquid diarrheal feces. Feed and feces scores for each pig were recorded three times per day (morning, afternoon and evening) throughout the pre-experimental and experimental periods. Every morning, feces consistency scores of 2 or 3 were further confirmed at the time of taking rectal swabs. The results of feces consistency are expressed as the daily relative proportion (percentage) of piglets grouped according to their feces scores. Rectal swabs of pigs with feces consistency of 2 or 3 were taken, placed in tubes containing 2 mL of 0.01 mol/L PBS, pH 7.5, and assayed within a few hours after collection for hemolytic *Escherichia coli* and rotavirus assays to determine if these pathogens were the cause of diarrhea. Rectal swabs were processed for bacteriological culturing of hemolytic *E. coli* using blood agar with 5% sheep blood (Carr Scarborough Microbiologicals, Decatur, GA). After 24 h of incubation at 37°C, the cultures were evaluated for presence of hemolysis. A commercial kit (Virogen Rotatest®, Wampole Laboratories, Cranbury, NJ), based on a rapid latex particle agglutination slide test, was used for the qualitative detection of rotavirus in fecal specimens.

At the beginning of Experiment 1, urine samples were obtained from 5 to 6 pigs of each group, using a bladder puncture technique (Parker et al. 1979). At the end of both experiments, urine samples of all piglets were taken from the bladder after they were killed and the abdominal cavity opened. Urine samples were frozen until they were assayed for inorganic sulfate by a turbidimetric analysis (Jackson and McCandless 1978).

At the end of each experiment, piglets were sedated with an intramuscular injection of a mixture of 0.8 mL of Ketamine hydrochloride (Ketaset®, 100 g of Ketamine per L, Fort Dodge Laboratories, Fort Dodge, IA) and 0.2 mL of Xylazine (Rompun®, 20 g Xylazine/L, Mobay, Shawnee, KS), and killed with an intracardiac lethal dose (1 mL/4.5 kg body wt) of an euthanasia solution (Beuthanasia®-D Special, manufactured for Schering-Plough Animal Health, by Steris Laboratories, Phoenix, AZ). In each experiment, five replicates (first, third, fifth, seventh and ninth) of pigs, from the heaviest to the lightest, were used to obtain kidney weight. Kidneys were removed from the abdominal cavity, connective tissue was trimmed, and organs were blotted on paper towels and weighed. Samples of each kidney were immediately taken, weighed and placed in an oven (65°C) for at least 48 h to determine the dry matter content. Relative fresh weights of kidneys are expressed as gram per kilogram of body weight.

Statistical analyses. Data were analyzed as a randomized complete block design, using individual piglets as the experimental unit, and following the general linear model procedures of SAS (SAS Institute, Cary, NC). Values are reported as means for each diet group with either SEM or pooled SD. Following a significant F test ($P < 0.05$), the Duncan's multiple range test (Steel and Torrie 1980) was used to identify differences among individual groups.

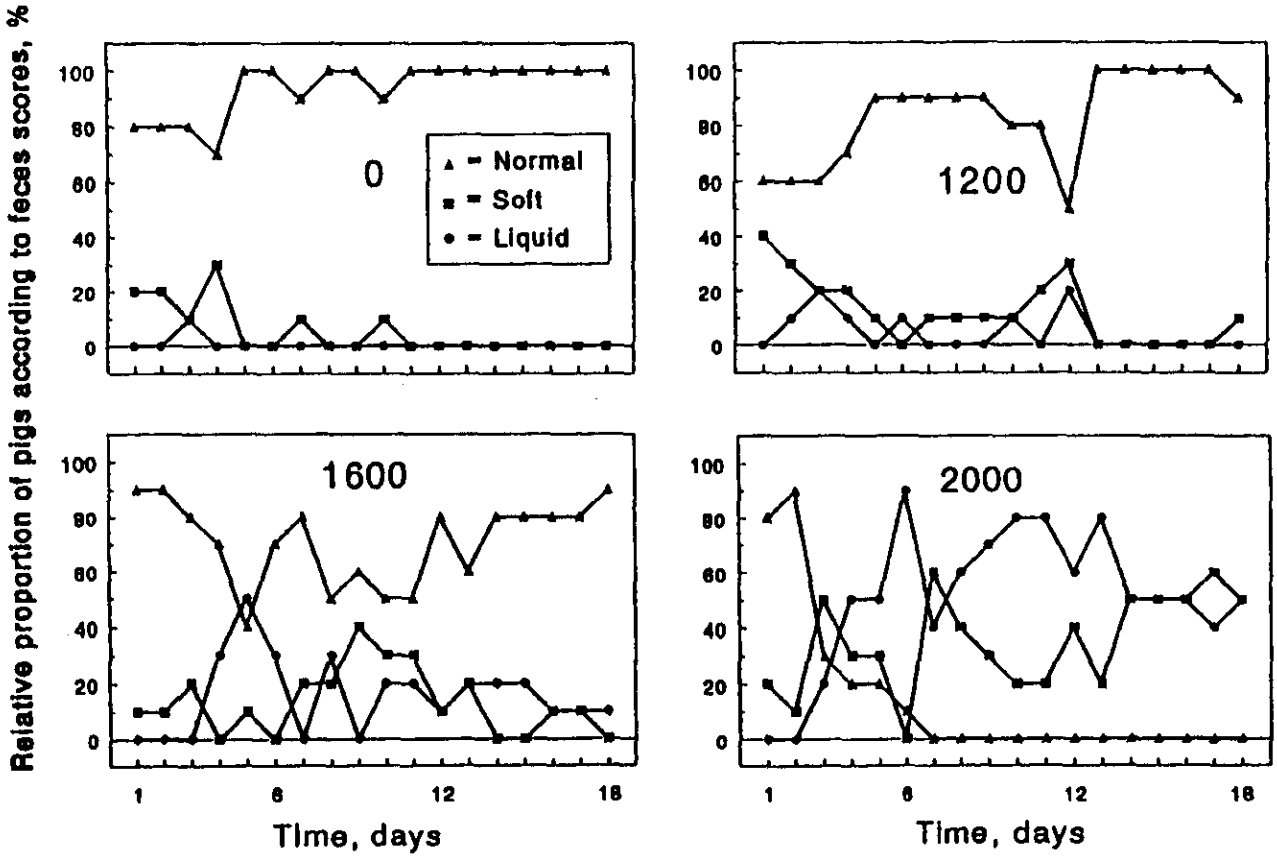

FIGURE 1 (Experiment 1) The effect of level of added inorganic sulfate on feces consistency of artificially reared neonatal piglets. Levels of added sulfate, appearing in each quadrant, are expressed in mg/L of diet. Feces scores were given as 1 = normal, solid feces; 2 = soft, looser than normal stools; and 3 = liquid, diarrheal feces. Values are expressed as the daily relative proportion or distribution (%) of piglets in each diet group (n = 10) according to their feces scores.

RESULTS

Food intake and weight gain. By the end of the adaptation period (from 2 to 5 d of age), piglets had adjusted to the Autosow and were all eating the basal diet normally (feed score of 1). From the beginning of each trial, piglets consumed similar amounts (feed scores of 1, not shown; $P > 0.05$) of all four experimental diets throughout the entire experimental periods, indicating that the levels of added sulfate did not affect food intake. The calculated overall food intakes per pig were 3.76 ± 0.19 (n = 40) and 3.10 ± 0.10 (n = 40) kg of dry matter for Experiments 1 and 2, respectively. Average initial body weights of piglets at 5 d of age were 1.94 ± 0.08 kg (n = 40) and 1.85 ± 0.07 kg (n = 40) for Experiments 1 and 2, respectively. Final body weights were similar ($P > 0.50$) among the four experimental groups in each trial (6.47 ± 0.34 and 6.01 ± 0.41 kg, n = 40 each, for Experiments 1 and 2, respectively). In each experiment, weight gains were similar ($P > 0.05$) for piglets fed the basal diet and the sulfate-supplemented diets. The overall average gains were 267 ± 18 and 278 ± 24 g, n = 40 each, for Experiments 1 and 2, respectively.

Feces consistency. At the beginning of the experiments, between 80 and 100% of the piglets had solid, normal stools. **Figures 1** and **2** present the results for feces consistency as affected by diets in Experiments 1 and 2, respectively. In Experiment 1, the proportion of piglets showing liquid feces consistency increased as the level of sulfate was incremented, but diarrhea response to the highest sulfate level (2000 mg/L) varied between 40 and 80% of piglets in that group throughout the experimental period (Fig. 1). In Experiment 2, practically all (90 to 100%) piglets fed diets with added sulfate of 2000 or 2200 mg/L showed liquid feces consistency beginning 2 d after the start of the trial and persisting throughout the experimental period (Fig. 2). In both experiments, rectal swabs of piglets having softer than normal or liquid feces (scores of 2 or 3) were negative for hemolytic *E. coli* and porcine rotavirus, indicating that piglets had nonpathogenic diarrhea when fed high levels of inorganic sulfate.

Relative kidney weight and sulfate concentration in urine. The relative kidney weights along with their dry matter concentration and the inorganic sulfate concentration in urine at the end of the experimental periods are given in **Table 2**. There were no differences ($P > 0.05$) in fresh kidney weights nor in their dry matter content.

Sulfate concentration in urine of piglets at the beginning of Experiment 1, at 5 d of age, was 2.4 ± 0.2 mol of inorganic sulfate per L ($n = 22$). By the end of the experimental periods, the sulfate concentration in urine of piglets fed the basal diet rose to 8.7 ± 1.1 ($n = 10$) and 8.8 ± 1.1 ($n = 10$) mol/L for Experiments 1 and 2, respectively. Concentration of inorganic sulfate in urine was affected ($P < 0.05$) by dietary levels of inorganic sulfate (Table 2). The highest sulfate concentrations were found in urine of piglets fed diets with added sulfate levels of 1600 and 1800 mg/L for Experiments 1 and 2, respectively.

DISCUSSION

A national secondary drinking water standard (NSDWS) of 250 mg sulfate/L has been established by the U.S. Public Health Service (1962). The appropriate regulatory limit is uncertain because adequate studies have not been performed. The present research was conducted to provide preliminary estimates of the level of sulfate that may be tolerated in human infant formula. Neonatal piglets were selected because their size and intestinal physiology is similar to those of human infants.

All former studies on the effect of sulfate in drinking water in pigs (Anderson and Stothers 1978, Patterson et al. 1979, Veenhuizen et al. 1992) have been performed with older weanling pigs. In those studies, pigs were fed dry diets and the inorganic sulfate source was incorporated in the drinking water, which was supplied separately. In our study, artificially reared neonatal piglets were fed the experimental liquid diets only, and did not have access to any separate source of drinking water. The use of younger pigs reared under strictly controlled conditions with a combined source of nutrient as conducted in our study mimics situations encountered with human infant formula feeding.

The concentration of inorganic sulfate in the deionized, distilled water used was <1 mg/L, whereas the basal diet supplied, on the average, 270 mg/L. Most of the inorganic sulfate in the basal diet originated from the milk-derived ingredients (nonfat dry milk and 8/50-SPL) and to a minor extent from the minute amounts of sulfate salts incorporated in the trace mineral premix. Therefore, between 82 and 89% (for added sulfate levels of between 1200 and 2200 mg/L, respectively) of the total inorganic sulfate in the diets was contributed by the sulfate added to the basal diet.

Apparently, high sulfate concentration imparts a bitter taste to drinking water (Peterson 1951). The human taste threshold for sulfate in water, determined as the concentration at which it affected the taste of brewed coffee, is between 300 and 400 mg/L (Lockart et al. 1955). The concentration of sulfate at which it could be detected by taste in drinking water depends upon the nature of the sulfate salts present. Thus, sulfate from sodium sulfate was detected at an anion concentration range between 169 and 372 mg/L, and sulfate from magnesium sulfate was detected between 320 and 479 mg/L (Whipple 1907). However, the palatability of high sulfate waters seems to be an adaptable phenomenon. Thus, although high sulfate water was considered tasteless by ~50% of the residents in Saskatchewan who regularly drank it, it was not as palatable to the general public (Chien et al. 1968). Our results show that levels of added sulfate as high as 2200 mg/L of diet did not affect diet consumption by artificially reared neonatal piglets.

Addition of 1200 mg sulfate/L had essentially no effect on feces consistency (Fig. 1). Added sulfate levels >1200 mg/L increased the prevalence of diarrhea as evidenced by the higher proportion of piglets showing liquid feces consistence (Fig. 1 and 2). The dose at which 50% of pigs had diarrhea seemed to be between the levels of 1600 and 1800 mg added sulfate/L (Fig. 1 and 2). In both experiments, rectal swabs of piglets that had liquid or softer than normal feces consistency were negative for hemolytic *E. coli* and rotavirus, indicating that the diarrhea observed was not due to these pathogens.

TABLE 2

***Effect of inorganic sulfate level on relative kidney weights and sulfate concentration in urine of artificially reared piglets*[1]**

Level of added sulfate	Kidneys		Urine sulfate
	Fresh wt	Dry matter	
	g/kg body		
mg/L	*wt*	*g/100 g*	*mol/L*
Experiment 1			
0	7.3	17.33	8.7[d]
1200	7.5	17.00	30.2[c]
1600	6.8	17.29	45.5[a]
2000	6.9	17.46	37.2[b]
Pooled SD	0.7	0.71	6.8
Experiment 2			
0	7.4	17.25	8.8[c]
1800	7.3	17.64	56.1[a]
2000	7.5	17.36	32.6[b]
2200	7.1	17.96	35.4[b]
Pooled SD	0.4	0.77	10.7

[1]Values are means, $n = 5$ for kidney data and $n = 10$ for sulfate concentration in urine, except for the group fed the diet with 1800 mg added sulfate/L in Experiment 2 in which $n = 9$. Values in a column of each experiment with unlike superscripts are significantly different ($P < 0.05$) from each other.

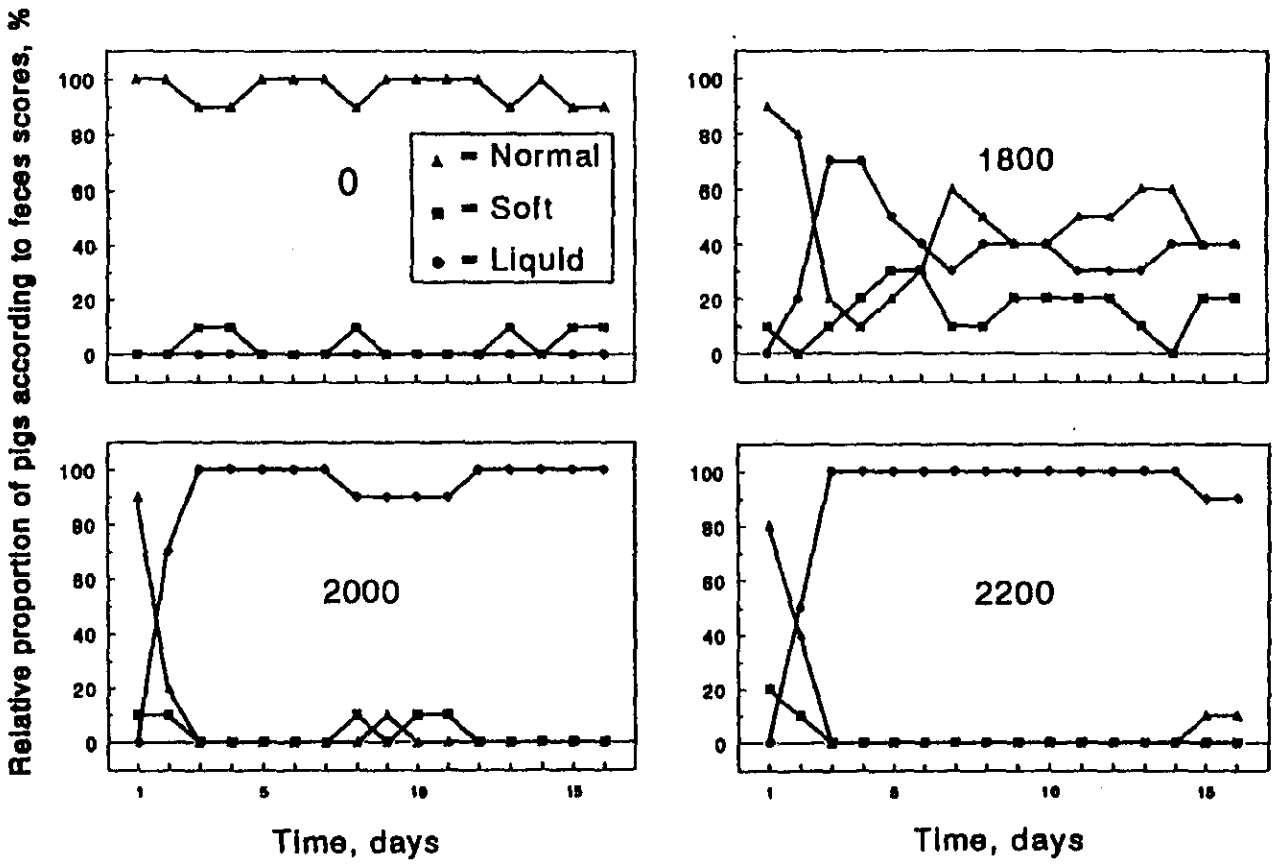

FIGURE 2 (Experiment 2) The effect of level of added inorganic sulfate on feces consistency of artificially reared neonatal piglets. Levels of added sulfate, appearing in each quadrant, are expressed in mg/L of diet. Feces scores were given as 1 = normal, solid feces; 2 = soft, looser than normal stools; and 3 = liquid, diarrheal feces. Values are expressed as the daily relative proportion or distribution (%) of piglets in each diet group (n = 10) according to their feces scores.

The results of this study indicate that nonpathogenic diarrhea was caused when sulfate levels were >1200 mg of added sulfate/L of diet. Chien et al. (1968) described three cases in Saskatchewan of infants who developed diarrhea when given formula made with water containing between 620 and 1150 mg of sulfate/L. Peterson (1951), using survey data collected from water consumers in North Dakota, indicated that a laxative effect was perceived at 750 mg sulfate/L but not at 600 mg/L or less. In a detailed analysis of these data, Moore (1952) concluded that most people experienced a laxative effect when sulfate plus magnesium exceeded 1000 mg/L. However, these conclusions are based on uncontrolled data. The results of the present study suggest that under controlled conditions, neonatal piglets did not experience a laxative effect until the added sulfate concentration in the food formula reached 1200 mg/L.

This study confirms previous reports that high levels of inorganic sulfate did not affect the rate of growth of weanling pigs (Anderson and Stothers 1978, Patterson et al. 1979, Veenhuizen et al. 1992). No significant differences among treatments occurred in the body weight of piglets throughout the entire experimental periods, nor in their overall daily gains. Furthermore, the levels of added sulfate assessed did not affect kidney weights of artificially reared piglets (Table 2).

At the end of the trials, the concentration of inorganic sulfate in the urine of piglets fed the basal diet (8.7 ± 1.1 and 8.8 ± 1.1 mol/L for Experiments 1 and 2, respectively) was ~3 times higher than the average concentration found in the urine of 5-d-old piglets (2.4 ± 0.2 mol/L, n = 22, Experiment 1). The inorganic sulfate concentration in the urine increased ($P < 0.05$) as the level of added sulfate in the diet was incremented, reaching maximum values in urine of pigs fed diets containing between 1600 and 1800 mg added sulfate/L and declining at higher levels (Table 2). These results suggest that levels of added sulfate >1600 mg/L resulted in an apparently higher excretion of sulfate in the feces, which caused the cathartic effects associated with diarrhea.

Sulfate is absorbed by the intestine at a relatively slow rate and, henceforth, sodium and particularly magnesium sulfate are effective osmotic laxatives. There is no information in the literature on the effect of continuous administration of high levels of inorganic sulfate either in the diets or in drinking water on sulfate absorption and excretion. Cocchetto and Levy (1981) studied the absorption of a large amount of sodium sulfate (18.1 g as decahydrate, equivalent to 8.0 g of the anhydrous salt) when administered orally either as a single dose or as four equally divided hourly doses to five healthy men; the 72-h urinary recovery of free sulfate was 53.4 ± 15.8 and 61.8 ± 7.8% for single and divided doses, respectively. Furthermore, whereas the single dose produced severe diarrhea, the divided doses caused only mild or no diarrhea. A study on the absorption of sulfate from orally administered magnesium sulfate (Morris and Levy 1983) in human subjects indicated that the bioavailability of sulfate from magnesium sulfate was lower and more variable than that found with sodium sulfate (Cocchetto and Levy 1981). Magnesium sulfate seemed to be absorbed less completely and more erratically, and produced more adverse effects on bowel function than sodium sulfate (Cocchetto and Levy 1981, Morris and Levy 1983). Although this study was not intended to assess the absorption and excretion of sulfate in artificially reared neonatal piglets, the results suggest that levels of added sulfate, as sodium sulfate, >1800 mg/L of diet altered bowel function, producing a laxative or cathartic effect in practically all piglets that persisted throughout the duration of the feeding trials.

The contribution of dietary sulfate from food sources is considered to be negligible; thus human exposure to sulfate is limited mainly to drinking water. The importance of sulfate as it affects water quality is contingent upon its taste and laxative properties. The reports in the literature indicate that taste as well as laxative properties of sulfate ions depends upon their concentration and the nature of the sulfate salts present in drinking water. Our results were obtained with sodium sulfate only, which seems to have milder laxative properties than magnesium sulfate (Cocchetto and Levy 1981, Morris and Levy 1983).

This study demonstrated that added inorganic sulfate levels as high as 2200 mg/L of diet did not affect growth of artificially reared neonatal piglets. Although 1200 mg added sulfate/L of diet had essentially no effect on feces consistency, levels >1800 mg/L of diet resulted in a persistent, nonpathogenic diarrhea in neonatal piglets. On the basis of the results of this study as well as on the available reports on the effects of sulfate in drinking water, the national secondary drinking water standard set by the U.S. Public Health Service (1962) at 250 mg sulfate/L is a safe quality standard for drinking water furnished by public water supply systems, and this safe limit could probably be set higher.

ACKNOWLEDGMENTS

We express special appreciation to William D. Heizer of the School of Medicine, University of North Carolina, Chapel Hill, for his critical review of the manuscript; J. G. Lecce for his support to this study; R. Goforth, N. Carbajal, O. Thirakoune, and J. Xu for technical assistance; L. Enzor-Manzon for preparation of figures; and Milk Specialties and Central Soya for supplying the 8/50-SPL and vitamin premix, respectively.

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Response of Cow-calf Pairs to Water High in Sulfates[1]

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BEEF 2005 – 05

Summary

Data from our laboratory showed water sulfate levels of 3,000 ppm reduced performance and health of growing steers during summer months. In addition, water averaging 2,600 ppm in sulfates for cow-calf pairs had little impact on calf growth or milk production, but caused small reductions in cow BW and body condition score (BCS). This experiment was conducted to evaluate the effects of high sulfate water on cow and calf performance, milk production, and reproduction. Ninety-six crossbred, lactating cows (ages 2-13; average calving date of April 14) and their calves were assigned, after stratifying by age, weight, and previous winter management, to one of six pastures (16 cows/pasture). Pastures were randomly assigned to one of two water sulfate levels (three pastures/level). Treatments were low sulfate (LS) water (average 368 ± 19 ppm sulfates) or high sulfate (HS) water (average 3,045 ± 223 ppm sulfates). The HS water was created by adding sodium sulfate to the LS water. Cows grazed native range and received a conventional mineral supplement ad-libitum from June 3 to August 26, 2004. Water was provided in aluminum stock tanks. Cow 12-h milk production was estimated by the weigh-suckle-weigh method on August 7. Cows were synchronized with a single injection of prostaglandin and bred by natural service. There were no differences in cow weight or BCS change during the trial ($P > 0.15$). Twelve-hour milk production in August was higher ($P = 0.02$) for LS (9.0 lb) than HS (7.5 lb). Calf ADG tended to be higher ($P = 0.14$) for LS (2.56 lb/d) than HS (2.45 lb/d). The percentage of cows that became pregnant during the first 25 days of the breeding season was higher ($P = 0.06$) for LS (81%) than HS (64%), and final pregnancy rates (55-d breeding season) were 92% and 83%, respectively ($P = 0.20$). Sulfate levels averaging 3,045 mg/L in the drinking water of cow-calf pairs during the summer reduced cow milk production and the number of cows bred early in the breeding season.

Introduction

Our research group continues to evaluate the effects of high sulfate water on cattle, with a goal of defining critical levels of total dissolved solids (TDS) and sulfates in the drinking water. Patterson et al. (2002) reported that water with 3,000 ppm sulfates or greater reduced ADG, DMI, water intake, and gain/feed of growing steers in confinement compared to water with approximately 400 ppm sulfates. Additional work showed a quadratic decline in ADG, DMI, and gain/feed as sulfates in water for confined steers increased from approximately 400 to 4,700 ppm (Patterson et al., 2003). These reports also showed that cattle in confinement consuming water with 3,000 ppm sulfates or greater were at a higher risk of polioencephalomalacia (**PEM;** Patterson et al. 2002; 2003). Based on these studies, we have concluded that the critical level of sulfates in the water for growing cattle during the summer months is 3,000 ppm. Since water requirements increase with elevated temperatures (NRC, 1996), this critical level may be different in various environments.

Johnson and Patterson (2004) reported that water with 3,941 ppm sulfates or greater reduced performance of grazing stocker steers in South Dakota. Few health problems were observed in stocker cattle receiving the high sulfate water over that two-year study. In addition, intermediate levels of sulfates were not tested, so a "critical" level could not be determined. Patterson et al. (2004) reported that water averaging 2,600 ppm sulfates for cow-calf pairs resulted in reduced cow weights but had little impact on reproduction or calf growth. The objective of this study was to evaluate the effects of sulfates in water averaging 3,000 ppm for cow-calf pairs grazing

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native range during the summer on cow and calf performance, milk production, and cow reproduction.

Materials and Methods

The study was conducted from June 3 to August 26, 2004 at South Dakota State University's Cottonwood Range and Livestock Research Station, near Philip, SD. Ninety-six crossbred, lactating cows (ages 2-13 yr; 1281 lb) and their calves (average birth date April 14; ages 18–80 days; 181 lb) were assigned, after stratifying by age, weight, and previous winter management, to one of six pastures (16 cows/pasture). Pastures were randomly assigned to one of two water sulfate levels (three pastures/level). Treatments were low sulfate (**LS**) water or high sulfate (**HS**) water. Water was provided daily in aluminum stock tanks (round tanks; approximately 98 inches in diameter).
The LS water was from a rural water system, and the HS water was created by adding sodium sulfate to LS water to a targeted 3,000 ppm sulfate level. LS water was added to two storage tanks (one provided water for two HS pastures and one provided water for the remaining HS pasture). Sodium sulfate was added to LS water in the storage tanks during the afternoon of each day. Stock tanks were filled the following morning with either LS water or the previously-mixed HS water from the storage tanks. Samples from each water source were taken as stock tanks were being filled. Water samples were composited weekly and sent to the Water Resource Institute in Brookings, SD for sulfate analysis. A locally available commercial mineral was provided to cows in each pasture ad-libitum (13% Ca; 12% P; 13% salt; 2,000 ppm Cu; 8,000 ppm Zn).

On June 3 (trial initiation) and August 26 (trial termination), both cows and calves were weighed and cows were assigned a body condition score (**BCS**; 1-9 scale; Richards et al., 1986) by two trained technicians (to the nearest 0.5 of a BCS). Cow-calf pairs were all on LS water and grazed native range prior to trial initiation. Cows and calves were separated and not allowed access to feed or water for approximately 12 h prior to initial weight measurements. At the end of the trial, all cows and calves were placed on LS water for three days prior to final weight measurements. Cows and calves were separated and housed in a drylot without access to feed or water for approximately 12 h prior to final weight measurements.

On August 7, all cows were used to estimate twelve-hour milk production by the weigh-suckle-weigh method (Boggs et al., 1980). In brief, calves were separated from cows at approximately 0800 the day prior to measurements. Calves were returned to dams at 1800, allowed to suckle until content, and again removed. Calves were weighed the following morning at 0600, returned to dams and allowed to suckle until content, and then weighed again. The difference in calf weight prior to and post-suckling was used as an estimate of 12-h milk production. There were two calves in the LS group that did not suckle their dam, so their data were removed from analysis (LS: n = 46; HS: n = 48).

One two-year-old bull was turned into each pasture on July 2. On July 6, cows were given an injection of prostaglandin F_{2a} (25 mg i.m. ProstaMate, Phoenix, Scientific, Inc., St. Joseph, MO) to synchronize estrus. Bulls were rotated between pastures within treatment on July 29. Bulls were removed from pastures on August 26. Pregnancy was determined by rectal ultrasonagraphy 55 and 88 days following bull turnout. Pregnancies detected at 55 days were determined to be conceived in the first 25 d of the breeding season.

Water disappearance was measured by the daily change in water depth in the tank located in each pasture. This was adjusted for evaporation and precipitation using data collected at a weather station located near the experimental pastures.

Data were analyzed as completely randomized design. Cow and calf weight and cow body condition score data were analyzed by ANOVA in PROC GLM of SAS (SAS Inst. Inc., Cary, NC) with pasture as the experimental unit. Twelve-hour milk production data were analyzed by ANOVA with animal as the experimental unit. Cow pregnancy rates were analyzed by Chi-Square in PROC GENMOD of SAS, with pasture as the observation and animal as the event within observation.

Results and Discussion

Compiling all weekly water composite sample results revealed the LS water averaged 368 ± 19

ppm sulfates, and the HS treatment averaged 3,045 ± 223 ppm sulfates. The HS target of 3,000 ppm was achieved. Patterson et al. (2004) added sodium sulfate directly to stock tanks instead of storage tanks and reported that the target sulfate level of 3,000 ppm was not achieved (average 2,608 ± 408 ppm). Letting the water set in the storage tanks during the afternoon and overnight after mixing salts may have allowed more sulfates to go into solution in this experiment.

One cow from the HS treatment died two weeks prior to the end of the experiment. Diagnostics of brain tissue revealed no indication of PEM but did show high brain sodium levels.

Cow weight change from June 3 to August 26 was not different between treatments (P = 0.17; Table 1). In addition, both groups of cows maintained body condition over the experimental period (P = 0.93; Table 1). Patterson et al. (2004) showed that cows on 2,600 ppm sulfates had higher weight and body condition score loss over the summer than cows on 390 ppm sulfates. Calves in this study tended to have a lower ADG (P = 0.14) when the cow-calf pair was on HS water (Table 1), and the difference was supported by the HS cows having lower (P = 0.02) 12-h milk production than LS cows (Table 2). Patterson et al. (2004) did not report a significant effect of high sulfate water on calf performance or milk production. There was no difference in water disappearance (Table 1).

A higher (P = 0.06) percentage of cows on the LS treatment were bred in the first 25 days of the breeding season (81.3%) than were cows on the HS treatment (63.8%). This difference in early-season pregnancy could impact reproduction and weaning weights the following year. Overall pregnancy rates were not different (P = 0.20) between treatments (LS = 92%; HS = 83%).

It is not evident why results varied between this study and those reported by Patterson et al. (2004). The water in the current study was higher in sulfates and more consistent (narrower range) than Patterson el. (2004) reported. In addition, there were more two-year-old cows in the current study (34/96; 5-6/pasture) than in the former study (17/96; 2-3/pasture). Weather patterns and forage conditions are other possible reasons for differences between studies. Indeed, Johnson and Patterson (2004) reported a vegetation type by water quality interaction for ADG in yearling steers.

It is important to note that in the current study treatments were applied in a very specific and rather narrow time frame (one to four months post-calving). If the cattle were exposed to the HS water at different times, influences of physiological state and temperature may cause different responses. For example, at four to six months post-calving, calves would be expected to consume less milk (as a % of BW) and more water, which could make them more directly affected by water sulfates. Finally, the bull to cow ratio used in this study was approximately 1:16. Lower bull to cow ratios could potentially impact reproduction in high sulfate situations.

We conclude that water provided to cow-calf pairs that averaged 3,045 ppm in sulfates reduced milk production, calf gains, and the percentage of cows bred early in the breeding season.

Implications

High sulfate water had negative impacts on reproduction and calf gains. Grazing cattle receiving high sulfate water may not have the degree of reduction in gain that cattle in confinement have. Additional work should address whether the effects of high sulfate water on reproduction are due to direct of effects of the water, induced trace mineral deficiencies, or both.

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Tables

Table 1. Performance of cow-calf pairs grazing native range and supplied water with low sulfates (average 368 ppm) or high sulfates (average 3,045 ppm) during the summer (Least Squares Means)[a]

	Treatment		
Item	Low Sulfate (LS)	High Sulfate (HS)	SEM
Cow initial weight, lb	1279	1283	16.8
Cow final weight, lb	1305	1290	21.0
Cow weight change, lb	26	9	17.4
Cow initial body condition score	5.54	5.46	0.088
Cow final body condition score	5.45	5.38	0.122
Cow body condition score change	-0.09	-0.08	0.059
Calf initial weight, lb	181	181	6.8
Calf final weight, lb	397	388	8.2
Calf ADG, lb/d	2.56[b]	2.45[c]	0.042
Water Disappearance, gallons/d	18.6	18.2	0.58

[a]Trial lasted from June 3 to August 26, 2004 (84 days); Average calving date of April 14.
[b,c]Within a row, means with unlike superscripts differ (P = 0.14).

Table 2. Estimates of twelve-hour milk production using the weigh-suckle-weigh method for cow-calf pairs grazing native range and supplied water with low sulfates (average 368 ppm) or high sulfates (average 3,045 ppm) during the summer (Least Squares Means ± SEM)[a]

	Treatment	
Item	Low Sulfate (LS)[a]	High Sulfate (HS)[b]
12-h Milk, lb	9.0 ± 0.49[c]	7.5 ± 0.46[d]

[a]n = 46.
[b]n = 48.
[c,d]Within a row, means with unlike superscripts differ (P = 0.02).

THE UNIVERSITY OF BRITISH COLUMBIA

RESEARCH REPORTS

dairy education & research centre

Vol 2 No 9 **December 2002**

Water Quality Affects Cattle Drinking Behaviour and Consumption

Amanda Zimmerman, Doug Veira, Marina von Keyserlingk, Dan Weary and David Fraser

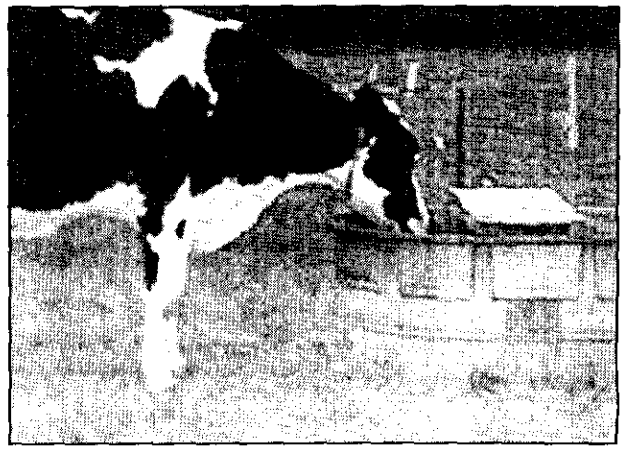
Water forms the largest component of an animal's body and is an essential nutrient required for all biological functions including temperature regulation, digestion, fetal development, and milk production. Dairy cattle require an adequate supply of fresh water – from 75 to over 100 L per day. We know that water consumption is closely tied to feed dry-matter intake and that milk production is dependent upon access to large volumes of water. Thus, if water intake declines due to restricted access or inferior quality, both feed consumption and milk production can be negatively impacted.

It is well established that water quality is one of the most important factors affecting water intake which in turn can affect herd health and milk production. There are two further aspects to consider regarding water quality: what causes water quality to decline, and what happens when cows only have access to poor quality water?

Water quality is reduced when it contains either biological or inorganic contaminants. One of the main biological contaminants found in water available to dairy cows is manure. Manure may contain pathogenic bacteria and when it contaminates drinking water disease can easily spread between animals drinking from the same trough. Inorganic contaminants such as sulphates, which occur naturally in many water sources, also decrease water quality and can lead to nutritional disorders.

Previous research has shown that cattle do not like "bad smelling" water and, not surprisingly, find it unpalatable. We also know that they can learn to associate illness with water flavour. Once cattle establish this link it has been shown that they will actually refuse to continue drinking the water.

Water quality is an issue that affects both the beef and dairy industries. All cattle are sensitive to decreasing water quality whether it is through biological or inorganic contamination. Our research was conducted using beef heifers and steers but the findings apply equally to dairy cattle. We conducted several trials to examine the effect of contaminated water on intake and drinking behaviour of cattle. Our research has shown that cattle respond to decreases in quality by changing their drinking behaviour and reducing their water consumption. In particular, cattle given water containing sulphate compounds such as sodium sulphate and magnesium sulphate found it unpalatable and reacted to their presence in water by changing their drinking patterns, drinking more often at night when compared to the animals that had access to good quality water. Additionally, as sulphate concentration in the water increased, cattle reduced their water consumption (Figure 1).



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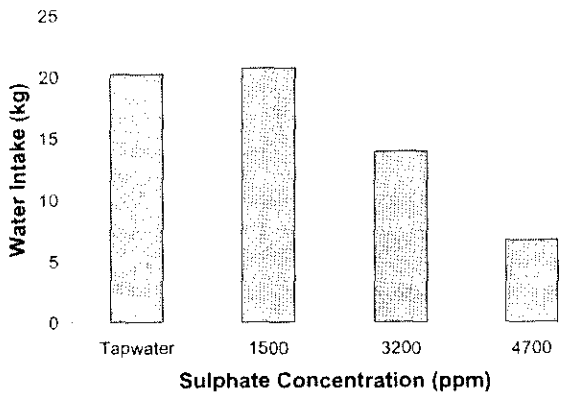

Figure 1. Average water intake per drink, when drinking twice daily, declines as concentration of sulphate (in the form of MgSO4) in drinking water increased.

Other researchers have demonstrated that the presence of manure in water also drastically reduces how much cattle will drink. As manure is one of the most common water contaminants in a dairy barn, it is important to recognize the potential for reduced water intake and impaired milk production.

Additionally, our research demonstrated that some cattle are particularly sensitive to declining water quality and that water intake was reduced when cattle had access to water only twice daily as compared to free access (Figure 2).

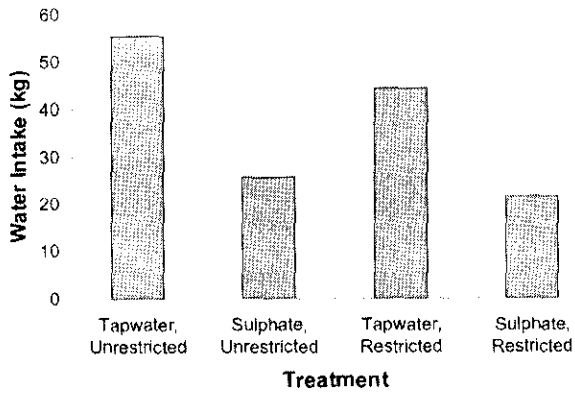

Figure 2. Cattle drink less water per day when it contains sulphate compared to tapwater, and less water when access is restricted to twice daily compared to unrestricted access.

If cattle do not have access to good quality water, their behaviour is affected. When cattle were forced to drink sulphate-contaminated water, we saw a shift towards more aggressive encounters. This could result in even lower water intakes in some animals, negatively impacting milk production and decreasing animal welfare.

Not only is it important that good quality water be provided to dairy cattle, but this clean water must be available at all times. Even if water troughs are dirty only part of the day, cattle may refuse to drink enough water to maintain milk production. The quality of the water supplied to the herd must be carefully monitored, which can be done through visual inspection for manure and simple chemical testing for minerals. Contamination can result in herd health problems or cause cattle to drink less water, negatively impacting feed intake and milk production.

We thank Lavona Liggins and the staff of Agriculture and Agri-Food Canada - Kamloops Range Research Unit for the use of their facilities and their assistance with this research. We are grateful for the financial support of the Beef Cattle Industry Development Fund, the British Columbia Cattlemen's Association, and the dairy industry through the funding of the Animal Welfare Program by the Dairy Farmers of Canada, the British Columbia Dairy Foundation, and the many others listed at www.agsci.ubc.ca/animalwelfare.

This article is based on thesis research of graduate student Amanda Zimmerman. Dr. Veira is an adjunct professor at The University of British Columbia and works closely with the UBC Animal Welfare Program. He is based at the AAFC Kamloops Range Research Unit. Dr. von Keyserlingk is an assistant professor, Dr. Weary an associate professor, and Dr. Fraser a professor in the UBC Animal Welfare Program. For more information on this research, please contact Amanda at amandaz@interchange.ubc.ca.

Best Wishes for a Wonderful Christmas and a Prosperous New Year from the Faculty, Students and Staff of the UBC Dairy Education and Research Centre.

NEXT MONTH: Neck Rail Placement

Default

DRINKING OF SULFATE-WATER BY CATTLE [1, 2]

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ACCORDING to the drinking water standards of the U. S. Public Health Service (1962) sulfate should not be present in a drinking water supply in excess of 250 mg/liter if more suitable supplies are or can be made available. What the physiological effects of such a drinking water might be are not too apparent. Surface and ground waters which contain sulfate in excess of this maximum do occur. Miller, Hardman and Mason (1953) analyzed 1,006 water samples taken from wells, streams and lakes in Nevada. Twenty-three percent of these samples contained more than 250 ppm sulfate. More recently six samples taken from the Stillwater Wildlife Management Area in Nevada contained 364 to 4,757 ppm sulfate (D. Thran, *unpublished data*). Cattle graze on the area, drinking the water. Macfadyen (1953) analyzed water from an area of large gypsum deposits in British Somaliland. Many of the samples contained between 2,000 and 3,000 ppm sulfate and the water from one Village well contained 4,400 ppm sulfate.

There is information on the tolerance of animals (Heller and Paul, 1934; Heller and Haddad, 1936; Ballantyne, 1957; Peirce, 1960) including cattle (Embry *et al.*, 1959) for sulfate in the drinking water. From a review of information available in 1963, McKee and Wolf assumed that water containing 500 mg/liter of sulfate would not be detrimental to livestock. Reported below are the results of a study designed to characterize some of the effects on cattle of drinking water contaminated with a known concentration of sulfate.

Experimental Procedure

Nine Hereford heifers averaging 256 kg body weight were offered *ad libitum* either tap-water, 4,110 ppm NaCl-water or 5,000 ppm Na_2SO_4-water in a 3 x 3 latin square with three replicates experiment. The salts were added to the tap-water which contained 112 ppm sulfate. The length of each water-treatment period was 30 days. Feeding was mixed grass hay *ad libitum*. Proximate analysis of the hay was: protein, 11.7%; ether extract, 2.8%; fiber, 29.2%; ash, 14.2%; and sulfate, 0.75% on a dry matter basis. It contained 5.1% water.

The experiment was conducted during summer. The heifers were in individual, partially shaded pens. Average daily maximum and minimum temperatures were 31 and 8 C, and relative humidity at 4 pm averaged 21%. Water loss from a nearby evaporating pen averaged 7.6 mm per day. Sun was shining 91% of the possible time.

During the last 7 days of each period the heifers were haltered and total urine was collected *via* indwelling, inflation-type catheters. Collected urine was weighed and sampled twice daily. A portion of the sample was acidified for calcium analysis. Samples were stored frozen. On the sixth day of each urine collection week a 2-hr. clearance observation was made, as previously described (Weeth and Lesperance, 1965) on each heifer.

For evidence of dehydration plasma protein concentration was estimated by refractometry (Weeth and Speth, 1968). Osmotic pressures of plasma and urine were determined with a vapor pressure osmometer. Concentrations of total hemoglobin, methemoglobin and sulfhemoglobin were estimated by the method of Hainline (1965). Sodium concentrations were determined by atomic absorption spectrophotometry, calcium by the alizarin method of Natelson and Penniall (1955), and inorganic sulfate by the turbidimetric method of Berglund and Sorbo (1960). Renal clearance and reabsorption estimates were made as suggested by Pitts (1963).

The various items observed were subjected to analyses of variance, and differences among means were tested for significance using Duncan's new multiple-range test (Steel and Torrie, 1960).

Results and Discussion

In a preliminary study with weanling rats it was found that their growth was unaffected

[1] Conducted in cooperation with Western Region Research Project W-46, The Effects of Environmental Stresses on Range Cattle and Sheep Production.
[2] Journal Paper No. 168.

by 7,500 ppm Na_2SO_4 in the drinking water. Total hemoglobin and methemoglobin concentrations were unaltered. There was no detectable sulfhemoglobin in any blood sample. The smallest amount of sulfhemoglobin detectable by the technique used was 1.46 mg/100 ml. On the basis of these observations and those of Embry *et al.* (1959) with cattle, the study described above, but using 7,500 ppm Na_2SO_4 was initiated. Some of the heifers refused to drink this water for 24 hr.; therefore, the experiment was restarted using 5,000 ppm Na_2SO_4. The concentration of NaCl in the chloride-water was adjusted to provide the same sodium concentration (1,619 ppm) as in the sulfate-water.

Water consumption was reduced 35% on the sulfate-water and increased 19% on the chloride-water treatment (table 1). Feed consumption was reduced 30% by sulfate-water, but unaffected by chloride-water. As a consequence, the heifers lost weight while drinking the sulfate-water, but gained weight in equal amounts on the tap- and chloride-water treatments.

As expected (Weeth, Lesperance and Bohman, 1968) the heifers were diuretic when drinking 4,110 ppm NaCl-water (table 1). Urine excretion on the sulfate-water treatment did not differ from the excretion on tap-water, although the Na_2SO_4 reduced water consumption. The percentage of free-water intake lost in urine was significantly higher with sulfate-water than with tap-water. Boyazoglu, Jordan and Meade (1967) noted increased urine excretion without increased water intake by sheep fed 7.6 g sulfate sulfur per day.

Plasma protein concentrations were not altered by the saline waters. Apparently the reduced consumption of sulfate-water caused no anhydremia. That the heifers were able to maintain osmo-equilibrium is also suggested by the unaltered plasma sodium concentrations and osmotic pressures. Both saline waters were hypotonic, the 5,000 ppm Na_2SO_4-water having an osmotic pressure of 101 mOsm/kg and the 4,110 ppm NaCl-water 146 mOsm/kg.

There were no differences among water treatments in total hemoglobin, all values being within a normal range (Schalm, 1965). Drinking the sulfate-water caused a 450% increase in methemoglobin concentration, at which concentration it was 2.8% of total hemoglobin. The NaCl-water had no effect on methemoglobin concentration, therefore, the sulfate ion was involved in the formation of methemoglobin. Finch (1948) stated that certain oxidizing drugs which produce sulf-

TABLE 1. EFFECTS OF DRINKING TAP-, 4,110 ppm NaCl- or 5,000 ppm Na_2SO_4-WATER ON HEREFORD HEIFERS

Item	Drinking water treatment[a]					
	Tap		NaCl		Na_2SO_4	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
Water consumption, kg/day	37	1.6	44	2.5	24	1.9
Feed consumption, kg/30 day	203	5.2	197	9.4	143	7.1
Sulfate intake, g/day	52	1.3	52	2.4	120	8.3
Weight change, kg/30 day	+19	3.4	+22	5.0	−15	3.5
Urine excretion, kg/day	9.2	0.51	16.0	1.23	9.3	0.72
Urine/free water,[b] %	22.1	1.59	34.8	3.12	33.8	1.72
Plasma protein, g/100 ml	7.9	0.10	8.0	0.12	8.0	0.15
Plasma sodium, mg/100 ml	359	4.6	352	3.2	354	6.7
Plasma osmolality, mOsm/kg	294	2.1	296	1.7	298	2.8
Total hemoglobin, g/100 ml	12.1	0.42	11.8	0.52	12.2	0.44
Methemoglobin, mg/100 ml	61.4	14.39	55.2	18.42	337.7	64.75
Sulfhemoglobin, mg/100 ml	30.8	21.28	92.5	33.80	416.9	85.55
Serum sulfate, mg/100 ml	16.8	1.00	15.3	0.96	27.4	2.09
Plasma calcium, mg/100 ml	9.9	0.18	10.0	0.19	10.0	0.22
Urine calcium, mg/100 ml	2.8	0.39	2.0	0.30	3.1	0.76
Creatinine clearance, liter/hr.	24.4	0.88	25.8	0.99	21.4	1.05
Urine osmolality, mOsm/kg	976	25.6	845	25.0	966	42.3
Osmolal clearance, liters/hr.	1.3	0.09	1.9	0.17	1.2	0.12
Free water clearance, ml/hr.	−876	62.4	−1205	103.8	−775	78.0
Sodium clearance, ml/hr.	165	42.2	840	100.4	603	270.4
Filtered sodium reabsorbed, %	99.31	0.190	96.77	0.328	97.18	0.381
Urine sulfate, mg/100 ml	373	28.9	193	14.8	928	72.4
Sulfate filtered, g/hr.	4.06	0.141	3.93	0.252	5.90	0.561
Sulfate reabsorbed, g/hr.	2.91	0.127	2.80	0.193	2.11	0.204

[a] Nine observations per item treatment mean.
[b] Urine water estimated by refractometry (Weeth, Witton and Speth 1969). Free water is water drunk plus feed water.

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hemoglobin also produce methemoglobin. Sulfhemoglobin did appear in the blood of heifers drinking sulfate-water. It was not detected in the blood of any heifer before it had consumed the sulfate-water. After 30 days of drinking the sulfate-water, sulfhemoglobin concentration averaged 3.4% of total hemoglobin. Methemoglobin and sulfhemoglobin are incapable of reversibly combining with oxygen (Finch, 1948), however, in the present study there was no overt evidence of hypoxia. Hematocrit values were unchanged by the sulfate-water treatment ($36.2 \pm 1.26\%$ *vs.* $35.8 \pm 1.31\%$ tap-water).

Wintrobe (1967) states that no symptoms of hypoxia are seen until methemoglobin comprises more than 20% of total hemoglobin, a percentage considerably above that seen in these heifers. Seerley *et al.* (1965) used sheep and Emerick and Embry (1961) cattle with nitrate ingestion to develop a more marked methemoglobinemia, but reported no symptoms of hypoxia. Oxidation of hemoglobin to methemoglobin occurs rapidly in ruminants (Smith and Beutler, 1966) but fortunately the natural reduction of methemoglobin occurs most readily in ruminants. Harris *et al.* (1968) observed a significant reduction in oxygen transport by human blood when methemoglobin comprised 7.6% of total hemoglobin. In the present study with cattle the concentrations of non-functional hemoglobins were only approaching this level.

The sulfate-water treatment increased serum sulfate 63%. Ingested inorganic sulfate is readily absorbed by the bovine (Hansard and Mohammed, 1969), perhaps in the upper alimentary tract. Serum sulfate concentrations reflect dietary intakes of sulfur (Weir and Rendig, 1954). Some ingested sulfate is reduced to sulfide in the rumen (Lewis, 1954) and absorbed. Some of the sulfide can be fixed in amino acids (Block and Stekol, 1950). As observed by Evans and Davis (1966), and in the present study, cattle ingesting large amounts of sulfate occasionally produced a pronounced hydrogen sulfide odor. The source of the odor was not established, however, Brav (1969) stated that hydrogen sulfide could be detected on the breath of sheep infused intraruminally with sodium sulfide.

From the present study it does not appear that the chronic consumption of 5,000 ppm Na_2SO_4-water caused any hypocalcemia or hypercalcuria in the heifers (table 1). The concentration of calcium in the urine was small and highly variable on all treatments. Others have shown that intravenous infusion (Wolf and Ball, 1950; Walser and Browder, 1959) or feeding (Goodrich and Tillman, 1966) of inorganic sulfate adversely affects absorption and retention of calcium.

Endogenous creatinine clearance was reduced 12% ($P<.05$) by the sulfate-water, but unchanged with the chloride-water treatment. The reason for the reduced creatinine clearance of heifers while drinking sulfate-water, is not apparent. Clearance urine volumes were not lower on the sulfate-water. Walser and Browder (1959) state that glomerular filtration rates usually remained within normal limits when dogs were infused with sulfate salts.

As seen in previous studies (Weeth *et al.*, 1968; Thornton, 1970), heifers had a saline diuresis while consuming the chloride-water. This is indicated by the decreased daily urine osmotic pressure, increased osmolal clearance and increased reabsorption of solute-free water (table 1). Similar effects were not seen with sulfate-water drinking. Both saline waters affected renal clearance, reabsorption and excretion of sodium in a manner expected with sodium loading of cattle (Weeth *et al.*, 1968).

Drinking water containing 5,000 ppm Na_2SO_4 increased the concentration of inorganic sulfate in the urine (table 1). Urinary excretion of sulfate was increased 150%. This sulfate-water increased the renal filtration of sulfate by 45%. Sodium chloride loading had no effect on sulfate filtering or reabsorption. The sulfate-water treatment reduced the renal reabsorption of sulfate. Consequently, as a result of the increased filtering and decreased reabsorption, the percentage of filtered sulfate which was reabsorbed was only 36 for the sulfate-water treatment *vs.* 72 for tap-water. This is, of course, advantageous to the animal ingesting large amounts of sulfate. Goudsmit, Power and Bollman (1939) noted with dogs the ratio of sulfate to creatinine clearance was normally about 0.10 and reached 0.70 when plasma sulfate increased from 9.3 up to 21.8 mEq/liter. In the present study the ratio increased from 0.27 to 0.63 as serum sulfate concentrations increased from 10.5 to 17.1 mEq/liter. Lotspeich (1947) observed that reabsorption of sulfate was not increased as plasma concentration in dogs was increased by sulfate infusion. Wolf and Ball (1950) concluded that the sulfate ion was diuretic with a low threshold. The peculiar problem which the bovine with a high potassium intake could have in the renal excretion of ex-

cessive sulfate has been mentioned by Pickering (1965).

The adverse effects noted when heifers drank water containing 5,000 ppm Na_2SO_4 appear to be at variance with observations of Embry *et al.* (1959). They observed definite toxicity when growing cattle were watered with 10,000 ppm Na_2SO_4, but animals were unaffected by 7,000 ppm Na_2SO_4-water. Furthermore, a 10,000 ppm solution of mixed salts containing 6,817 ppm of sulfate was not deleterious. The season was summer, but water consumption appears slightly lower than in the present study. Their data do indicate, as does this experiment, that there is a toxicity with the sulfate ion not seen with chloride. Peirce (1960) offered mature sheep a mixed NaCl-Na_2SO_4 saline drinking water containing 5,000 ppm Na_2SO_4 in a 15-month study. Body weight was unaffected, although water consumption and plasma sulfate were increased. There was no hypocalcemia. Lotspeich (1947) has shown that an excess of chloride anion in tubular fluid of the dog decreased the transport maximum for sulfate ion. It is apparent, however, from this study that growing Hereford heifers were unable to tolerate during summer drinking water containing 3,493 ppm of inorganic sulfate.

Summary

Nine growing Hereford heifers were offered as drinking water either tap-water, 5,000 ppm Na_2SO_4-water or 4,110 ppm NaCl-water. The experimental design was a 3 x 3 latin square with replicates. Experimental periods were 30 days. Total urine was collected on the last 7 days with renal clearance observations being made on the sixth day. The season was summer.

The heifers drank less, ate less and lost weight while consuming the sulfate-water. The sulfate ion caused a relative diuresis. Percent urine water of free-water intake was 33.8 with sulfate-water, but only 22.1% with tap water. Total hemoglobin concentration was unaffected by the saline drinking waters, however, the sulfate-water caused a 450% increase in methemoglobin concentration and the development of 416.9 mg/100 ml of sulfhemoglobin. The two nonfunctional hemoglobins comprise 6.2% of total hemoglobin at this time. Drinking the sulfate-water increased serum sulfate concentration 63.1%, increased renal filtration of sulfate 45.2%, but decreased renal reabsorption of sulfate by 27.5%. Drinking sulfate-water did not alter plasma calcium concentration or renal excretion of calcium. A specific toxic effect of drinking the Na_2SO_4-water was not apparent, however, the adverse effects seen were related to the sulfate ion. Only a slight polyposia and diuresis were observed with drinking of the NaCl-water.

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EFFECTS OF SULFATE IN WATER ON SWINE REPRODUCTION AND YOUNG PIG PERFORMANCE[1]

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Summary

Thirty-one sows and 27 gilts were each allotted to three treatments to study the effect of water quality during gestation and lactation. Sodium sulfate was added to the water to give sulfate and total dissolved solids in ppm as follows: (1) 320, 620, (2) 1,820, 2,840 and (3) 3,320, 5,060. Water was offered *ad libitum* from about 30 days postbreeding through 28 days lactation. There were no significant differences in gestation or lactation gains and number or weight of pigs at birth or at weaning. Fecal consistency was normal in all treatments. Water consumption did not differ during gestation but increased during lactation as salt level increased. These results suggest that sulfates up to and including 3,320 ppm in water have no significant effect on reproduction in the gilt or sow.

Fifty-four weaned pigs representing the above three sow treatments equally were given water with 0, 3,000 ppm added sulfate from sodium sulfate or 3,000 ppm added sulfate from magnesium and sodium sulfate in a 1:1 ratio for a 28-day period. No significant treatment differences ($P<.05$) occurred in average daily gain or feed to gain ratio. Scouring was more common with fecal condition less firm ($P<.01$) and water consumption greater ($P<.05$) among pigs that received water with added sulfates. No differences were observed in pigs that received water containing sodium sulfate or equal parts of sulfate from sodium and magnesium sulfate.
(Key Words: Water Quality, Sulfates, Swine, Reproduction, Pigs.)

Introduction

Highly saline water are found in many parts of the western half of the United States (Subcommittee on Nutrient and Toxic Elements in Water, NRC, 1974). Often these are the most readily available or the only sources of livestock water. Several studies on the tolerance of livestock for saline waters have been reported as reviewed by Anderson and Stothers (1978). Of the salts naturally present, chlorides and sulfates predominate. It has been suggested that the sulfates are the more harmful (Heller, 1933; Weeth, 1973), and that cattle and sheep are more resistant to the effects of saline water than are swine (Heller, 1933).

Experimental data on the effects on swine of drinking waters of high sulfate content are limited. Such data are essential to the evaluation of drinking water involvement in poor performance or actual losses in swine. What data are available are confined to weanling pigs. Embry *et al.* (1959) reported the addition of up to 6,300 ppm of a salt mixture to the drinking water of weanling pigs increased water intake and caused a temporary diarrhea but had no harmful effect on performance during the 80-day trial. The salt mixture and the water to which it was added gave a sulfate content of 4,400 ppm. Anderson and Stothers (1973) reported similar findings with weanling pigs allowed water containing about 6,000 ppm of total dissolved salts (TDS) containing up to 2,400 ppm of sulfate. Their data did suggest some slight but not statistically significant reduction in feed intake and increase in feed to gain ratio. Although the effects of salinity and sulfate on reproduction and the rearing of the young have not been reported for swine, The Committee on Water Quality Criteria (1972) suggest that water containing over 5,000 ppm of TDS should be avoided for pregnant animals. Unconfirmed reports have suggested that a concentration of about one-half this level might be harmful. This experiment was conducted to investigate the effects of high sulfate waters given to swine during gestation and lactation and to their offspring when weaned at 28 days.

[1] Published with the approval of the Director of the South Dakota Agr. Exp. Sta. as Publication No. 1631 of the Journal Series.

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Experimental Procedure

The reproductive trial involved 31 sows and 27 gilts of Hampshire × Yorkshire × Duroc breeding. Sows and gilts were grouped separately on the basis of ancestry and weight. Outcome groups were randomly assigned to the three treatments, shown in table 1, about 30 days postbreeding. The local water supply was used as a control and for making up the experimental waters. Sodium sulfate was selected as the salt for addition. A 10% solution of the salt (analytical grade) was added as appropriate to give the desired concentrations. Sulfate content was determined weekly by a turbidimetric method (Anonymous, 1973). The averages with their standard deviations for the entire experimental period were as follows: control, 320 ± 24 ppm; low sulfate, 1,790 ± 35 ppm and high sulfate, 3,298 ± 139 ppm.

During gestation, all animals were housed in uninsulfated, wooden, colony type houses located in dry lots. Feed was restricted to 1.8 kg per head daily and fed in individual feeding stalls. Water was available *ad libitum* from 227 liter circular tank waterers. Self-feeders containing the lactation diet and the 227-liter waterers were located in concrete lots outside the farrowing house. Sows were allowed access to this lot for feed and water each morning and evening for 2.0 and 1.5 hr, respectively. Saline water was available in the creep area for pigs after 10 days of age. Fortified corn-soybean meal diets with 10% alfalfa meals (gestation) and 10% beet pulp (lactation) included .5% trace mineralized salt. Calculated crude protein content was 12.65 and 15.70% for gestation and lactation diets, respectively.

At parturition, the number of live and stillborn pigs as well as litter weight and average pig weight were obtained. Litter weight at 14 days, number of pigs at 28 days, litter weight and average pig weight at 28 days were recorded.

To determine the effect of water quality on the offspring after weaning, 54 4-week-old pigs, initially averaging 7.5 to 8.0 kg, were allotted into nine groups. Each group consisted of two pigs from each of the three sow treatments. These groups were randomly allotted to three replications of three treatments: (1) control water, (2) 3,000 ppm of added sulfate from sodium sulfate and (3) 3,000 ppm of added sulfate supplied equally from magnesium and sodium sulfate. Each 2.4 × 3 m pen contained six pigs. All pigs were offered water and an 18% protein, fortified corn-soybean meal diet *ad libitum* for the 28-day trial. Fecal condition was scored on a one to five basis, with one being most firm.

Data were analyzed by least squares analysis of variance. Least square means are presented in all tables.

TABLE 1. TOTAL DISSOLVED SOLIDS, SULFATE AND SODIUM CONCENTRATIONS IN CONTROL AND EXPERIMENTAL WATERS (PPM)[a]

Treatment	Total dissolved solids	Sulfate	Sodium
Control	620	320	20
Low sulfate	2840	1820	740
High sulfate	5060	3320	1460

[a]Values for control water by analysis. Values for low and high sulfate treatments were calculated from analysis of the water and the known salt additions.

Results and Discussion

Sulfate content of water consumed during gestation had no significant effect on gestation gain, number of pigs per litter at birth (total and live) or average pig and litter birth weights (table 2). Lactation gain, number of pigs at 28 days and average pig and litter weights at 28 days were not significantly affected by sulfates in water during lactation. Slightly less saline water was consumed during gestation. However, in lactation, water consumption increased ($P>.05$) as total dissolved solids increased. Gilts consumed more water than sows during gestation but slightly less during lactation.

Significant differences existed in gestation and lactation gain between gilts and sows. Gilts gained more during gestation and also gained an average of 5.5 kg during lactation, while sows lost an average of 7.0 kg during this time.

The general condition and performance of the pigs during the 28-day nursing period were similar among groups. No excessive scouring was noted in any of the treatments. Roy and Boyland (1964) also reported no excessive scouring problem when 4,500 ppm total solids were added to the water of four sows and their litters over a 6-week period.

No significant differences occurred at 28 days in average daily gain or feed to gain ratio among weaned pigs that received the control water and those that consumed saline water containing 3,000 ppm of added sulfates (table 3). Sulfate was added as sodium sulfate or

TABLE 2. EFFECT OF SULFATE CONTENT OF WATER ON REPRODUCTIVE PERFORMANCE

Parameter	Added sulfates (ppm) 0	1500	3000	Gilts	Sows
No. litters	12	13	14	16	23
Avg gestation gain, kg[a]	30.2	27.5	26.0	41.0	18.6
Avg lactation gain, kg[b]	1.5	−5.5	1.7	5.5	−7.0
Water consumption, liters/day					
Gestation	13.3	11.2	10.6	15.1	9.2
Lactation	13.6	14.2	16.8	14.4	15.5
Pigs/litter					
Total	11.1	10.9	10.0	9.8	11.7
Live	9.6	10.0	8.2	8.7	9.9
Avg pig birth weight, kg[b]	1.4	1.4	1.5	1.3	1.5
Avg litter birth weight, kg	13.5	13.5	11.8	11.6	14.2
No. pigs at 28 days	6.7	6.9	6.3	6.5	6.8
28-day pig weight, kg	6.1	6.2	6.3	6.1	6.4
28-day litter weight, kg	40.4	42.2	40.2	39.5	42.3

[a]Significant difference ($P<.01$) between gilts and sows.

[b]Significant difference ($P<.05$) between gilts and sows.

equally from sodium and magnesium sulfate to provide 5,080 ppm total solids. Similar results have been reported by Berg and Bowland (1960) with 12-kg pigs supplied with 5,000 ppm of TDS and Anderson and Stothers (1978) for 4- to 6-kg pigs that consumed water with 6,000 ppm total solids. These workers found no significant differences in gains or feed efficiency between control pigs and those that received saline water.

Water consumption increased significantly among treatments. Approximately 30% more water was consumed by pigs that received saline water that contained sodium and magnesium sulfates and 50% more water was consumed by pigs on the sodium sulfate treatment. Anderson and Stothers (1978) reported a similar magnitude of increase in water consumption

TABLE 3. EFFECTS OF MAGNESIUM AND SODIUM SULFATES ON PERFORMANCE OF WEANED PIGS

Parameter	Water treatment Control	Sodium sulfate[a]	Magnesium-sodium sulfate[b]
No. of pigs[c]	16	18	17
Avg initial wt, kg	7.5	8.0	7.7
Avg final wt, kg	13.4	15.0	13.8
Avg daily gain, kg	.21	.25	.22
Feed to gain ratio	2.25	2.05	2.18
Avg daily water consumption, liters	1.25[d]	1.89[e]	1.63[f]
Avg fecal condition[g]	1.7[h]	3.3[i]	3.6[i]

[a]Three thousand ppm of sulfate.

[b]Three thousand ppm of total sulfates from magnesium and sodium sulfates.

[c]Three replications of six pigs per treatment. Three pigs died, data not included.

[d,e,f]Means on same line with different superscripts are significantly different ($P<.05$).

[g]Based on a score of 1 to 5, with 1 being firm.

[h,i]Means on same line with different superscripts are significantly different ($P<.01$).

during the initial week and an average 17% increase during a 6-week trial. Sulfate content of their water was only 2,400 compared to 3,320 ppm in this experiment; however, TDS was higher in their water.

A significant difference existed in average fecal condition between pigs that received control or saline water. Scouring was considerably more evident during the first 2 weeks in pigs that received saline water. High levels of sulfate in water have been shown to cause scouring in young pigs (Anderson and Stothers, 1978) and growing-finishing pigs (Embry *et al.*, 1959) without affecting growth performance. Anderson and Stothers (1978) also reported fecal dry matter was reduced 2 to 6% for pigs that received water that contained TDS and sulfate contents of 6,000 and 2,400 ppm, respectively.

Although saline water consumption of sows also increased during lactation, there was no evidence of scouring in either sows or their nursing pigs. This study did not allow one to determine the amount of total dissolved solids in water necessary to cause problems in reproducing swine. However, the results confirm the recommendation of the Committee on Water Quality Criteria (1972) that water containing 5,000 ppm total solids is not harmful, even when it contained 3,320 ppm sulfates.

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EFFECTS OF SALINE WATER HIGH IN SULFATES, CHLORIDES AND NITRATES ON THE PERFORMANCE OF YOUNG WEANLING PIGS[1]

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SUMMARY

Three experiments were conducted involving 162, 4 to 6 kg pigs group fed. Nine pigs were allotted per treatment according to breed, weight and sex and received feed and water *ad libitum*. Each experiment had a control treatment (125 ppm total solids) compared to saline water treatments (approximately 6,000 ppm total solids) high in either sulfates or chlorides. In addition the sulfate water was treated with 150 ppm nitrate nitrogen (NO_3-N) or with 300 ppm NO_3-N while the chloride water was also treated with 300 ppm NO_3-N. Average final weights in experiment I and III were 20 kg after 6 weeks on test while average final weights in experiment II were 9 kg after a 3-week test. No significant treatment differences ($P < .05$) occurred in average daily gain in any experiment. However, with the exception of the pigs given the chloride water in experiment III, the control pigs tended to consume more feed, gain faster and have a better F/G than those receiving 6,000 ppm total solids, particularly in experiment I.

Scouring was consistently more common among the sulfate water fed pigs than either the control of chloride fed pigs. Approximately 80% of the scouring occurred in the first week on test. Water consumption was generally higher for saline water treatments. No treatment differences occurred among liver vitamin A values, kidney weights, or kidney histological structure in the four pigs per treatment sacrificed at the end of Experiment 1. In conjunction with experiment 1, blood, fecal and urine samples were collected from two pigs per treatment housed in metabolic cages. Urinary sodium was significantly higher ($P < .01$) and fecal dry matter percent tended to be less for pigs receiving the sulfate water with or without the added NO_3-N.

(Key Words: Saline Water, Nitrates, Sulfates, Chlorides, Weanling Swine, Water Consumption.)

INTRODUCTION

Heller (1933) reported that sodium chloride at 15,000 parts per million (ppm) in water was toxic to pigs, especially for pigs weighing less than 45 kilograms. Subsequently several workers experimented with saline water containing a variety of pure and mixed salts at different levels from 2,000 ppm to as high as 20,300 ppm total solids with pigs tested most commonly within the weight range of 20 to 90 kg (Embry *et al.*, 1959; Berg and Bowland, 1960; Stothers, 1960; Stothers and Palmer, 1961; Stothers, 1970). Results ranged from slightly improved average daily gain, feed consumption and feed efficiency (Embry *et al.*, 1959) when pigs received up to 6,300 ppm total solids, to decreased growth rates, poorer feed efficiency and higher water consumption when the total solids content of the water was 15,900 ppm or higher (Stothers, 1960).

Case (1957, 1963) suggested that levels of nitrate nitrogen (NO_3-N) above the recommended maximum level of 10 ppm for humans could be potentially hazardous for pigs. Seerley *et al.* (1965) administered nitrate and nitrite continuously in drinking water at levels up to 300 ppm NO_3-N for growing-finishing pigs with no performance differences among treatments although they did note measurable but small increases in blood methemoglobin.

Thus, separately, research has been reported on the effects of high levels of total solids and of NO_3-N (saline waters) on the performance of growing pigs. No studies have been reported

[1] Financial support for this project provided by Feedrite Mills (1962) Ltd., Manitoba Pool Elevators and the Manitoba Department of Agriculture.

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considering the effects of these two factors in combination.

Field observations by producers and extension workers have related poorer pig performance to the use of saline waters. Most of the data available are for older pigs and with the trend to earlier weaning (3 weeks), information is required on the response of the younger pig which is generally more sensitive to its environment. Since evaluation of water analyses requested by producers indicated the predominant salts were chlorides, sulfates and minor amounts of nitrates with the total of all salts at a maximum of approximately 6,000 ppm total solids, these experiments were initiated with 3- to 4-week-old weaned pigs (4 to 6 kg) to study the effects of saline waters having a total solid concentration of approximately 6,000 ppm, high in either sulfates or chlorides, alone or in combination with either 150 ppm or 300 ppm NO_3-N.

MATERIALS AND METHODS

Three experiments, involving 162 Managra or Managra x Yorkshire pigs, group fed, nine per treatment, were conducted with a control water treatment compared to saline water treatments containing either sulfates or chlorides alone or in combination with either 150 ppm NO_3-N or 300 ppm NO_3-N (table 1).

Newly weaned pigs between 3 and 4 weeks of age, and initially weighing 4 to 6 kg, were allotted to treatment by weight, sex and litter. Saline water prepared in plastic containers was available to pigs *ad libitum* from 64 liter painted metal barrels fitted with watering bowls. Feed was available *ad libitum*. A commercial feed (18% protein) for early weaned pigs was fed to an average weight of 7 kg at which time the ration was changed to a prestarter (wheat-soybean meal-fish meal, 19% protein). After reaching a weight of approximately 15 kg pigs received a starter ration (barley-soybean meal, 18% protein). All rations were balanced to meet or exceed the NRC (1973) nutrient requirements for swine with .5% trace mineralized salt added to all rations. Combination of the sodium chloride in the dry feed and mixed salts in the water gave a total salt intake equivalent to 11,000 ppm for the saline treatments pigs and 5,000 ppm for the control treatment pigs. Pens were checked daily for scouring and water consumption while pig weight and feed consumption were recorded weekly in Experiments I, II and III.

During Experiment I blood samples were drawn on days 24 and 31 from three pigs per treatment selected at random for analysis of percent methemoglobin by the method of Evelyn and Malloy (1938). At the termination of experiment I, four pigs per treatment (two per replicate) were sacrificed. Liver samples were taken, frozen and maintained at −20 C for subsequent analysis of Vitamin A content by the method of Gallup and Hoefer (1946). Kidney weights were recorded and slices of kidney were prepared for histological examination using the standard Harris hematoxylin and eosin staining technique (American Registry of Pathology, 1968).

Concurrent with Experiment I, an additional two barrows per treatment were housed in circular, adjustable wire mesh metabolism cages, described by Bell (1948), fitted with bite waterers, for a total of three 7-day periods for collection, separation and subsequent analysis of feces and urine. Test periods were days 1 to 7, 8 to 14 and 29 to 35. Quantities of daily urine and fecal excretions were recorded. Representative aliquots of urine and feces were retained and stored at −20 C for future analysis of sodium and potassium by flame photometry using a Technicon II (Model AA11-07).

Fecal samples retained from odd numbered days were analyzed for percent dry matter by freeze drying in a Virtis freeze dryer and for percent ash by ashing at 500 C for 15 hours. To the ashed samples 5 ml of demineralized water was added and the samples shaken for 24 hr before analysis of sodium and potassium by flame photometry. The remainder of the fecal samples, those collected and retained from even numbered days, were subjected to a Carver laboratory press (Model C) from which expressed juice was diluted and analyzed for sodium and potassium concentration, using the same procedure as for the other fecal samples. Fecal sodium and potassium data were reported in milliequivalents excreted per day. Blood samples were drawn from the anterior vena cava on day 15 of the test and analyzed for percent hematocrit, plasma sodium and potassium ion concentrations.

Statistical analysis was accomplished by the method of Steel and Torrie (1960). If analysis of variance was significant ($P<.05$) means were differentiated using Student-Neuman-Keuls Test (SNK).

TABLE 1. SALT COMPOSITION OF WATER TREATMENTS AND EXPERIMENTAL DESIGN USED IN WEANLING PIG EXPERIMENTS

	Water treatments					
Item	Control	Sulfate	Sulfate plus 150 ppm NO_3-N	Sulfate plus 300 ppm NO_3-N	Chloride	Sulfate plus 300 ppm NO_3-N
A. Salt composition of water treatments						
Salt[a]						
Calcium chloride	...	780	780	780	780	780
Magnesium sulfate	...	1694	1694	1694	...	...
Sodium bicarbonate	...	2671	1844	1040	2671	1040
Sodium nitrate	...	...	910	1818	...	1818
Sodium sulfate	...	708	708	708	...	...
Sodium chloride	...	...	...	...	2401	2401
Total solids[b]	125	5978	6061	6065	6077	6164
B. Experimental design						
Experiment I[c,d]	18	18	18	18		
Experiment II	9	9			9	9
Experiment III	18				18	18

[a]Salt quantities and total solids reported in parts per million (ppm).

[b]Total solids concentration includes that found in control water plus added salts.

[c]Experiments I and III were replicated with nine pigs/trt/replicate. Experiment duration was 42 days for Experiments I and III and 21 days for Experiment II.

[d]Experiment I treatments also used in a metabolic cage study.

RESULTS AND DISCUSSION

No significant differences occurred in average daily gain among treatments (table 2). Feed consumption and feed to gain ratio indicated a similar result. These results are in general agreement with those of Berg and Bowland (1960) using 12 kg pigs receiving 5,000 ppm of total solids in the water with no supplemental salt in the diets, Roy and Boylan (1964) using 6-week-old, 13 kg pigs receiving a chloride water containing 4,300 parts per million total solids and Stothers (1970) using water containing 2,000 ppm total solids fed to 6.4 kg pigs who found no significant differences between control pigs and those receiving saline waters.

Although there were no significant differences in experiment I there was a tendency for ADG to be higher for the control pigs, whereas in both experiment I and III the ADF were slightly higher for the control pigs than those receiving saline water treatments. F/G was generally more favorable for the control pigs with the exception of chloride plus 300 ppm NO_3-N in experiments II and III. Stothers (1970) indicated a similar trend towards decreased ADG and F/G when pigs received saline waters.

Water consumption was generally higher for the saline treatments as compared to water consumption by the controls with the difference being most apparent during the initial week on test. Although overall difference in water consumption was 5 to 15% higher in favor of the saline water treatments for the entire experimental period the difference was most pronounced during the initial week when saline water consuming pigs recorded intakes 33 to 66% greater than the controls.

Similarily with respect to scouring, the incidence was more pronounced during the initial adaptation period (first week on test). Eighty percent of all the scour days were observed during the initial period. The pigs receiving sulfate containing water had 148 to 182% more scour days than the controls during the initial week whereas the pigs receiving chloride containing water had slightly fewer scour days. Since the scour days did not persist and little or no loss of condition accompanied their occurrence the scouring could be considered to be of a dietary nature. The work by Stothers (1970) and comments by Herrick (1971) describe the cathartic effect of high levels of sulfate in water on young pigs evident only during the first week on experiment.

Performance of 3-week-old pigs as measured by weight gain and feed consumption was not adversely affected by levels of NO_3-N up to 300 ppm NO_3-N. F/G for sulfate plus NO_3-N pigs was slightly poorer than for sulfate alone. Inclusion of NO_3-N to the chloride water did not produce the same results (table 2). Seerley *et al.* (1965) supplied 300 ppm NO_3-N or 100 ppm NO_2-N in water to older pigs with no resulting reduction in weight gains or general thriftiness.

Concern has been expressed regarding the conversion of nitrate to nitrite. Case (1963) reported nitrite to be 10 to 15 times more toxic than nitrate from farm water supplies. Using mixtures of minced grass and water Barnett (1953) reported a range of 13 to 26% conversion of nitrate to nitrite. Seerley *et al.* (1965) noted slight conversion of nitrate to nitrite which they attributed to bacterial contamination of the drinking cups used resulting in subsequent microbial reduction of the nitrate. In our experiments, assuming a 25% conversion to nitrite, the 300 ppm NO_3-N water treatment would result in a consumption of water containing 75 ppm NO_2-N. This level, significantly higher than the 10 ppm NO_3-N proposed by Case (1963) as potentially hazardous did not result in reduced weight gains among the young pigs.

Methemoglobin content of the blood expressed in gram per 100 ml of blood (table 3) indicated elevated levels as the amount of NO_3-N increases in the water. These values were the same whether measured on days 24 or 31 of the experiment. Control animal values of .09 g methemoglobin per 100 ml blood were identical to those reported by Seerley *et al.* (1965), .09 g methemoglobin per 100 ml blood for older pigs (32.6 kg body weight). Seerley *et al.* (1965) reported methemoglobin values of .34 and .47 g/100 ml blood for pigs receiving 100 ppm NO_2-N. Highest values obtained for 300 ppm NO_3-N in this experiment were .24 g/100 ml blood representing half the highest value given by Seerley *et al.*

Liver vitamin A stores were unaffected by the levels of NO_3-N in the water (table 3). Seerley *et al.* (1965) found similar results with levels of (0, 25, 50, 100 ppm) NO_2-N given to older pigs, although their vitamin A liver values were lower (14.4 to 17.4 μg/g) than results reported in this experiment. According to Garrison *et al.* (1966) growing and finishing pigs receiving NO_3-N at 420 ppm and 0 ppm showed significant difference ($P<.05$) in liver stores of vitamin A. Since in our tests no significant dif-

TABLE 2. PERFORMANCE OF WEANLING PIGS RECEIVING VARIOUS WATER TREATMENTS IN EXPERIMENTS I, II AND III

	Water treatment					
Item	Control	Sulfate	Sulfate plus 150 ppm NO_3-N	Sulfate plus 300 ppm NO_3-N	Chloride	Chloride plus 300 ppm NO_3-N
Experiment I						
ADG[a] (kg/day)	.40	.33	.35	.37		
ADF[a] (kg/day)	.79	.71	.75	.74		
Feed/gain	1.89	2.02	2.32	2.28		
ADWC (1/day)[b]	1.15 (.66)[c]	1.35 (1.04)	1.31 (.85)	1.36 (.86)		
Scour days[d]	3.5 (3.5)[e]	6.0 (8)	6.5 (8)	6.5 (6.5)		
Experiment II						
ADG	.19	.18			.19	.18
ADF	.45	.42			.45	.40
Feed/gain	2.35	2.41			2.41	2.28
ADWC	.80 (.63)	1.24 (1.01)			1.21 (1.06)	1.14 (1.01)
Scour days	0 (0)	5 (5)			1 (1)	2 (2)
Experiment III						
ADG	.35				.31	.35
ADF	.70				.62	.63
Feed/gain	2.00				2.01	1.84
ADWC	.88 (.59)				.09 (.72)	1.15 (.79)
Scour days	2 (4)				1 (2)	0 (0)

[a]ADG is average daily gain, ADF is average daily feed both reported in kg/day.

[b]ADWC is daily water consumption (liters/day) reported only for first 3 weeks since almost enire treatment differences occurred during this period.

[c]ADWC in parenthesis are consumption during the first week on experiment.

[d]Scour days reported for first week only; 1 scour day represents any amount of scouring occuring within a pen regardless of the number of animals involved.

[e]Scour days in parenthesis are for the total experimental period.

TABLE 3. METHEMOGLOBIN, LIVER VITAMIN A AND KIDNEY SIZE AS RELATED TO SALINE WATERS USED IN EXPERIMENT I

Item	Water treatment			
	Control	Sulfate	Sulfate plus 150 ppm NO_3-N	Sulfate plus 300 ppm NO_3-N
Methemoglobin[a] (g)	.09 ± .03	.14 ± .09	.22 ± .04	.24 ± .06
Vitamin A liver values (μg/g)	60.7 ± 5.3	69.4 ± 7.0	62.2 ± 9.7	55.0 ± 7.0
Kidney size[b] (%)	.44 ± .02	.52 ± .01	.50 ± .01	.48 ± .03

[a]Methemoglobin expressed as g methemoglobin/100 ml blood. Means of samples taken days 24 and 31.

[b]Kidney size expressed as a % of warm carcass weight.

ferences occurred among treatments it can be assumed that very little nitrate was reduced to nitrite coinciding with little oxidation of vitamin A in the gastrointestinal tract. This finding is also supported by Emerick and Olson (1962) who found liver vitamin A stores of rats to be affected by dietary nitrite but not dietary nitrate. Liver stores of vitamin A did not reflect conversion of nitrate to nitrite therefore the increased methemoglobin blood levels could be due to the nitrate content of the water and not caused by nitrite converted from nitrate by microbial reduction.

No apparent treatment differences occurred in kidney weights (table 3) or histological sections of kidney supporting the suggestion that young pigs can adapt themselves to levels of salinity of approximately 6,000 ppm.

Performance data from the metabolic cage studies (table 4) support the data presented from experiment I and II with the exception of F/G where the metabolism caged pigs tended to be more efficient. No apparent treatment differences in blood hematocrit, sodium and potassium were observed. Male pigs housed in the circular cages minimized the possibility of contamination of the urine by feces even during the periods when scouring occurred. Urine volumes were unaffected by treatment. Urinary potassium excretions were similar among treatments but urinary sodium excretions were significantly higher ($P<.01$) in the saline water treatments. No differences were observed in fecal sodium and potassium values between the two methods of preparing feces for analysis although the expressed juice method required less sample preparation time. Mean fecal sodium values ±SEM were 38.3 ± 28.4 meq/day and 41.6 ± 30.7 meq/day while mean fecal potassium values ±SEM were 77.1 ± 10.0 meq/day and 80.5 ± 10.6 meq/day for the ashing procedure and expressed juice procedures, respectively.

Although there were no differences among treatments for fecal % ash, fecal sodium and fecal potassium, the fecal dry matter percent seems to reflect the cathartic effect of the sulfate ion for the saline treatments tend to be lower than the controls by 2 to 6%. Pigs housed in the metabolic cages showed a slightly greater number of scour days with generally little effect on performance.

No marked adverse biological effects were observed among the pigs receiving saline waters with or without added NO_3-N. The addition of

TABLE 4. PERFORMANCE, BLOOD, URINE AND FECAL DATA AS RELATED TO SALINE WATERS USED IN METABOLIC CAGE STUDY OF EXPERIMENT I

Item	Water treatment			
	Control	Sulfate	Sulfate plus 150 ppm NO_3-N	Sulfate plus 300 ppm NO_3-N
A. Performance				
ADG (kg/day)	.33	.34	.28	.30
ADF (kg/day)	.48	.47	.41	.56
Feed/gain ratio	1.45	1.38	1.46	1.87
ADWC (1/day)	1.71	2.09	2.05	1.75
Scour days	1	9	11	7
B. Blood[a]				
Hematocrit (%)	31.8 ± .4	28.6 ± .5	31.8 ± 1.0	31.1 ± 1.5
Serum sodium (meq/1)	140.1 ± 1.4	140.6 ± 1.5	146.1 ± 2.6	152.1 ± 6.8
Serum potassium (meq/1)	4.9 ± .4	4.9 ± .2	4.1 ± .5	4.8 ± .3
C. Urine and fecal				
Urine volume (ml/day)	593 ± 124	595 ± 132	574 ± 175	585 ± 118
Urinary sodium (meq/1)	35.3 ± 34.2B[b]	85.8 ± 34.2A	77.3 ± 34.2A	92.1 ± 34.2A
Urinary potassium (meq/1)	51.7 ± 4.4	56.6 ± 10.6	45.3 ± 5.7	73.9 ± 21.5
Fecal ash (%)	15.1 ± 2.0	16.5 ± 1.8	15.4 ± 1.4	18.1 ± 2.1
Fecal sodium (meq/day)	22.0 ± 30.0	52.7 ± 29.6	42.8 ± 29.6	42.5 ± 29.6
Fecal potassium (meq/day)	82.5 ± 5.8	82.6 ± 11.6	76.0 ± 12.9	74.0 ± 10.9
Fecal dry matter (%)	26.2 ± 1.9	22.6 ± 1.4	19.7 ± 1.1	24.0 ± 1.4

[a]From blood samples drawn on day 15.

[b]Means in the same row followed by different superscripts are significantly different (P<.01) using Student Newman Keuls (SNK).

150 or 300 ppm NO_3-N to water resulted in small increases in methemoglobin in blood. Significantly higher sodium urinary excretion and the tendency toward lower fecal dry matter percent were accompanied by the higher water consumption recorded for pigs receiving saline waters high in sulfate and sodium salts.

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Water for Dairy Cattle

Cooperative Extension Service
College of Agriculture and Home Economics

Guide D-107

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This publication is scheduled to be updated and reissued 2/07.

INTRODUCTION

Water constitutes 60 to 70 percent of a livestock animal's body. Water is necessary for maintaining body fluids and proper ion balance; digesting, absorbing, and metabolizing nutrients; eliminating waste material and excess heat from the body; providing a fluid environment for the fetus; and transporting nutrients to and from body tissues. Dairy cattle get the water they need by drinking and consuming feed that contains water, as well as from metabolic water produced by the oxidation of organic nutrients. Water loss from the body occurs via urine, feces, and milk; through sweating; and by evaporation from body surfaces and the respiratory tract. The amount of water lost from a cow's body is influenced by the animal's activity, air temperature, humidity, respiratory rate, water intake, feed consumption, milk production and other factors. This publication covers water intake guidelines and water quality issues for dairy cattle.

WATER INTAKE AND REQUIREMENTS

Lactating cows: Drinking water or free water intake satisfies 80 to 90 percent of a dairy cow's total water needs. The amount of water a cow drinks depends on her size and milk yield, quantity of dry matter consumed, temperature and relative humidity of the environment, temperature of the water, quality and availability of the water, and amount of moisture in her feed. Water is an especially important nutrient during periods of heat stress. The physical properties of water are important for the transfer of heat from the body to the environment. During periods of cold stress, the high heat capacity of body water acts as insulation–conserving body heat. Water intake (lbs/day) for lactating cows can be predicted from the following equation:

Water intake, lbs/day =
35.25 + 1.58 x Dry matter intake (lbs/day)
+ 0.90 x Milk yield (lbs/day)
+ 0.11 x Sodium intake (grams/day)
+ 2.65 x Weekly mean minimum temperature (°F/1.8 – 17.778)

The equation predicts water consumption will change 1.58 pounds for each 1.0-pound change in dry matter consumed, 0.90 pounds for each 1.0-pound of milk produced, 0.11 pounds for each gram of sodium consumed, and 1.47 pounds for each degree Fahrenheit (F) change in weekly mean minimum temperature. Weekly mean minimum temperature typically is 10 to 15 °F lower than mean daytime temperature. Table 1 lists the estimated daily water intake for lactating cows using the above equation.

Table 1. Estimated daily water consumption for a 1,500-pound lactating cow producing 40 to 100 pounds of milk daily[a].

Milk Production (lbs/day)	Estimated DM Intake (lbs/day)	Mean Minimum Temperature[b]				
		40°F	50°F	60°F	70°F	80°F
		gallons per day[c]				
40	42	18.4	20.2	22.0	23.7	25.5
60	48	21.8	23.5	25.3	27.1	28.9
80	54	25.1	26.9	28.7	30.4	32.2
100	60	28.5	30.3	32.1	33.8	35.6

[a]Sodium intake = 0.18% of DM intake.

[b]Mean minimum temperature typically is 10 to 15° F lower than the mean daytime temperature.

[c]1 gallon of water weighs 8.32 pounds.

Dry cows: The major factors affecting free water intake of dry cows are concentration of dry matter in the diet, dry matter intake and amount of protein in the diet. Water intake of dry cows can be estimated by the following equation:

Water intake, lbs/day =
-22.80 + 0.5062 x Diet dry matter (%)
+2.212 x Dry matter intake (lb/day)
+0.0869 x Diet crude protein $(\%)^2$

For example, a 1,500-pound nonlactating cow that eats 28 pounds of dry matter containing 12 percent moisture and 12 percent crude protein would consume 96 pounds (11.6 gallons) of water per day at air temperatures between 50°F and 80°F. Water intake may be 120 to 200 percent greater during periods of heat stress.

Calves and heifers: During the liquid feeding stage, calves receive most of their water as milk or milk replacer. However, studies show that calves offered water by free choice in addition to a liquid diet gain faster and consume dry feed earlier than calves provided water only in their liquid diet. Therefore, it is recommended to provide water by free choice to calves receiving liquid diets to enhance growth and dry matter intake.

Weaned dairy heifers consume approximately 1.0 to 1.5 gallons of water per 100 pounds of body weight (table 2). As with all livestock, water should be fresh, clean and always available. Care should be taken to ensure adequate water supplies during periods of heat stress.

Table 2. Estimated water intake for dairy heifers.

Weight	Air Temperature		
(lbs)	40°F	60°F	80°F
	gallons per day		
200	2.0	2.4	3.3
400	3.8	4.6	6.1
600	5.4	6.5	8.7
800	6.8	8.2	11.0
1000	8.0	9.6	12.7
1200	9.0	10.8	14.5

DRINKING BEHAVIOR

Providing the opportunity for livestock to consume a relatively large amount of clean, fresh water is essential. Water is consumed several times per day and generally is associated with feeding or milking. Cows may consume 30 to 50 percent of their daily water intake within 1 hour after milking (fig. 1). Reported rates of water intake vary from 1 to 4 gallons per minute. On the basis of farm studies, the length of water troughs should be 2 inches per cow with an optimal height of 24-32 inches. Reducing the height 2 to 3 inches may be logical for Jerseys. Water depth should be a minimum of 3 inches to allow the animal to submerge its muzzle 1 to 2 inches. Provide at least one watering device for every 15 to 20 cows, or a minimum of 2 feet of tank space per 20 cows. At least two water locations are needed in the loafing area for each group of cows. For confinement operations, waterers should be allocated at milking parlor exit and within 50 feet of the feed bunk or at every crossover in freestall barns. Heifers should be provided at least one watering space per 20 animals with a minimum of two waterers per group.

The temperature of drinking water has only a slight effect on drinking behavior and animal performance. Under most circumstances, responses to chilling water would not warrant the additional cost. Given a choice, cows prefer to drink water with moderate temperatures (63-82°F) rather than very cold or hot water.

WATER QUALITY

Water quality is an important issue in dairy cattle production and health. The five properties most often considered in assessing water quality for both humans and livestock are organoleptic properties (odor and taste), physiochemical properties (pH, total dissolved solids, total dissolved oxygen and hardness), along with the presence of toxic compounds (heavy metals, toxic minerals, organophosphates and hydrocarbons), excess minerals or compounds (nitrates, sodium sulfates and iron) and bacteria and algae. Research on water contaminants and their effects on cattle performance are sparse. The following discussion attempts to define some common water quality problems in relation to cattle performance.

Salinity, total dissolved solids (TDS) **and total soluble salts** (TSS) are measures of constituents soluble in water. Sodium chloride is the first consideration in this category. Other components associated with salinity, TDS, or TSS are bicarbonate, sulfate, calcium, magnesium and silica. A secondary group of constituents, found in lower concentrations than the major constituents, includes iron, nitrate, strontium, potassium, carbonate, phosphorus, boron and fluoride. Guidelines for TDS in water for dairy cattle are presented in table 3.

Research has shown feedlot cattle drinking saline water (TDS = 6,000 parts per million, ppm) had lower weight gains than cattle drinking normal water (TDS

= 1,300 ppm), when the ration's energy content was low and during heat stress. High-energy rations and cold environmental temperatures negated the detrimental effects of high-saline water consumption. Likewise, milk production of dairy cows drinking saline water (TDS = 4,400 ppm) was not different from that of cows drinking normal water during periods of low environmental temperature. But it was significantly lower during summer months. Cows offered salty water drank more water per day (36 versus 32 gallons per cow) over a 12-month period than cows drinking normal water.

Table 3. Guidelines for use of saline waters for dairy cattle.

Total Dissolved Solids (ppm)	Comments
Less than 1,000	Presents no serious burden to livestock.
1,000 to 2,999	Should not affect health or performance,but may cause temporary mild diarrhea.
3,000 to 4,999	Generally satisfactory, but may cause diarrhea especially upon initial consumption.
5,000 to 6,999	Can be used with reasonable safety for adult ruminants. Should be avoided for pregnant animals and baby calves.
7,000 to 10,000	Should be avoided if possible. Pregnant, lactating, stressed or young animals can be affected negatively.
Over 10,000	Unsafe. Should not be used under any conditions.

ppm = parts per million

Hardness is generally expressed as the sum of calcium and magnesium reported in equivalent amounts of calcium carbonate. Other cations in water, such as zinc, iron, strontium, aluminum and manganese, can contribute to hardness but usually are very low in concentration compared with calcium and magnesium. Hardness categories are listed in table 4. Water hardness has no effect on animal performance or water intake.

Table 4. Water hardness guidelines.

Category	Hardness, milligrams/liter[a]
Soft	0-60
Moderately hard	61-120
Hard	121-180
Very hard	> 180

[a]1 grain/gal = 17.1 milligrams per liter

Nitrate can be used in the rumen as a source of nitrogen for synthesis of bacterial protein, but reduction to nitrite also occurs. When absorbed into the body, nitrite reduces the oxygen-carrying capacity of blood and in severe cases results in asphyxiation. Symptoms of nitrate or nitrite poisoning are labored breathing, rapid pulse rate, frothing at the mouth, convulsion, blue muzzle and bluish tint around eyes, and chocolate brown blood. More moderate levels of nitrate poisoning have been linked to poor growth, infertility problems, abortions, vitamin A deficiencies, reduced milk production and general unhealthiness.

The general safe concentration of nitrate in water is less than 44 ppm and less than 10 ppm of nitrate-nitrogen (table 5). In evaluating potential nitrate problems, feed also should be analyzed for nitrate in that the effects of feed and water are additive.

Sulfate guidelines for water are not well-defined, but general recommendations are less than 500 ppm for calves and less than 1,000 ppm for adult cattle. When sulfate exceeds 500 ppm, the specific salt form of sulfate or sulfur should be identified, since the form of sulfur is an important determinant of toxicity. Hydrogen sulfide is the most toxic form and concentration as low as 0.1 milligrams per liter can reduce water intake. Common forms of sulfate in water are calcium, iron, magnesium and sodium salts. All are laxative, but sodium sulfate is the most potent. Cattle consuming water high in sulfates (2,000–2,500 ppm) show diarrhea initially, but appear to become resistant to the laxative effect. Iron sulfate has been reported to be the most potent depressor of water intake compared with other sulfate forms. Water and feed with high sulfate contents have been linked to polioencephalomalacia (thiamin deficiency) in beef calves.

Table 5. Concentration of nitrates (NO_3) and nitrate-nitrogen (NO_3-N) in drinking water and expected response.

NO_3 (ppm)	NO_3-N (ppm)	Comments
0-44	10	No harmful effects.
45-132	11-20	Safe, if diet is low in nitrates and nutritionally balanced.
133-220	21-40	Could be harmful if consumed over a long period of time.
221-660	41-100	Dairy cattle at risk; possible death losses.
661-800	101-200	High probability of death losses; unsafe.
Over 800	Over 200	Do not use; unsafe.

ppm = parts per million

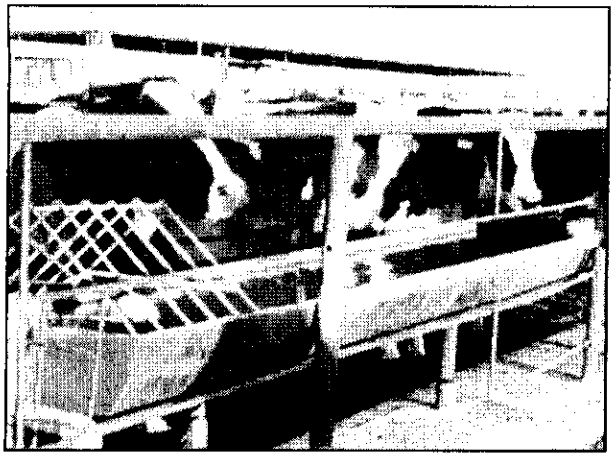

Figure 1. Cows may consume 30 to 50 percent of their daily water intake within 1 hour after milking.

pH is a measure of acidity or alkalinity. A pH of 7 is neutral, less than 7 is acidic and more than 7 is alkaline. Little is known about the specific pH's effect on water intake, animal health and production, or the microbial environment in the rumen. The preferred pH of drinking water for dairy animals is 6.0 to 8.0. Waters with a pH outside of the preferred range may cause nonspecific effects related to digestive upset, diarrhea, poor feed conversion and reduced water and feed intake.

Microbiological analysis of water for coliform bacteria and other microorganisms is necessary to determine sanitary quality (fig. 2). Since some coliform bacteria are soil borne or nonfecal, a fecal coliform test may be used to determine if the source of total coliform is at least in part from feces. A fecal streptococci test may be run on fresh samples to determine if the contamination is from animal or human sources. If fecal coliforms exceed fecal streptococci, human sources of pollution may be suspect. If fecal streptococci exceed fecal coliform, animal sources of pollution are indicated. For animal consumption, especially young calves, total and fecal coliform counts should be less than 1 per 100 milliliters. For adult animals, total and fecal coliform counts should be under 15 and 10 per 100 milliliters, respectively. It is recommended that fecal streptococci counts not exceed 3 or 30 per 100 milliliters for calves and adult cattle, respectively.

Total bacteria count measures virtually all pathogenic as well as noninfectious bacteria that use organic nutrients for growth. Total bacteria counts in excess of 500 per 100 milliliters may indicate water-quality problems. Water sources with total bacteria counts in excess of 1 million per 100 milliliters should be avoided for all livestock classes. Most water supplies will have counts below 200 per 100 milliliters continuously.

Blue-green algae have been reported to cause illness when cattle are allowed to consume water containing this organism. Although the causative agent has not been identified specifically, cattle should be prevented from drinking water with heavy algae growth. Symptoms in blue-green algae poisoning include ataxia or incoordination of voluntary muscle movement, bloody diarrhea, convulsions and sudden death. This is an occasional problem in freestanding water, such as farm ponds. Shading water troughs and frequent sanitation will minimize algae growth.

Other potentially toxic compounds and organisms sometimes are found in water and can pose a health hazard to cattle. For safe consumption, water contaminants should not exceed the guidelines in table 6. However, many dietary, physiologic and environmental factors affect these guidelines and make it impossible to accurately determine the concentrations at which problems may occur.

Table 6. Generally considered safe concentrations of some potentially toxic nutrients and contaminants in water for cattle.

Item	Upper-Limit Guideline (ppm)
Aluminum	0.50
Arsenic	0.05
Barium	10.0
Boron	5.0
Cadmium	0.005
Chromium	0.10
Cobalt	1.0
Copper	1.0
Fluoride	2.0
Iron	2.0
Lead	0.015
Manganese	0.05
Mercury	0.01
Nickel	0.25
Selenium	0.05
Vanadium	0.10
Zinc	5.0

ppm = parts per million

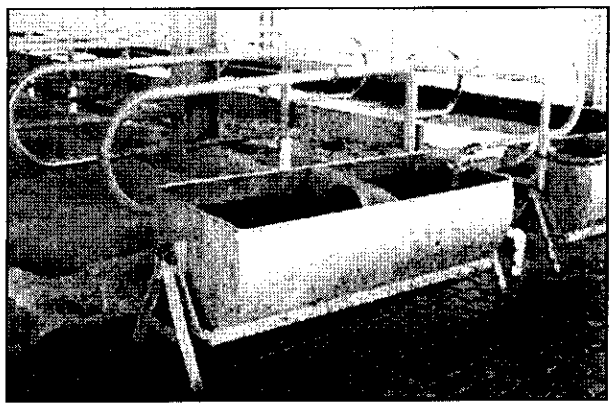

Figure 2. Microbiological analysis of water for coliform bacteria and other microorganisms is necessary to determine sanitary quality.

WATER SAMPLING AND TESTING

Typically, 1 or 2 quarts of water from the source in question should be adequate to complete any needed tests. Samples may be sent to any accredited commercial or state operated laboratory for analyses. Producers should consult with their herd veterinarian or state Extension personnel for assistance in selecting a laboratory, as well as for assistance in selecting appropriate tests and interpreting results.

SUMMARY

Water availability and quality are extremely important for animal health and productivity. Limiting water availability to cattle will depress production rapidly and severely.

The most common water quality problems affecting livestock production include high concentrations of minerals (excess salinity), high nitrogen content (nitrates and nitrites), bacterial contamination, heavy growth of blue-green algae and accidental contamination by petroleum, pesticides or fertilizer products.

On the basis of the scientific literature, no widespread specific production problems have been caused by consumption of low quality water. Poor water quality might cause reduced production or nonspecific diseases and should be one aspect investigated when there are herd health and production problems.

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Printed February 2002

Las Cruces, NM
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Salinity and Livestock Water Quality

Criteria for judging the suitability of water for livestock have been suggested in the past by several sources. Often these criteria have been based on observation, although in some instances experimental work has been done to assist in their development. However, the lack of experimental work and the variation among standards that have been published made the establishment of criteria for use at this experiment station difficult. Therefore, research to assist in the development of reasonably accurate standards for livestock was undertaken.

Some have recommended that standards for livestock waters should be the same as they are for human consumption. This, however, would eliminate from use dams, dugouts, and certain other common sources because they would fail to meet bacteriological standards. In addition, animals possibly can tolerate higher salinities than can humans, and it is conceivable that they differ from man in their tolerance for certain specific substances. Actually, the standards used for water for human consumption are obviously much higher in many respects than is necessary for livestock waters.

In establishing standards for livestock waters, several factors must be considered. These include microbial contamination, presence of toxic inorganic chemicals, presence of organic toxins, accidental contamination with agricultural chemicals, alkalinity, and salinity. Of these, salinity seems to be most often involved in causing waters to be unfit for livestock in South Dakota. For this reason, the studies reported here have dealt entirely with salts or mineral content.

The tolerance of livestock and poultry toward minerals in water will depend on many things, including: kind of animal, age, season of year, climate, kind of salts in the water, physiological condition of the animal, and feed. All of these variables could not be included in the work reported here. However, rats, cattle, poultry, and swine were used and several types of salts were studied. The experiments with the different animals are reported separately.

RAT STUDIES

Experiments with albino rats were undertaken preliminary to work with large animals. The purpose here was two-fold: (1) to compare several kinds of salts and get some idea of their relative toxicities; and (2) to establish what concentrations of salts would be best used in experimental work with large animals.

Methods

Male albino rats (Sprague-Dawley) were placed on experiment at an average weight of about 68 grams. They were housed on wire

in individual cages and were allowed feed and water free choice. The temperature of the room in which they were housed was maintained at about 75-80° F. The experiment was terminated at 50 days.

The diet used for each group of rats was as follows: corn, 77.9%; casein, 15.0%; brewer's yeast, 2.0%; salts (USP XIV), 2.0%; a vitamin B_{12} concentrate (Nutritional Biochemicals Corp.), 0.1%; and cottonseed oil (Wesson), 3.0%. Vitamins A and D were administered orally twice each week.

The plan of the experiment is shown in table 1. While the rats were housed individually, feed and water consumption were measured by group. Five rats were used per group, and a control group receiving distilled water was used for each salt mixture. Five different salts were studied, each being added to the drinking water at four levels. Analytical grade salts were used in making up each of the waters.

Table 1. Effect of Saline Drinking Waters on Rats

Group	Salt used	Concentration of salt in drinking water		Average daily gain of rats, gm.	Feed consumed/ rat/day, gm.	Water consumed/ rat/day, ml.
		Equivalents/l.	p.p.m.			
I	None			6.18	17.7	37.2
II	Sodium chloride	0.05	2,923	6.44	16.2	38.1
III	Sodium chloride	0.10	5,845	6.14	20.5	49.2
IV	Sodium chloride	0.15	8,768	6.37	19.0	48.0
V	Sodium chloride	0.20	11,690	6.03	18.6	39.0
VI	None			6.16	17.7	35.0
VII	Sodium sulfate	0.05	3,552	6.20	17.6	43.5
VIII	Sodium sulfate	0.10	7,103	6.06	17.9	42.2
IX	Sodium sulfate	0.15	10,655	5.88	17.7	42.2
X	Sodium sulfate	0.20	14,206	5.39	17.5	36.8
XI	None			6.18	16.8	36.2
XII	Magnesium chloride	0.05	2,381	6.07	17.8	37.8
XIII	Magnesium chloride	0.10	4,762	5.98	17.8	37.1
XIV	Magnesium chloride	0.15	7,143	5.58	15.8	36.0
XV	Magnesium chloride	0.20	9,524	4.93	16.2	41.2
XVI	None			6.02	16.7	34.4
XVII	Magnesium sulfate	0.05	3,010	6.16	17.4	39.4
XVIII	Magnesium sulfate	0.10	6,019	5.56	16.7	31.9
XIX	Magnesium sulfate	0.15	9,029	5.71	17.7	36.8
XX	Magnesium sulfate	0.20	12,038	5.60	16.0	34.6
XXI	None			6.00	16.5	39.6
XXII	Calcium chloride	0.05	2,775	6.04	17.6	33.1
XXIII	Calcium chloride	0.10	5,550	6.07	15.6	36.3
XXIV	Calcium chloride	0.15	8,325	6.10	17.8	27.4
XXV	Calcium chloride	0.20	11,100	5.84	15.0	27.8

Results and Discussion

Results of the work with rats are summarized in table 1. The various salts and concentrations used appeared to have no consistently great effect on feed consumption. Sodium chloride in the drinking water appeared to increase water intake, especially at the intermediate levels. Essentially the same was true for sodium sulfate. The magnesium salts had no particular effect on water consumption at any of the concentrations used. Calcium chloride reduced water intake at all concentrations.

The average daily gains for the rats were little affected by sodium chloride at any of the levels used. Sodium sulfate and the magnesium salts caused reduced growth rates at the higher levels. Calcium chloride had some slight effect in reducing daily gains at the highest level.

None of the animals died during the experiment, and while several showed symptoms of diarrhea on the sulfate salts, the symptoms were mild. Reduction in rate of gain seemed the most obvious effect of the saline waters.

These experiments indicated that the establishment of the exact level at which a salt or a mixture of salts becomes toxic or harmful would be difficult. Levels below 4,000 parts per million (p.p.m.) of a salt in the drinking supply appeared to have no adverse effect, while 10,000 p.p.m. usually did. On

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Concentration of salt in drinking water		Average daily gain	Feed consumed/ rat/day,	Water consumed/ rat/day,
Equivalents/l.	p.p.m.	of rats, gm.	gm.	ml.
		6.18	17.7	37.2
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CATTLE STUDIES

The salts commonly present at high concentrations in excessively saline waters of South Dakota are sodium sulfate, sodium chloride, and magnesium sulfate. Either sodium chloride or sodium sulfate will often account for over 75% of the total salts in these waters, while magnesium sulfate usually accounts for lesser amounts. As a rule magnesium sulfate is accompanied by high levels of sodium sulfate and some chlorides.

In view of this, the cattle studies were made with sodium chloride, with sodium sulfate, and with a mixture of magnesium sulfate with these two salts. The first trial, with sodium sulfate, included three levels of the salt, 4,000, 7,000 and 10,000 p.p.m. The second trial, involving the other salts, was limited to the two higher levels.

Methods

First trial. Twenty-four heifers in medium condition and weighing an average of about 670 pounds were started on the first trial on June 27, 1957. They were weighed without shrink and allotted into four uniform lots of six each.

All lots were fed alike. Alfalfa hay was limited to 6 pounds per head daily, and a concentrate mixture composed of 95% rolled shelled corn and 5% soybean meal was full fed.

Trace mineral salt and a mineral mixture (3 parts bone meal, 1 part limestone, and 1 part trace mineral salt) were offered free choice. The cattle were implanted with diethylstilbestrol after being on the experiment about 1 month.

Water from the Brookings water system was supplied to each lot in 350 gallon steel tanks. Sodium sulfate was dissolved in the water in these proportions: Lot 1, 10,000 p.p.m.; Lot 2, 7,000 p.p.m.; Lot 3, 4,000 p.p.m.; Lot 4, none (control). No adjustment period was used to allow the cattle to become accustomed to the water.

Second trial. Twenty steers and ten heifers of the Hereford and Angus breeds were used in this trial. They were in a fleshy condition and weighed an average of about 730 pounds when put on experiment June 3, 1958.

Rations fed were similar to those used in the first trial, except that the mineral mixture was composed of 2 parts bonemeal, 1 part limestone, and 1 part trace mineral salt. All animals were implanted with diethylstilbestrol at the beginning of the trial.

The cattle were weighed without shrink and allotted into five lots on the basis of weight, condition, and sex. Each lot was composed of four steers and two heifers.

The system of watering was similar to that used in the first trial. Salts were added to the water as follows: Lot 1, none (control); Lot 2, 7,000 p.p.m. sodium chloride; Lot 3, 10,000 p.p.m. sodium chloride; Lot 4, 7,000 p.p.m. mixed salts (sodium 955 p.p.m., sulfate 4,772 p.p.m., chloride 425 p.p.m., and magnesium 848 p.p.m.); Lot 5, 10,000 p.p.m. mixed salts (sodium 1,364 p.p.m., sulfate 6,817 p.p.m., chloride 607 p.p.m., and magnesium 1,212 p.p.m.)

Results and Discussion

First trial. Results of the first trial are summarized in table 2. Adding 10,000 p.p.m. of sodium sulfate to the water caused a marked reduction in feed consumption and rate of gain. The heifers in this lot (Lot 1) lost an average of 62 pounds per head during the first 2 weeks of the trial, and even after 56 days the average loss per head was 22 pounds (0.4 pounds per day).

Scours were rather severe in Lot 1, and two of the heifers showed pronounced additional symptoms indicating toxic effects. These symptoms were rapid and difficult respiration and incoordination. One of the heifers was removed from the experiment and given control water. Respiration and gait were normal on the following day and the animal was returned to experiment 8 days later. The other survived the experiment without being removed from the lot. A third heifer died after 55 days on experiment without showing the symptoms mentioned. A post mortem examination did not reveal the cause of death.

It was apparent after 56 days of the trial that 10,000 p.p.m. of sodium salfate made the water unsatisfactory, so at that time Lot 1 was offered control water. The experiment was continued for another 28 days. The return to normal appetite and appearance was rapid and the animals in this lot gained 4.8 pounds per day during this period (table 2).

The rates of gain for the lots receiving the water with 4,000 and 7,000 p.p.m. of added sodium sulfate were 2.50 and 2.73 pounds, respectively, as compared to 2.60 pounds for the control lot. The differences probably represent normal variation for the number of cattle

Table 2. Effect of Different Concentrations of S
(June 27-Sept. 19,

	10,000 p.p.m. sodium sulfate	None
Number in lot	6†	5†
Days	56	28
Av. initial weight, lb.	673.0	635.6
Av. daily gain, lb.	—.40	4.8
Av. daily ration consumed, lb.		
Alfalfa hay	3.2	5.9
Concentrate mixture	5.9	14.2
Mineral mixture	.050‡	
Trace mineral salt	.060‡	
Feed per 100 lb. gain, lb.		
Alfalfa hay	——	——
Concentrate mixture	——	——
Mineral mixture	——	——
Trace mineral salt	——	——
Av. daily water consumption, gal.		
June 27-Aug. 21	6.60	
Aug. 22-Sept. 19		8.1
June 27-Sept. 19	7.07	

*Lot 1, cattle changed to control water after 56 days.
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The rates of gain for the lots receiving the water with 4,000 and 7,000 p.p.m. of added sodium sulfate were 2.50 and 2.73 pounds, respectively, as compared to 2.60 pounds for the control lot. The differences probably represent normal variation for the number of cattle used. Feed consumption also was not affected by these levels of sodium sulfate in the water.

All levels of sodium sulfate reduced free choice consumption of trace mineral salt. Consumption of the salt-bonemeal-limestone mineral mixture was reduced by the 7,000 and 10,000 p.p.m. levels.

Adding 4,000 or 7,000 p.p.m. of sodium sulfate to the water resulted in slight increases in the consumption of water. However, 10,000 p.p.m. of the salt caused a marked reduction in water consumption. The cattle offered the highly saline

Table 2. Effect of Different Concentrations of Sodium Sulfate in Water for Cattle (June 27-Sept. 19, 1957)

	10,000 p.p.m. sodium sulfate	None	7,000 p.p.m. sodium sulfate	4,000 p.p.m. sodium sulfate	Control water (Brookings)
Number in lot	6†	5†	6	6	6
Days	56	28	84	84	84
Av. initial weight, lb.	673.0	635.6	669.7	676.0	667.7
Av. daily gain, lb.	—.40	4.80	2.73	2.50	2.60
Av. daily ration consumed, lb.					
Alfalfa hay	3.2	5.9	5.8	5.9	5.8
Concentrate mixture	5.9	14.2	13.9	13.9	13.9
Mineral mixture	.050‡		.034	.092	.089
Trace mineral salt	.060‡		.062	.043	.117
Feed per 100 lb. gain, lb.					
Alfalfa hay	——	——	215	236	222
Concentrate mixture	——	——	511	557	536
Mineral mixture	——	——	1.23	3.67	3.44
Trace mineral salt	——	——	2.29	1.71	4.53
Av. daily water consumption, gal.					
June 27-Aug. 21	6.60		8.52	8.41	8.27
Aug. 22-Sept. 19		8.16	7.86	7.64	7.39
June 27-Sept. 19	7.07		8.30	8.15	7.98

*Lot 1, cattle changed to control water after 56 days.
†One heifer died. Gain made up to last weigh day before death counted in gain for the lot.
‡Values for entire experiment.

water would consume only a small quantity at one drinking. They often licked the water with their tongues rather than drinking in a normal manner. Cattle in Lot 1 drank much more when returned to control water.

Second trial. Results of the second trial are presented in table 3. Since 7,000 p.p.m. of sodium sulfate in the water was satisfactory for cattle but 10,000 p.p.m. was toxic, these levels were used for testing the salts in this trial.

Neither 10,000 p.p.m. of sodium chloride nor the mixed salts produced the toxic effects or depression in feed consumption noted with a similar level of sodium sulfate in the first trial. However, this level of the salts resulted in a rather pronounced decrease in the rate of gain. Water with 7,000 p.p.m. sodium chloride or mixed salts did not affect rate of gain or feed consumption. This is in agreement with the results of the first trial. Apparently the toxic levels of salts in the water lie between 7,000 and 10,000 p.p.m., possibly at the physiological level (about 8,500 to 9,000 p.p.m.).

Effects of the added salts on mineral and salt consumption were variable. Both levels of added sodium chloride reduced consumption of the trace mineral salt and the salt-bonemeal-limestone mixture. The addition of mixed salts to the water, however, increased consumption of the mixture and had variable effects on salt consumption.

To see if the type of water had an effect on shrinkage, the cattle were shrunk for 24 hours at the end of the second trial. The differences shown in table 3 are not large considering the small number of animals used. Shrinkage was greatest for the control lot.

Four animals were removed from the experiment in this trial. One heifer was removed from Lot 1 after 88 days because of a prolapse of the rectum. One steer, previously treated with a sulfa drug for bloody scours, was removed from Lot 3 after 27 days because of an edematous condition. This condition may have resulted from urinary calculi, a matter that was not definitely established. One steer was removed from Lot 4 after 23 days because of urinary calculi, and one was removed from Lot 5 after 45 days with a condition diagnosed as edema of the glottis. In this latter case again the animal had been treated with a sulfa drug for bloody scours just prior to the appearance of the edema.

Cases of urinary calculi had been observed in the group of cattle from which those used in this experiment were selected, and it is doubtful that the water treatment was involved in causing this problem here. With reference to the edematous condition, however, the sulfa drug and the high level of salt may have been contributing factors.

An increased water consumption was noted for both levels of added sodium chloride. However, the addition of the mixed salts appeared to have no effect on water consumption, the small differences between the treatments and the control probably representing a normal variation for groups of such small numbers of animals.

Table 3. Effect of Different Concentrations of S
Water for Cattle (June 3-Sept.

	Control water (Brookings)	7,00(p.p.m sodiu chlori
Lot number	1	2
Number in lot*	6	6
Av. initial weight, lb.	734.0	729.0
Av. daily gain, lb.†	2.41	2.3
Av. daily ration consumed, lb.		
Alfalfa hay	5.2	5.5
Concentrate mixture	14.0	14.5
Mineral mixture	.037	.0
Trace mineral salt	.071	.0
Feed per 100 lb. gain, lb.		
Alfalfa hay	214	231
Concentrate mixture	583	615
Mineral mixture	1.55	1.1
Trace mineral salt	2.94	2.2
Av. daily water consumption, gal	7.69	8.9
Shrink, 24 hrs. off feed and water, %	6.72	5.7

*Numbers shown are for the initial number.
†Includes gain made up to last weigh day for those rer

SWINE STUDIES

It is generally assumed that swine are more susceptible to injury from saline waters than are cattle. Therefore, in undertaking a study with growing pigs, it was decided that lower concentrations of salts should be used. In addition, facilities were such that the work had to be limited to one type of saline water, so it was decided that a mixture of salts should be used. This mixture included sodium chloride, magnesium sulfate, and sodium sulfate, added at a ratio similar to that found often in natural waters.

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Cases of urinary calculi had been observed in the group of cattle from which those used in this experiment were selected, and it is doubtful that the water treatment was involved in causing this problem here. With reference to the edematous condition, however, the sulfa drug and the high level of salt may have been contributing factors.

An increased water consumption was noted for both levels of added sodium chloride. However, the addition of the mixed salts appeared to have no effect on water consumption, the small differences between the treatments and the control probably representing a normal variation for groups of such small numbers of animals.

Table 3. Effect of Different Concentrations of Sodium Chloride and Mixed Salts in Water for Cattle (June 3-Sept. 23, 1958—112 days)

	Control water (Brookings)	7,000 p.p.m. sodium chloride	10,000 p.p.m. sodium chloride	7,000 p.p.m. mixed salts	10,000 p.p.m. mixed salts
Lot number	1	2	3	4	5
Number in lot*	6	6	6	6	6
Av. initial weight, lb.	734.0	729.0	733.3	733.3	730.0
Av. daily gain, lb.†	2.41	2.36	1.96	2.28	1.80
Av. daily ration consumed, lb.					
Alfalfa hay	5.2	5.5	5.1	5.6	5.4
Concentrate mixture	14.0	14.5	14.1	14.3	13.0
Mineral mixture	.037	.028	.020	.044	.059
Trace mineral salt	.071	.053	.052	.087	.050
Feed per 100 lb. gain, lb.					
Alfalfa hay	214	231	261	248	301
Concentrate mixture	583	615	718	627	723
Mineral mixture	1.55	1.16	.99	1.95	3.28
Trace mineral salt	2.94	2.24	2.66	3.83	2.77
Av. daily water consumption, gal	7.69	8.96	9.94	7.38	7.78
Shrink, 24 hrs. off feed and water, %	6.72	5.75	5.46	5.79	6.46

*Numbers shown are for the initial number.
†Includes gain made up to last weigh day for those removed from lot.

SWINE STUDIES

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Methods

Sixty weanling pigs averaging approximately 37 pounds were used in this trial conducted in concrete drylot from June 10 to September 8, 1958. The pigs were divided into four lots of 15 pigs each on the basis of ancestry, weight, and sex. All lots of pigs were self-fed the same basal ration. This ration consisted of 84 parts corn, 10 parts soybean meal, 5 parts tankage, 0.5 part steamed bonemeal, 0.5 part trace mineral salt, and B-vitamin and antibiotic supplement. When the pigs weighed about 110 pounds the corn was increased to 91 parts and the soybean meal and tankage were reduced to 5 and 2.5 parts, respectively.

Each of the four lots of pigs received a different water, as follows: Lot 1, Brookings water; Lot 2, Brookings water plus 2,100 p.p.m. of added salt mixture; Lot 3, Brookings water plus 4,200 p.p.m. of added salt mixture; and Lot 4, Brookings water plus 6,300 p.p.m. of added salt mixture. The salt mixture was composed of 1 part of sodium chloride and 3⅛ parts each of sodium sulfate and magnesium sulfate. The pigs were placed on those waters directly, no attempt being made to accustom them to each gradually.

Results and Discussion

The results summarized in table 4 show that there were no harmful effects from water containing up to 6,300 p.p.m. of the salt mixture (about 7,000 p.p.m. total salts when the composition of the Brookings water is considered) on growing-finishing pigs. In fact, the average daily gain, feed consumption, and feed efficiency were better for all three lots given water with added salts than for the control lot (water with no added salts).

Increasing the salt content of the water did increase water consumption. It was also noted that the pigs receiving the salt in their water scoured during the early weeks of this trial. This scouring was more apparent in Lot 4 than in the other lots. However, it apparently had no harmful effect on the gains or general condition of the pigs.

The increased weight of the pigs getting water with added salt was not due to an increase in fill. After the final weigh period, all pigs were withheld from feed and water for 16 hours and reweighed. The average shrink per pig was 10.1, 8.9, 9.3, and 9.7 pounds for Lots 1, 2, 3, and 4, respectively. It was not determined in this trial whether there was a greater water retention in the tissues of the pigs receiving the water with added salt.

POULTRY STUDIES

Only limited work with poultry has been completed, but studies are being continued and results will be reported more completely later. Therefore only a summary of findings to date is reported here.

Laying hens in cages have been kept on waters containing 4,000, 7,000, and 10,000 p.p.m. of added sodium chloride and on water with no added salt. At all levels of added salt, watery droppings have been observed. The severity of this condition appears to correlate with salt content of the water. It has also been found that the added salt increases water consumption, the greater the salt content, the greater the water consumption.

Except for watery droppings, the 4,000 and 7,000 p.p.m. of added sodium chloride did not appear to harm the birds. Egg production and body weight data were as good for these two salt levels as for the control hens. At the 10,000 p.p.m. level, however, egg production and body weight were adversely affected.

From the study discussed here, it appears that poultry may be very much like other animals with respect to their tolerance of saline waters. Studies now in progress should clarify this matter, especially those studies dealing with growing poultry.

Table 4. Saline Waters and Swi

	Lot 1 no added salts
Number of pigs	15
Av. initial weight, lbs.	37.4
Av. final weight, lbs.	164.6
Av. daily gain, lbs.	1.4
Feed/pig/day, lbs.	5.3
Feed/pound of gain, lbs.	3.7
Water consumption (gal./pig/day)	1.0

SUMMARY

The purpose of the work described here was to determine the effects of saline waters on livestock and the level at which salinity makes a water unsuitable for livestock. Rats, cattle, swine, and poultry were used in the various studies.

Preliminary experiments were made with rats, using five different salts, each at four levels. These experiments indicated some differences with regard to effects of the various salts, but it appeared that water with a salinity of about 4,000 p.p.m. had no toxic effect, while water with a salinity of around 10,000 p.p.m. usually did, regardless of the type of salt.

Trials with fattening cattle included the study of waters containing added sodium sulfate, sodium chloride, or a salt mixture containing sodium chloride, sodium sulfate, and magnesium sulfate. Here it was found that in each case a level of 7,000 p.p.m. caused no reduction

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Only limited work with poultry has been completed, but studies are being continued and results will be reported more completely later. Therefore only a summary of findings to date is reported here.

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From the study discussed here, it appears that poultry may be very *much like other animals with* respect to their tolerance of saline waters. Studies now in progress should clarify this matter, especially those studies dealing with growing poultry.

Table 4. Saline Waters and Swine Performance

	Lot 1 no added salts	Lot 2 2,100 p.p.m. added salts	Lot 3 4,200 p.p.m. added salts	Lot 4 6,300 p.p.m. added salts
Number of pigs	15	15	15	15
Av. initial weight, lbs.	37.4	37.4	37.2	37.2
Av. final weight, lbs.	164.6	172.8	180.1	174.8
Av. daily gain, lbs.	1.41	1.51	1.59	1.53
Feed/pig/day, lbs.	5.35	5.47	5.54	5.59
Feed/pound of gain, lbs.	3.79	3.62	3.47	3.66
Water consumption (gal./pig/day)	1.06	1.30	1.42	1.48

SUMMARY

The purpose of the work described here was to determine the effects of saline waters on livestock and the level at which salinity makes a water unsuitable for livestock. Rats, cattle, swine, and poultry were used in the various studies.

Preliminary experiments were made with rats, using five different salts, each at four levels. These experiments indicated some differences with regard to effects of the various salts, but it appeared that water with a salinity of about 4,000 p.p.m. had no toxic effect, while water with a salinity of around 10,000 p.p.m. usually did, regardless of the type of salt.

Trials with fattening cattle included the study of waters containing added sodium sulfate, sodium chloride, or a salt mixture containing sodium chloride, sodium sulfate, and magnesium sulfate. Here it was found that in each case a level of 7,000 p.p.m. caused no reduction in weight gain or feed consumption, and the animals appeared normal. At a level of 10,000 p.p.m., reduced gains were found with all of the waters, and in some animals on sodium sulfate water, severe symptoms of toxicity were observed.

Three different levels of an added mixture of salts were used for swine. The highest level gave a total salts content of about 7,000 p.p.m. Other than some slight scouring in the pigs on the higher levels early in the experiment, no ill effects were observed. Increasing salt content resulted in increased water intake, but rate of gain and feed efficiency were not adversely affected.

In laying hens, added sodium chloride at a level as low as 4,000 p.p.m. caused watery droppings. At 7,000 p.p.m. no additional adverse effects were noted, while at 10,000 p.p.m. egg production and body weight were both adversely affected.

In general, the results of these studies indicate that toxic effects can be expected from waters containing 10,000 p.p.m. of *soluble* salts, regardless of the type of salts.

Note salt deposits around the edge of this dugout.

Waters with 7,000 p.p.m. of soluble salts apparently cause little, if any, real damage to livestock, but because of taste qualities and laxative effects from certain salts these waters cannot be considered as entirely satisfactory for livestock. Incorporating a reasonable margin of safety to provide for exceptional conditions, it appears that a water with over 7,000 p.p.m. of soluble salts should be classed as unsatisfactory for livestock.

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Based on these studies and on observations made during the past several years, the following criteria are suggested for relating salinity to the quality of a livestock water:

Total Salts Content of Water* (p.p.m.)	Quality
0-999	Excellent
1,000-3,999	Good
4,000-6,999	Satisfactory
7,000 and over	Unsatisfactory

*Values for conductivity in micromhos per cm. at 25° C. may be used here if total salts content is not known.

Other factors are, of course, important in determining the quality of livestock waters. These include such things as whether or not the water is excessively turbid, stagnant, or insanitary.

In addition, excessive nitrates, alkalinity (not to be confused with salinity), or unusual poisons make livestock waters unsatisfactory. Occasionally iron content is so high as to make a water objectionable because of its taste. Therefore, these factors must be considered in addition to salinity in evaluating a livestock water. Lack of experimental work prevents publication of standards relating to these factors at this time.