Int J Biometeorol (2008) 52:239–247
DOI 10.1007/s00484-007-0118-3

ORIGINAL PAPER

Water salinity effects on performance and rumen parameters of lactating grazing Holstein cows

Silvia E. Valtorta · Miriam R. Gallardo · Oscar A. Sbodio · Germán R. Revelli · Cristina Arakaki · Perla E. Leva · Mónica Gaggiotti · Esteban J. Tercero

Received: 5 March 2007 / Revised: 1 August 2007 / Accepted: 7 August 2007 / Published online: 5 September 2007

Abstract Eighteen multiparous lactating grazing Holstein cows, 9 ruminally cannulated, average 136.1±14.6 days in milk, were randomly assigned to three treatments consisting of water containing different levels of total dissolved solids (TDS; mg/l): Treatment 1=1,000; Treatment 2=5,000 and Treatment 3=10,000, at the Experimental Dairy Unit at Rafaela Experimental Station (31°11′S latitude) during summer 2005. Animals were arranged in a randomized complete block design with three 28-day experimental periods, with 3 weeks for water adaptation and 1 week for measurements. Feed and water intake, milk production and composition, body weight and condition score and rumen parameters were evaluated. No treatment effects were observed in any of the variables evaluated, with the exception of water intake, which was higher for animals receiving 10,000 mg/l TDS in the drinking water (189 l/day vs. 106 and 122 l/day for cows receiving water with 1,000 and 5,000 mg/l TDS, respectively). Water intake was significantly higher for animals in treatment 10,000 ($P<0.05$). It was concluded that the rumen presents a surprising buffer capacity and that consideration of TDS alone is insufficient to characterize drinking water quality.

Keywords Total dissolved solids · Dairy cows · Water intake · Grazing · Summer

S. E. Valtorta · P. E. Leva
Facultad de Ciencias Agrarias - Universidad Nacional del Litoral, Esperanza, CONICET,
Santa Fe, Argentina

S. E. Valtorta (✉)
INTA, Centro Nacional de Investigaciones Agropecuarias,
Acuña de Figueroa 121 Piso 7, Depto. 51,
C1180AAA Buenos Aires, Argentina
e-mail: svaltorta@cnia.inta.gov.ar

M. R. Gallardo
Departamento de Producción Animal, EEA INTA Rafaela,
Santa Fe, Argentina

O. A. Sbodio
Instituto de Tecnología de Alimentos. Facultad de Ingeniería Química, Universidad Nacional del Litoral,
Santa Fe, Argentina

G. R. Revelli
Cooperativa Tambera Nueva Alpina, Ceres,
Santa Fe, Argentina

C. Arakaki
Instituto de Patobiología, INTA Castelar,
Buenos Aires, Argentina

M. Gaggiotti
Laboratorio - EEA INTA Rafaela,
Santa Fe, Argentina

E. J. Tercero
Facultad de Ingeniería Química, Universidad Nacional del Litoral,
Santa Fe, Argentina

Introduction

An adequate supply of clean, fresh drinking water is widely considered essential for optimal cow health and maximum milk production (Church 1991; Ensminger et al. 1990). The total dissolved solids (TDS) guidelines provided by the National Research Council (NRC 2001), suggest that water for dairy cattle should contain less than 5,000 mg/l TDS. They also reported that the five criteria often considered to assess water quality are organoleptic and physiochemical properties, presence of toxic compounds, excess of minerals or compounds and presence of bacteria.

A recent study (Pérez Carrera et al. 2005) performed in the milking area of Cordoba (Argentina), showed that 37% of the samples from groundwater were non adequate for dairy cattle as assessed in terms of TDS. A similar situation was found in large areas of the Central Santa Fe milking region (Revelli et al 2002). In the latter, 53% of the samples taken from dairy operations were considered unsuitable for lactating dairy cows and, therefore, were not recommended for animal intake. Both Cordoba and Santa Fe are within the most important milking region in Argentina.

Water intake is expected to be highest during the hottest months because of its relationship with environmental temperature. Water intake increases as environmental temperature goes up (NRC 2001; Holter and Urban 1992).

Thus, a trial was performed to study the effects of different TDS levels in the drinking water on performance and rumen parameters of grazing dairy cows in summer.

Materials and methods

Location

The trial was performed at the Dairy Unit at Rafaela Experimental Station (INTA), Santa Fe, Argentina (31°11′S; 61°33′W) from 6 January until 2 April 2005.

Meteorological data

Air temperature and relative humidity data were obtained from a meteorological station located about 500 m from the experimental dairy farm. Average daily temperature humidity index (THI) was calculated after Armstrong (1994).

Animals and treatments

Eighteen multiparous lactating Holstein cows, 9 ruminally cannulated, average days in milk 136.1±14.6 days, were randomly assigned to three treatments. The treatments consisted of water containing different levels of TDS (mg/l): Treatment 1,000; Treatment 5,000 and Treatment 10,000. Cows were balanced for milk production during the week previous to the beginning of the trial (31.9± 4.1 l cow^{-1} day^{-1}), body weight (BW, 521±61 kg/cow) and body condition score (BCS, 2.3±0.24). Animals were arranged in a randomized complete block design with three 28-day experimental periods, which consisted of 3 weeks for water adaptation and 1 week for measurements. Feed and water consumption, as well as production data were measured in all 18 cows, while the 9 ruminally cannulated animals were utilized for rumen parameter analyses.

Feeding and grazing management

Animals were milked twice a day, at 0400 hours and 1600 hours. From the evening to the morning milking all cows were on an alfalfa pasture, in a daily strip grazing system. All experimental groups grazed within the same paddock and were separated by electric fences in a sub-paddock, where cows had access to their respective treatment water ad libitum.

The trial was performed during summer, when radiation and temperatures are high. Therefore, each group was sent to a pen where the treatment water ad libitum and shade were available, from 0900 hours until the 1600 hour milking. There, animals also received alfalfa hay and cottonseed wholes with lint. A mixed concentrate was offered in the milking parlor during both milkings. The concentrate contained 3.2% of a commercial mineral and vitamin premix.

Water formulation

In order to formulate the water for the different treatments, the normal available water (2,880 mg/l TDS) was treated with reverse osmosis equipment (OSMOTIKA Model OI-7.0-F; Entre Ríos, Argentina). The water for TDS 1,000 was prepared by mixing completely desalinated water with normal water to obtain 1,000 mg/l TDS. Treatment 5,000 mg/l TDS was obtained by adding and mixing 200 g sodium chloride, 8 g calcium chloride, 80 g magnesium sulfate, 50 g sodium sulfate and 20 g sodium bicarbonate to every 100 l of the equipment refusal water (3.51 mg/l TDS). The amounts of salts added per 100 l refusal water to obtain the drinking water for treatment 10,000 were: sodium chloride=500 g; calcium chloride=20 g, magnesium sulfate=200 g, sodium sulfate=130 g, and sodium bicarbonate=50 g.

Drinking waters were formulated to have not less than 100, 850 and 2,000 mg SO_4^{2-}/l for treatments 1,000; 5,000 and 10,000 mg/l TDS, respectively. Sulphate is the most limiting anion in the Argentine milking areas presenting low performance, assumed to be driven by water problems (Revelli et al. 2005).

Water samples were taken every week in order to analyze TDS and concentrations of sulfate, bicarbonate, chloride, sodium, calcium and magnesium ions.

Experimental measures and sample analysis

Water intake

Individual water intake was recorded during two non-consecutive days by pairing cows in sub-groups, both on paddock and in the shaded pen. The volumes of water offered to and refused by every pair of cows were estimated from the height the water reached in each drinker, together with the

drinker dimensions. The difference between both estimates (offered and refused) represented the total drunk water.

Daily water group consumption was also recorded by measuring the volumes offered and refused, as described above.

Dry matter intake

Individual pasture dry matter intake (DMI) was estimated during two non-consecutive days on 40 m^2 paddocks (9 in total), where pairs of cows were located. Within each paddock, five samples of 0.10 m^2 of pre- and post-grazing pasture mass were taken, as described in Gallardo et al. (2005).

The DMI of concentrate, hay and cottonseed were assessed every day, as the difference between the amounts offered and refused.

Chemical analyses of water and feeds and estimated mineral balance

Water samples were taken from the drinkers in 1,000-ml sterilized plastic bottles. Total soluble salts were determined by means of a Water Quality Checker U-10 Horiba (Kyoto, Japan), and SO_4^{2-}, CO_3^{2-}, Na^+, Cl-, Ca^{2+} and Mg^{2+} by colorimetric and volumetric methods (Merck, Darmstadt, Germany).

Representative pre-grazing pasture samples were taken by "plucking" for chemical analyses, following a protocol similar to that described by Roche et al. (2005). Pasture, hay, cotton seed and concentrate samples were analyzed for DM, CP, ash, and fat (AOAC 1990), NDF, ADF, and lignin (Van Soest et al. 1991). Energy concentration (NE_L/kg DM) of the diet was estimated according to NRC (2001).

Total estimated mineral balance (Total absorbable supplied − Total absorbed required) was estimated for both macrominerals and microminerals, according to the NRC (2001) theoretical model. Estimations for the macrominerals were based on the EEA Rafaela Laboratory database. Micromineral balances were estimated from the NRC (2001) database.

Body weight and condition score

At the beginning of the study, and on day 28 of each experimental period, BW was measured and body condition was scored by three experienced independent observers using the five-point BCS scale (1=thin, 5=fat; Edmonson et al. 1989).

Milk production and composition

Milk production was recorded daily during the measurement periods by Waikato® milk meters (Waikato Milking Systems, Hamilton, New Zealand). Milk samples were collected from 10 milkings (sequence am–pm) during the 7-day sample collection period and analyzed for fat, total protein, lactose, and milk urea nitrogen (MUN) by infrared spectrophotometer (Foss 605B Milk-Scan; Foss Electric, Hillerød, Denmark).

Rumen parameters

For two consecutive days, 50-ml liquid samples were obtained via a tube introduced in the ventral sac, at 0800 hours (immediately before feeding; time 0) and at times 3, 6, 12, 18 and 24 h. On those samples, pH was measured with a glass electrode and ammonia was analyzed by a colorimetric technique.

Sub-samples were utilized for volatile fatty acid (VFA) analyses. The sub-samples were filtered through two layers of gauze, acidified with m-phosphoric acid (24%) in 3 *N* H_2SO_4 and kept at −20°C before analysis. VFAs were determined with a Shimadzu gas chromatograph GC-14B (Shimadzu, Kyoto, Japan) using a 2 m glass column packed with 10% polyethylene glycol and 3% H_3PO_4 in chromosorb AW, and fitted with a flame ionization detector (Erwin et al. 1961). The working temperatures were 155°C, 185°C and 190°C for the column, injector and detector, respectively. A Shimadzu CR6A integrator was used for peak quantification and identification. The internal standard was 2-methyl valeric acid. For enumeration of protozoa, sub-samples from times 0, 3 and 6 samples were utilized. Equal parts of rumen fluid and a saline-formalin solution (20% formalin in 0.85% NaCl solution) were mixed and stored. Prior to counting, a 2 ml aliquot of the fixed rumen sample was stained for at least 4 h with 2 ml methyl green-formalin solution (Ogimoto and Imai 1981). Protozoa quantification and generic composition were determined using a 1 ml counting chamber (Hausser Scientific Partnership, Horsham, PA; cat. No. 3800), following the procedures described by Dehority (1993).

At time 0, samples of rumen content were collected for bacterial enumeration. Rumen solids and liquid (100 g + 100 ml) were homogenized under a CO_2 atmosphere and filtered through two layers of gauze. Samples were diluted in decimal series (10^{-1} to 10^{-10}). For total bacterial concentration, 10^{-6}, 10^{-7} and 10^{-8} dilutions were inoculated into 10 ml RGCSA medium according to the procedure described by Grubb and Dehority (1976), which follows the roll tube procedure of Hungate (1966). Inoculated roll tubes were incubated for 5 days at 39°C and counted under a dissecting microscope. Cellulolytic and amylolytic bacterial concentrations were estimated with a most probable number (MPN) procedure, using a basal medium with either cellulose (filter paper) or starch as the only added carbohydrate source (Bryant et al. 1958; Bryant and Robinson 1961). All tubes were incubated at 39°C.

Amylolytic bacteria were measured after 7 days, using Lugol's iodine reaction to determine starch digestion (Persia et al. 2002). After 15 days incubation, cellulolytic bacterial concentrations were determined by observing the disappearance of filter paper.

Statistical analysis

Data were analyzed using the PROC MIXED procedure of SAS (1989), in a cross-over randomized complete block design.

The following model was fit for all variables not having repeated measures over time:

$$Yijkl = \mu + Bi + Pj + Ck(i) + Tl + BTil + Eijkl$$

where Yijkl is the dependent variable, μ is the overall mean, Bi is the effect of Block i, Pj is the effect of Period j, Ck(i) is the effect of Cow k (within block i), Tl is the effect of Treatment l, BTil is the interaction between Block i and Treatment l, and Eijkl is the residual error.

The following model was adopted for ruminal pH, ammonia, and VFA, which had repeated measures over time:

$$Yijkl = \mu + Bi + Pj + Ck(i) + Tl + BTil + E1ijkl + Hm + HTml + E2ijklm$$

where Yijkl is the dependent variable, μ is the overall mean, Bi is the effect of Block i, Pj is the effect of Period j, Ck(i) is the effect of Cow k (within square i), Tl is the effect of Treatment l, BTil is the interaction between Block i and Treatment l, E1ijkl is whole plot error, Hm is the effect of Hours post-feeding analyzed as repeated measurements, HTml is the interaction between Hour m and Treatment l and E2ijklm is the subplot error.

The spatial covariance structure SP(POW) was used for estimating covariances, and the subject of the repeated measurements was defined as cow (block x period x treatment). All terms were considered fixed except Ck(i), E1ijkl, and E2ijklm, which were considered random.

All reported values are least squares means, which were separated using the PDIFF test in SAS.

Results

Table 1 presents the composition of the diet offered during the trial to animals in all treatments. It represents a typical grazing system diet, except for the addition of cottonseed wholes. The latter were included because of their high fat contents and, therefore, their beneficial effect for summer diets (Grummer 1992). Pasture presented different quality as the trial progressed. Protein and NDF were 17.1 and 51.1%, as compared to 21.8 and 49.5% and 19.5 and 49.8% for periods 1 and 2, respectively.

Chemical composition of the water utilized during the trial is shown in Table 2. Sulfates represented about 11% TDS in treatment 1,000; 17% in treatment 5,000 and 23% in 10,000. In treatment 1,000, Na^+ and Cl^- together

Table 1 Ingredients and chemical composition of the total diet offered during the trial, for treatments containing different amounts of total dissolved salts (TDS): 1,000; 5,000 and 10,000 mg/l TDS in the drinking water. Chemical composition of pre-grazing alfalfa pasture is also presented. *DM* Dry matter, *NFC* non-fibrous carbohydrates, *NDF* neutral detergent fiber, *CP* crude protein

Data on total diet offered during the trial		
Ingredient (% on a DM basis)		
Alfalfa pasture	57.7	
Alfalfa hay	4.7	
Cottonseed wholes with lint	7.4	
Concentrate mixture [a]	30.2	
Composition	Total diet	Alfalfa pasture[b]
DM (%)	31.0±2.75	20.8±1.83
Crude protein (%)	16.2±1.65	19.5±2.01
Neutral detergent fiber (%)	39.3±6.5	51.03±6.7
Acid detergent fiber (%)	21.0±4.1	26.7±4.1
Non-fibrous carbohydrates [c] (%)	34.7±6.15	23.0±2.70
Ether Extract (%)	4.7±0.7	2.99±0.52
NEL [d] (Mcal/kg DM)	1.56±0.17	1.47±0.05

[a] Ingredients: 87.3% corn grain; 9.5% corn germ; 3.2% commercial mineral and vitamins premix: calcium carbonate: 31.5%; magnesium oxide: 18.5%; di-calcium phosphate: 38.4%; salt: 11.6% vitamins-micro-minerals = vit. A: 4,620 IU/kg; Vit. D3: 920 IU/kg; Vit. E: 12 IU/kg; Cu: 4.5 mg/kg; Zn: 31 mg/kg; Fe: 33 mg/kg; I: 0.6 mg/kg; Se: 0.12 mg/kg; Co: 0.375 mg/kg

[b] Alfalfa pasture sampled by hand-plucking before the grazing

[c] NFC = 100−(ash + CP + NDF + fat)

[d] Net energy estimated according to NRC (2001)

Table 2 Chemical composition of the water utilized during the trial, for treatments containing different amounts of total dissolved salts: 1,000; 5,000 and 10,000 mg/l in the drinking water

Component (mg/l)	Treatment					
	1,000		5,000		10,000	
	Mean	SD	Mean	SD	Mean	SD
Total solids	1,100	84	5,280	390	9,220	545
SO_4^{2-}	125	18	883	196	2,088	253
CO_3^{2-}	19	31	57	86	125	40
Na^+	335	40	1,528	186	2,767	316
Cl^-	115	18	1,425	124	2,775	361
Ca^{2+}	9	9	64	6	85	9
Mg^{2+}	9	3	103	7	211	13

represented about 40% TDS, while they were 60% TDS in treatments 5,000 and 10,000.

Table 3 presents pasture, concentrate and total DM intake for each treatment. No significant differences were observed in response to level of salinity. However, pasture DM consumption was significantly lower during the third experimental period, regardless of the water salinity level ($P<0.05$). During periods 1 and 2, pasture DM intake averaged 10.6±1.85 kg cow^{-1} day^{-1} while in period 3 it was 8.8±0.6 kg cow^{-1} day^{-1}. Water intake data per treatment and period (Table 4) ranged between 97.5 and 202.2 l cow^{-1} day^{-1}, with animals in treatment 10,000 showing the highest levels.

The meteorological data recorded during the 28-day experimental periods, as well as during the 1-week measuring periods, are shown in Table 5. Environmental conditions were quite variable, especially during the first period. The temperature was lower during the first measuring week, as compared to the whole period.

Table 6 presents milk production and composition, and BCS change. No treatment effects were observed in any parameter. However, milk production was affected by period, the highest yield being recorded in period 1. These

Table 3 Pasture, concentrate and total DM intake (kg cow^{-1} day^{-1}; mean ± SD), for treatments containing different amounts of TDS: 1,000; 5,000 and 10,000 mg/l in the drinking water

Item	Treatment		
	1,000	5,000	10,000
Pasture (alfalfa based)	10.4±1.0	9.8±2.7	9.7±1.7
Concentrate [a]	7.63	7.63	7.63
Total	18.03±1.0	17.43±2.7	17.33±1.7

[a] Concentrate composition: 71.5% concentrate mix; 17.5% cottonseed wholes with lint; 11% alfalfa hay.

Table 4 Water intake during the three measurement weeks (l cow^{-1} day^{-1}; mean ± SD), for treatments containing different amounts of TDS: 1,000; 5,000 and 10,000 mg/l in the drinking water. Within row different superscripts represent statistical significance ($P<0.05$)

Week	Treatment		
	1,000	5,000	10,000
1 (27 Jan–2 Feb)	97.5±23.4[a]	123.2±12.6[b]	169.6±18.3[c]
2 (24 Feb–2 Mar)	110.9±32.1[a]	127.1±9.5[a]	193.9±22.93[b]
3 (25 Mar–31 Mar)	108.4±41.0[a]	114.9±8.0[a]	202.2±28.2[b]

results are illustrated in Fig. 1, where the results for all treatments are combined for each period.

Rumen pH, ammonia and VFA (Table 7), as well as bacteria and protozoa (Table 8), were not affected by treatment. Figure 2 shows the temporal patterns of the acetate/propionate ratio for all treatments. The values fluctuated around 3 at all measuring times. Treatment 1,000 tended to be less variable.

The theoretical balance for total minerals, including diet and water (Table 9) showed that all minerals were in excess, with the exception of copper, which was slightly below the requirement.

Discussion

More than 50% of the diet was fresh grazed alfalfa, which usually has high levels of highly degradable protein and low fiber. Grazing diets generally tend to be unbalanced, because cows present a selective habit. Concentrate and cottonseed wholes were included to solve this problem, and

Table 5 Temperature and temperature humidity index (THI) during the three experimental and measuring periods, for treatments containing different amounts of TDS: 1,000; 5,000 and 10,000 mg/l in the drinking water

Period	Average temperature (°C)			Average THI	Total rainfall (mm)
	Mean	Max	Min		
1st Experimental	26.1±6.7	34.4±6.9	15.9±6.8	74.9±7.2	133.6
1st Measuring	22.5±5.9	31.3±7.2	13.7±4.6	70.9±6.3	61.1
2nd Experimental	24.3±2.6	30.2±3.4	16.7±3.9	73.1±4.8	39.7
2nd Measuring	24.1±3.2	29.3±3.9	17.0±3.5	72.9±5.8	0.0
3rd Experimental	23.2±3.6	29.3±3.7	16.5±2.7	70.6±3.8	311.5
3rd Measuring	22.1±2.6	28.0±3.8	17.2±1.8	70.4±4.1	20.2

Table 6 Milk yield and composition and body condition score (BCS) change for treatments containing different amounts of TDS: 1,000; 5,000 and 10,000 mg/l in the drinking water. *MUN* Milk urea nitrogen

Item	Treatment			SEM	Effects	
	1,000	5,000	10,000		Treat	Period
Milk yield (kg cow^{-1} day^{-1})	24.23	24.81	24.55	1.79	0.6304	<0.0001
Milk fat (%)	3.27	3.23	3.36	0.21	0.1939	0.0628
Protein (%)	3.40	3.34	3.36	0.17	0.6450	0.0004
Lactose (%)	4.92	4.90	4.91	0.13	0.9835	0.0662
MUN (mg/100 ml)	7.54	7.48	7.01	2.35	0.7641	<0.0001
BCS, change [a]	−0.11	0.05	−0.06	0.09	NS	NS

[a] Final BCS−initial BCS

to obtain a better balanced ration, as shown by the levels of milk yield (Table 6).

The water produced for each treatment presented the expected characteristics, as assessed in terms of TDS and SO_4^{2-} concentrations. Sulphates were selected as the main anion to characterize waters because excessive dietary SO_4^{2-} can interfere with the absorption of other elements, particularly copper and selenium. In addition, SO_4^{2-} may reduce feed intake and performance (NRC 2001). According to the guidelines for TDS (NRC 2001), treatment 1,000 represents a safe water for animal drinking. On the other hand, water containing 5,000 mg/l TDS should be avoided for pregnant or lactating animals, if maximum performance is the target, while water containing over 7,000 mg/l TDS should never be offered to dairy animals, since they could present health problems or poor production.

Pasture intake was lowest in the third period. This response could have been affected by the lower quality of the pasture offered in this period. Also, during that period rainfall was much higher than during the previous periods (317.6 mm vs 177.6 and 39.7 mm for periods 1 and 2, respectively). This environmental situation could have affected paddock conditions, so as to render grazing more difficult for the cows.

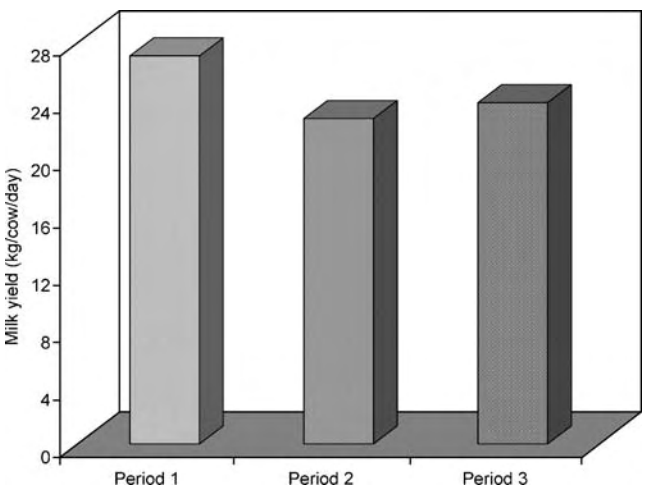

Fig. 1 Milk yield for the three experimental periods in a trial with treatments containing different amounts of total dissolved salts (TDS): 1,000; 5,000 and 10,000 mg/L in the drinking water. All treatments are averaged together

Surprisingly, animals in treatment 10,000 drank more water than the others in all three periods (Table 4). These results disagree with other reports where it was found that water intake for cows drinking desalinated water was higher compared to that of animals receiving salty water, defined as water containing >1,000 mg/l TDS (Solomon et al. 1995). However, in that report TDS and ion composition differed from the treatments in the present work.

Weeth and Hunter (1971) investigated maximum tolerable concentrations of sulfates in drinking water. Water intake of growing cattle was adversely affected by higher sulfate in their drinking water. These researchers concluded that the tolerable concentration of sulfate in drinking water for growing cattle in summer in Nevada was near 1,450 ppm.

On the other hand, Digesti and Weeth (1976) offered 110, 1,250 and 2,500 ppm sulfate in drinking water, by adding sodium sulfate. Neither feed and water intake nor growth rate of beef heifers were affected by sulfate levels in the drinking water during a 90-day long trial. Those heifers seemed to tolerate 2,500 ppm sulfate in drinking water with no adverse effects.

In Argentina, Revelli et al. (2005), found similar levels of water intake for animals drinking water with 1,000 and 10,000 mg/l TDS. However, their data were not obtained during the summer season. Warm environmental temperature (i.e., heat stress) is an important factor when evaluating water nutrition. Water intake increases as environmental temperature goes up (NRC 2001; Holter and Urban 1992).

Cows producing 20 l milk/day would take in about 90 l water/day at 16°C and about 105 l water/day at 26°C (Beede 1992). In the present study, the results for cows in treatment 1,000 fell within this range. Regarding treatments 5,000 and 10,000, it can be pointed out that diets high in salt, sodium or protein appear to stimulate water intake (Holter and Urban 1992). Furthermore, sodium intake alone was found to increase water intake by 0.05 kg/day per gram of sodium intake (Murphy et al. 1983). The authors derived

Table 7 Ruminal volatile fatty acids (VFAs), pH and ammonia concentration for treatments containing different amounts of TDS: 1,000; 5,000 and 10,000 mg/l in the drinking water

Measurement	Treatment			Contrast				
	1,000	5,000	10,000	Per	Col	Treatment (T)	Hour (H)	TxH
VFA, mmol/l:								
Acetate	76.51	74.03	75.29	0.42	0.46	0.71	<0.0001	0.90
Propionate	24.7	24.4	23.3	0.16	0.17	0.66	<0.0001	0.98
Isobutyrate	1.61	1.74	1.45	0.14	0.92	0.32	0.0025	0.30
Butyrate	11.55	11.26	11.17	0.34	0.63	0.89	0.0002	0.94
Isovalerate	1.72	1.60	1.41	0.31	0.69	0.18	<0.0001	0.94
Valerate	1.21	1.20	1.07	0.10	0.76	0.45	0.0004	0.94
Total	117.5	114.6	113.9	0.27	0.35	0.79	<0.0001	0.95
pH	6.37	6.37	6.36	0.30	0.71	0.41	<0.0001	0.98
Ammonia, g/l	0.076	0.081	0.084	0.039	0.068	0.049	<0.0001	0.94

a prediction equation for water intake, where minimum temperature and sodium intake were among the predicting variables. On the basis of that equation, the estimated overall average water consumption in the present trial was 91, 115 and 185 kg cow^{-1} day^{-1}, for treatments 1,000; 5,000 and 10,000, respectively. These values compare quite well with the actual overall averages: 106, 122 and 189 l cow^{-1} day^{-1}, for the respective treatments.

Milk yield and composition were not affected by treatment (Table 6). Solomon et al. (1995) reported higher yields and milk fat percentages for cows receiving desalinated water, as compared to levels obtained by animals drinking naturally salty water. Those results disagree with the present report, where no treatment effects on milk production and composition were detected. However, the latter trial was performed in a desert climate on non-grazing cows, and average milk production was higher than the levels obtained in the present study.

According to Tucker et al. (1988), DM intake is affected not only by sodium but also by potassium, chloride and phosphorus interactions, the response being different as a function of the concentration of the other minerals. Sánchez et al. (1992) examined interrelationships of sodium, potassium, chloride, magnesium, calcium and phosphorus and concluded that optimal concentrations of macromineral elements for maximum DM intake or milk yield depend on one another. In our study, no differential responses were detected. Furthermore, when animals changed treatments, no visual clinical signs, such as diarrhea or depressed appetite, were observed in the adaptation period. Those signs are usually detected as a response to high sulphate concentrations (Underwood 1981).

Under non-grazing conditions, Sánchez et al. (1994) found that milk production was reduced during the summer months in response to increasing intake of chloride and sulfate. They also found that feeding high amounts of sodium does not reduce milk production or lactation performance.

Different variables could have determined the period effects on milk production. First, total consumption was lower during period 3, as compared to the other periods. On the other hand, there is a natural trend towards decreased yields as lactation progresses. In any event, the levels obtained are quite good considering the grazing-based production system and the season. Also, the conversion efficiency was high: approximately 750 g DM/ kg milk, with no BCS lost (Table 3).

Milk fat and protein presented low concentrations. Similar results were obtained by Revelli et al. (2002, 2005). In treatments 1,000 and 5,000, fat and protein values were reversed. This response could indicate a somewhat low effective fiber content in the ingested forage, possibly affected by pasture intake behavior, since grazing animals select leaves and tender stems.

Rumen parameters and microbiology were not affected by water salinity (Tables 7, 8). Those results indicate the incredible buffer capacity of the rumen, probably due to the effects of the fresh alfalfa pasture, an important protein source,

Table 8 Ruminal amylolytic and cellulolytic bacteria and protozoa at sampling time 0 for treatments containing different amounts of TDS: 1,000; 5,000 and 10,000 mg/l in the drinking water. *MPN* Most probable number

Item	Treatment			Effects	
	1,000	5,000	10,000	*T*	*P*
Amylolytic bacteria, (MPN×10^9 / 100 ml rumen)	3.4	3.4	3.6	0.89	0.98
Cellulolytic bacteria, (MPN×10^6 /100 ml rumen)	20.5	31.9	14.5	0.55	0.81
Protozoa (×10^3/ml /ml)	9.3	13.8	12.9	0.46	0.25

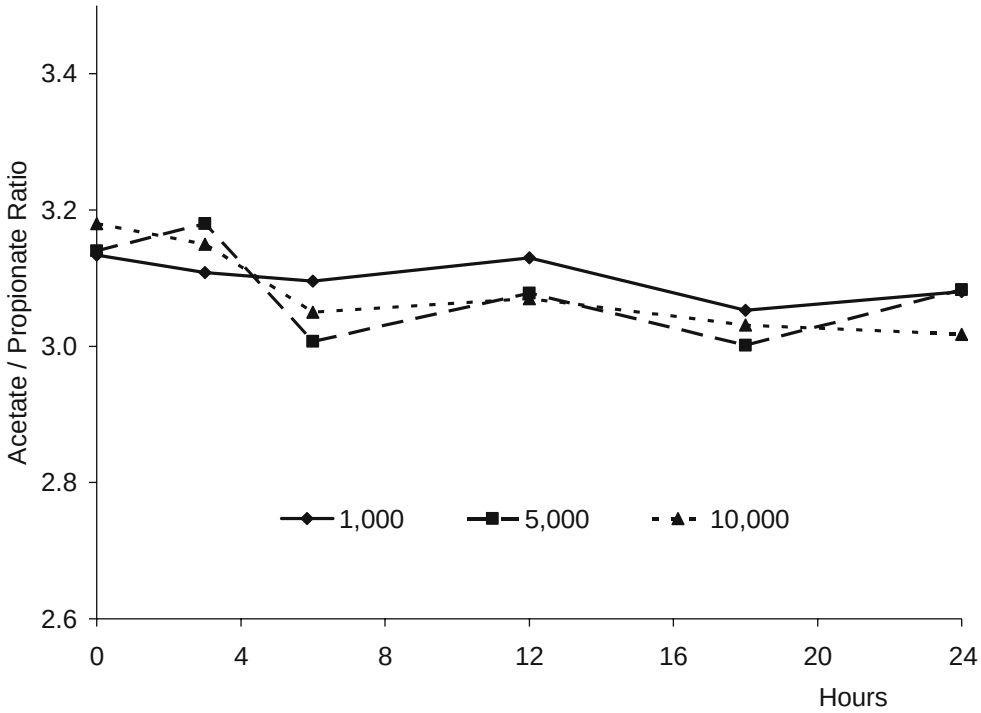

Fig. 2 Acetate / propionate ratio in the rumen of cows in treatments containing different amounts of TDS: 1,000; 5,000 and 10,000 mg/L in the drinking water

in the diet. The buffering system in the rumen includes not only the saliva, but also the feed (Van Soest 1994). In the present trial, average pH was quite constant and also relatively low, near 6. However, the values recorded for rumen ammonia (Table 7) agree with MUN (Table 6), and both indicate no excess in degradable protein in the diet.

There are very few reports on the effects of water salinity on rumen parameters. Potter et al. (1972) found no effects on VFA concentration when offering chaffed rations to sheep receiving either freshwater or a 1.3% sodium chloride solution. However, sheep are known to tolerate high amounts of salt in their drinking water (Peirce 1957).

The lack of effect of drinking water salinity on milk production and composition and on rumen parameters is striking, especially considering that treatment 10,000 had a TDS considerably above the levels considered to be limiting for lactating dairy cows . Also, minerals such as sodium, magnesium and sulfur were highly overbalanced in treatments 5,000 and 10,000. However, higher sodium excretion rates have been described as a response to high potassium levels (Beede 2005), such as those in fresh alfalfa (over 2% K on a DM basis). Probably, the high levels of potassium could have affected the excretion not only of sodium, but also of magnesium and calcium. Furthermore, according to Weiss (2004), the apparent digestibility of magnesium could be 30% lower than the mean value calculated by the NRC (2001) model.

These results indicate that consideration of TDS alone would be not enough to characterize drinking water quality. Other parameters, such as specific salt components and bacteriological quality, need to be included. More studies should be performed in commercial farms in order to assess the impact of naturally salty water on lactating dairy cow performance. It should be pointed out that, given the ability

Table 9 Total estimated mineral balance (total absorbable supplied − total absorbed required) and total absorbed required minerals (TAR) in the diet and water offered to cows in treatments containing different amounts of TDS: 1,000; 5,000 and 10,000 mg/l in the drinking water

	Treatment			TAR
	1,000	5,000	10,000	
Macrominerals (g cow^{-1} day^{-1})[a]	Balance[b]			
Ca	45.4	48.7	53.5	47.4
P	18.6	18.2	17.1	41.3
Mg	15.9	22.5	40.4	5.3
Cl	53.3	171.2	466.6	40.6
K	186.9	184.4	178.1	168.2
Na	8.7	124.8	400.8	36.3
S	11.1	18.5	45.9	36.2
Microminerals (mg cow^{-1} day^{-1})[c]				
Cu	−0.98	−0.98	−0.98	7.58
Fe	473.4	473.4	473.4	24.5
Mn	3.77	3.77	3.77	1.8
Se	8.71	8.71	8.71	5.4
Zn	655.6	655.6	655.6	122.8

[a] From the EEA Rafaela Laboratory database
[b] According to the NRC (2001) model
[c] Based on NRC (2001) database

of lactating dairy cows to excrete high amounts of minerals (Bannink et al. 1999), waters that lead to elevated mineral excretion could induce environmental contamination problems.

References

Association of Official Analytical Chemists (AOAC) (1990) Official methods of analysis, 15th edn. AOAC, Arlington, Va

Armstrong DV (1994) Heat stress interaction with shade and cooling. J Dairy Sci 77:2044–2050

Bannink A, Valk H, van Vuuren AM (1999) Intake and excretion of sodium, potassium and nitrogen and the effects on urine production by lactating dairy cows. J Dairy Sci 82:1008

Beede DK (1992) Water for dairy cattle. In: Van horn HH, Wilcox CJ (eds) Large dairy herd management. American Dairy Science Association, Champaign, IL, pp 260–271

Beede DK (2005) The most essential nutrient: water. Proceedings of the 7th Western Dairy Management Conference. 9–11 March 2005, Reno, NV, pp 13–31

Bryant MP, Robinson IM (1961) An improved nonselective culture medium for ruminal bacteria and its use in determining diurnal variation in numbers of bacteria in the rumen. J Dairy Sci 44:1446–1456

Bryant MP, Small N, Bouma C, Robinson IM (1958) Studies on the composition of the ruminal flora and fauna of young calves. J Dairy Sci 41:1747–1767

Church DC (1991) Livestock feeds and feeding, 3rd edn. Prentice-Hall, Englewood Cliffs, NJ

Dehority BA (1993) Laboratory manual for classification and morphology of rumen ciliate protozoa. CRC, Boca Raton, Florida

Digesti R, Weeth HJ (1976) A defensible maximum for inorganic sulfate drinking water of cattle. J Anim Sci 42:1498–1502

Edmonson AJ, Lean IJ, Weaver LD, Farver T, Webster G (1989) A body condition scoring chart for Holstein dairy cows. J Dairy Sci 72:68–78

Ensminger ME, Oldfields JE, Heinemann WW (1990) Feeds and nutrition, 2nd edn. Ensminger, Clovis, CA

Erwin ES, Marco GJ, Emery EM (1961) Volatile fatty analysis of blood and rumen fluid by gas chromatography. J Dairy Sci 44:1768–1771

Gallardo MR, Castillo AR, Bargo F, Abdala AA, Maciel MG, Perez-Monti H, Castro HC, Castelli MR (2005) Monensin for lactating dairy cows grazing mixed-alfalfa pasture and supplemented with partialmixed ration. J Dairy Sci 88:644–652

Grubb JA, Dehority BA (1976) Variation in colony counts of total viable anaerobic rumen bacteria as influenced by media and cultural methods. Appl Environ Microbiol 31:262–267

Grummer RR (1992) Feedind strategies for supplemental fat. In: van Horn HH, Wilcox CJ (eds) Large dairy herd management. ADSA, Champaign, IL, pp 248–259

Holter JB, Urban WE Jr (1992) Water partitioning and intake in dry and lactating dairy cows. J Dairy Sci 1472–1479

Hungate RE (1966) The rumen and its microbes. Academic, New York

Murphy MR, Davis CL, McCoy CG (1983) Factors affecting water consumption by Holstein cows in early lactation. J Dairy Sci 66:35–38

NRC (National Research Council) (2001) Nutrient requirements of dairy cattle, 7th edn. National Academic, Washington DC

Ogimoto K, Imai S (1981) Atlas of rumen microbiology. Japan Scientific Societies Press

Peirce AW (1957) Studies on salt tolerance of sheep for sodium chloride in the drinking water. Aust J Agric Res 8:711

Pérez Carrera A, Moscuzza C, Fernández Cirelli A (2005) Contenido de macrominerales en el agua de bebida de tambos de la provincia de Córdoba (Argentina) y su relación con los requerimientos de bovinos de leche. Rev Arg Prod Anim 25:115–121

Persia ME, Dehority BA, Lilburn MS (2002) The effects of enzyme supplementation of corn- and wheat-based diets on nutrient digestion and cecal microbial populations in turkeys. J Appl Poult Res 11:134–145

Potter BJ, Walker BJ, Forrest WW (1972) Changes in intraruminal function of sheep when drinking saline water. Br J Nutr 27:75–83

Revelli GR, Sbodio OA, Tercero EJ, Uberti M (2002) Impacto de la calidad de agua para bebida animal en relación a parámetros productivos, composicionales y reproductivos. Revista FAVE (Sección Ciencias Veterinarias) 1:55–67

Revelli GR, Sbodio OA, Gallardo MR, Valtorta SE, Tercero EJ (2005) Rendimiento de vacas lecheras de baja producción en condiciones pastoriles con la oferta de agua de bebida salada o desalinizada. Revista FAVE (Sección Ciencias Veterinarias) 4:77–88

Roche JR, Petch S, Kay JK (2005) Manipulating the dietary cation-anion difference via drenching to early-lactation dairy cows grazing pasture. J Dairy Sci 88:264–276

Sánchez WK, Beede DK, de Lorenzo MA (1992) Modeling the effects of macrominerals on lactational performance of dairy cattle. Proceedings of the National Feed Ingredients Association meeting, West Desmoines, IA

Sánchez WK, McGuire MA, Beede DK (1994) Macromineral nutrition by heat stress interactions in dairy cattle : review and original research. J Dairy Sci 77:2051–2079

SAS (1989) User's guide: statistics version, 6.04 edn. SAS, Cary, NC

Solomon R, Miron J, Ben-Ghedalia D, Zomberg Z (1995) Performance of high producing dairy cows offered drinking water of high and low salinity in the Arava Desert. J Dairy Sci 78:620–624

Tucker WB, Harrison GA, Hemken RW (1988) Influence of dietary cation-anion balance on milk, blood, urine, and rumen fluid in lactating dairy cattle. J Dairy Sci 71:346

Underwood EJ (1981) The mineral nutrition of livestock, 2nd edn. Commenwealth Agricultural Bureaux, Slough, England

Van Soest PJ (1994) Nutritional ecology of the ruminant, 2nd edn. Cornell University Press, Ithaca, NY

Van Soest PJ, Robertson JB, Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J Dairy Sci 74:3583

Weeth HJ, Hunter JE (1971) Drinking of sulphate-water by cattle. J Anim Sci 32:277–281

Weiss WP (2004) Macromineral digestion by lactating dairy cows: factors affecting digestibility of magnesium. J Dairy Sci 87:2167