What will our ruminants drink?

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Implications

- Historically, drinking water for ruminants has been a relatively inexpensive and abundant resource, but this is changing in both developed and developing countries.
- Despite the great amount of attention paid to other essential nutrients by animal scientists and livestock farmers in the last century, water nutrition and water quality have not been adequately examined. Even today, drinking water is seldom considered a potentially limiting factor for the productivity and health of ruminants. Farmers rarely have information about the 2 major initial factors for assessing the adequacy of water nutrition on any farm—how much the animals are drinking and what the quality of that water is.
- Although livestock will never rival humans for the world's supply of potable water, they do use large amounts in some production systems. Nonetheless, ruminants also hold a unique niche in the production of food and other tangibles for humans by their ability to consume fibrous and lower quality feedstuffs (e.g., forages and by-products) not utilizable as food directly by humans and other nonruminants, and to convert these feeds into high-quality proteins, vitamins, fats, and energy for humans. This unique capacity of ruminants very much depends on sufficient quantities of water for maintenance, digestion, absorption, and assimilation.
- Should potable drinking water become scare in some areas of the world, domestic ruminants may be forced to consume poorer quality water containing anti-quality factors. If we are to sustain the increasing demand for animal products and improve the standard of living globally, the conservation and recycling of clean drinking water on ruminant farms will be critical. Otherwise, the only alternative may be widespread use of water treatment systems.
- Doubtless, ruminant farmers must improve their management by carefully using and conserving the available clean water for their animals. The future viability of ruminant production systems depends on it. Through more efficient use of water, farmers can maximize animal performance and health while simultaneously optimizing on-farm use (from irrigation for feed crop production through recycling and conservation) to reduce the water footprint of each farm.

Key words: drinking water, water nutrition, water quality, water requirement, ruminant

Introduction

Water is required for life. Animals that serve humankind as sources of food, fertilizer, draught power, recreation, social status, and prosperity have an obligatory need for water. Ruminants (e.g., cattle, sheep, and goats) hold a unique place in the human food web, able to consume highly fibrous feedstuffs (e.g., forages often grown on land not suitable for other uses and by-product feeds), poor-quality protein feeds, or both, and convert them into high-biological-value nutrients and energy for humans. It is important that this conversion by microorganisms mainly in the rumen (and reticulum) of the digestive tract and assimilation in the tissues of the ruminant requires sufficient water.

Recent estimates are that animal agriculture uses about 8% of the available global water supply (Schlink et al., 2010). However, only about 1% of that is to nourish animals, service on-farm activities, and process raw animal products into food. The remainder of water use is to irrigate feed crops (e.g., corn and other cereals for grain and silages as well as high-energy, high-protein feedstuffs such as corn distillers grains, canola, and soybeans) for use in intensive livestock production systems of more developed countries. As described in detail in the present issue, the estimates of water use vary widely depending on the methods used and the starting and ending points chosen (Doreau et al., 2012; Hoekstra, 2012).

In terms of the efficiency of water use, current models cannot adequately distinguish between developing and developed countries or the types of production systems within them. However, recent estimates suggest that when the biological availability (quality) of each kilogram of protein produced for humans is considered, the efficiency of water use in animal agriculture overall is not different compared with that used to produce plant proteins; only soybean production is more water efficient than the production of milk, goat meat, and chicken, and no plant protein is produced with greater water efficiency than egg protein (Hoekstra and Chapagain, 2007; Schlink et al., 2010). However, the intensive beef feedlot production system is far less water efficient because of feed crop irrigation.

Nonetheless, the animal sector is growing faster than any other agricultural sector, which is ostensibly related to the improving standard of living and greater demand for high-quality animal protein in many countries. The growth and dispersion of human populations and environmental pollution of surface and groundwater in many developed and developing countries is narrowing the margin between the available water supply and the demand of humans and animals. Challenges lie ahead.

Similar to humans, ruminants require clean (potable) drinking water, unadulterated by naturally occurring anti-quality factors or by anthropogenic pollutants. However, ruminant livestock will not outcompete humans for the best potable water. There are natural groundwaters and surface waters seemingly unfit or marginally acceptable for human consumption because of extraordinarily high concentrations of anti-quality factors (e.g., some mineral elements) that have already been relegated to livestock. This trend will likely become more dominant in the fu-

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ture. Moreover, advancing global climate change (along with increasing global demand) is projected to bring more dynamic and accentuated cycles of scarcity and abundance of potable water for both livestock and humans (Haileslassie and Blummel, 2011). Therefore, it is important to understand if and how poorer quality waters might be utilized or treated, or both, to make them acceptable for ruminant production without compromising the health, welfare, and productivity of the animals, and perhaps the quality of the products (e.g., dairy food products).

This article portrays the general state of knowledge, and lack thereof, about water nutrition and quality issues for domestic ruminants, and it addresses likely challenges and opportunities to improve water nourishment. What will our ruminants drink?

Water for Life and Productivity

Physiological Needs

Water is intimately involved in a wide array of bodily functions as the universal solvent in the extracellular and intracellular compartments—as 99% of all molecules in the body—and as a direct participant in many of these functions [National Research Council (**NRC**), 2007]. Key roles include physiological maintenance (e.g., electrolyte balance and osmotic regulation, nutrient transport, intermediary metabolism, lubrication, thermoregulation, and excretion of urine and feces), growth, pregnancy, and lactation (NRC, 1996, 2001, 2007). The body composition of very lean ruminants (e.g., young growing animals) is 65 to 70% water, whereas in animals approaching physiological maturity, it may be only about 40 to 50% water, depending on the degree of fatness because fat contains relatively little water (<10%) compared with lean (nonfat) soft body mass (Houpt, 1993). Additionally, water is about 90% of blood plasma (81% of whole blood).

Water is indispensible for the digestion, absorption, and transport of nutrients and for milk secretion (NRC, 1996, 2001, 2007). There is a strong correlation between metabolic rate and body water turnover (Squires, 1988). As an example of the magnitude and dynamic nature of the importance of water, the daily body water flux of a lactating dairy cow can be as great as 30% (approximately 140 L) of its total body water (Woodford et al., 1984a; Holter and Urban, 1992; Andrew et al., 1995).

Consumption of Water

Intakes of water and feed are the principal determinants of productivity (growth, gestation, and milk production). However, because loss of body water is continuous but consumption is intermittent, dehydration is a never-ending process. Limitations on normal water intake reduce productivity precipitously and are proportional in general to the degree of restriction. Dehydration of even 10% of body water is considered problematic, and the loss of 15 to 25%, depending on the species, results in death. Typically, ruminants discontinue eating during a progressive, severe drinking water shortage. Facing this shortage, body tissues generate some water from metabolic oxidation: carbohydrate (0.14 mL/kcal, oxidized), fat (0.12 mL/kcal), and protein (0.10 mL/kcal; Houpt, 1993). This mechanism may be critically important, for example, for sheep in a desert environment with little drinking water for extended periods, during heat stress, or both. In contrast, metabolic water has minimal quantitative importance in well-watered and well-fed domestic ruminants. Free drinking water typically supplies the majority of needs (Figure 1),

Figure 1. Free drinking water is the major source to meet the ruminants' daily needs (source: copyright © 2012 irishviews.com; used with permission).

but for grazing ruminants or those consuming silages, water in or on feedstuffs becomes a proportionately greater part of total consumption.

The hypothalamic region of the brain controls thirst and drinking behavior by responding to changes in osmotic concentrations and signals from cells in various tissues. Physiological stimuli and mechanisms ensure normal water balance by stimulating consumption in response to dryness of the oral cavity and throat, decreased salivary flow (especially important to ruminants for supplying water and buffers to the microbes of the rumen), and osmotic changes in other tissues. A water deficit and sufficiency of the digestive tract are ensured by a feedback loop with the central nervous system so that overconsumption and "water poisoning" typically does not occur. Subsequently, some water absorption occurs in the oral cavity, with all digestive tract organs having the capacity to transport water back and forth from the lumen to blood circulation. In addition, a significant proportion (18 to 60%) of drinking water can bypass the rumen via esophageal groove closure and pass directly to the abomasum (Woodford et al., 1984b; Zorrilla-Rios et al., 1990). This normal physiological reflex offers a potential route to deliver other essential nutrients or supplements via drinking water when it is desirable to avoid potential fermentative breakdown in the rumen (Osborne, et al., 2009).

Ruminants are homeotherms, and regulation and maintenance of body heat balance require water for evaporative heat loss from the skin and lungs (Beede and Collier, 1986). High-producing dairy cows in hot weather inherently decrease internal metabolic heat production by reducing feed intake, consequently lowering milk yield. To try to reduce the internal heat load in hot weather, researchers at College Station, Texas, offered chilled drinking water (approximately 10 vs. 27°C) to lactating dairy cows. Overall body temperature and signs of heat stress were reduced somewhat, but only in the short term. Milk yield improved somewhat with chilled water in some studies, but not in others (Stermer et al., 1986; Wilks et al., 1990).

Most mammals prefer drinking water with a temperature near body temperature (Szlyk et al., 1989). Ruminants prefer to drink warmer water (30 vs. 12 to 14°C) even when environmental temperatures are quite warm (>25°C; Beede, 2006). However, the question of whether lactating cows will consume more water, eat more feed, and produce more milk with improved efficiency at different environmental temperatures if the drinking water is warmer (e.g., 27 vs. 2°C) has not been fully answered. Osborne et al. (2002), in Canada, conducted a study with lactating dairy cows to evaluate the effects of warm drinking water and found significant, but relatively small, differences in water consumption and productivity that were also influenced differently during winter and summer.

The optimal drinking water temperature for dairy cows (and perhaps other ruminants) in cold and warm climates requires more study, especially under field conditions. Overall, information is not conclusive regarding the most favored drinking water temperature range of ruminants, whether it varies by species, whether it is different in warm or cold environments, and whether the most preferred temperature is optimal for productivity.

Estimation of Water Requirements

The most common expression of the water requirement of an animal is the factorial summation of the amounts needed for maintenance, growth, pregnancy, and lactation (Murphy et al., 1983; NRC, 1996, 2001, 2007; Meyer et al., 2004). On a periodic basis (daily or longer, as with some pasture- or range-fed ruminants), the requirement is fulfilled when water intake equals water loss: (free drinking water + water in or on feeds consumed) − (water excreted in urine and feces + water secreted in milk, sweat, and respiratory vapor).

Dairy Cattle

Lactating dairy cows consume more water than any other nutrient, and it is the greatest component of milk (approximately 87%) and manure (approximately 88%; Van Horn et al., 1994). Young calves, transition dairy cows (3 weeks before through 3 weeks after parturition), and high-producing dairy cows have elevated metabolic rates, greater water turnover, and thus greater requirements for water compared with less productive animals (Squires, 1988).

In a number of controlled studies, the amounts and relative importance of several animal, dietary, and environmental factors were identified that influence the water needs of lactating dairy cows: body size; amount of milk produced; rate of dry matter intake; diet type (wet vs. dry forage, proportion of concentrate); dry matter (or water), sodium, and nitrogen contents of the diet; environmental temperature; relative humidity; and season. All were significant factors in some of the equations used to calculate water requirements (e.g., Holter and Urban, 1992; NRC, 1996, 2001, 2007; Cardot et al., 2008, to list only some). In most studies, cows were fed rations of conserved forages and concentrates (Beede, 1992; NRC, 2001), although water intake under a pasture system was also estimated (Stockdale and King, 1983). In a recent Canadian study (Cardot et al., 2008), predictions of drinking water intake and drinking water requirements were in good agreement with several previously published equations for lactating dairy cows (NRC, 2001). However, it is likely that drinking behavior and the thirst drive evolve as lactation progresses; thus, further study could prove useful to understand the relationships among stage of lactation, feed intake, and drinking behavior of individual- or group-housed cows, or both, under different environmental conditions.

It is perhaps not surprising that the most important factors influencing free drinking water intake are feed dry matter intake and milk yield. On average among several studies, the ratios of dry matter intake to water intake and milk yield to water intake were 4.1, and 2.8, respectively. However, considerable variability exists among all studies around these average ratios (3.2 to 5.4 for dry matter intake to water intake, and 2.0 to 3.4 for milk yield to water intake); factors other than dry matter intake and milk yield presumably also influence water intake and have practical importance. Furthermore, in most studies, water composition (an indicator of water quality) determined by laboratory analysis was not reported. Water quality factors may affect water intake and influence whether an animal naturally consumes its requirement (addressed subsequently).

Beef Cattle

Differences in water requirements between dairy and beef cattle stem mainly from different demands for the rate and composition of body growth and for the magnitude of milk yield. The NRC (1996) report on the nutrient requirements of beef cattle emphasized that water needs should be considered in light of environmental factors (e.g., ambient temperature, physical activity level), diet composition (e.g., feed type, forage-to-concentrate ratio, moisture content of the feed), and metabolic water derived from different feeds. The publication presented approxi-

Figure 2. Sheep in a pasture-based system consuming natural surface water (source: © 2010 iStockphoto.com/Dejan Gileski).

mate estimated daily total water intake values as influenced by body weight, environmental temperature, and class of animals (growing animals regardless of sex; finishing cattle; wintering, pregnant cows; lactating cows; and mature bulls), but suggested taking into consideration other potential but not yet quantified influencers. These recommendations are fashioned from the original research work of Winchester and Morris (1956). For feedlot steers, Hicks et al. (1988) developed an equation for water needs that includes average maximum ambient temperature, dry matter intake, precipitation, and salt (sodium chloride) content of the diet. Additional research could prove useful to better understand the relative quantitative importance of other factors, such as genetic origin (*Bos taurus* vs. *Bos indicus*) or accelerated growth rates of modern genetics, that may influence water needs at different stages of the life cycle in different environments.

Sheep and Goats

The water nutrition, approaches to estimating water requirements, and water needs of sheep and goats have been researched more extensively than those for other ruminants (NRC, 2007; Figures 2 and 3). This may be partly because of their smaller body size and relative ease of or availability for use in research. The fundamental factors affecting water intake and estimation of needs are similar to those of cattle addressed previously. It is not surprising that the most reliable small ruminant animal model when comparing different research-generated equations was the adult goat fed at maintenance requirements. Various expressions to estimate daily water intake and needs included one or more of the following: metabolic body weight, body weight, dry matter intake, digestible energy intake, or their combination. At a somewhat lower level of aggregation in small ruminants than in cattle, the additional factors considered in the modeling of water requirements included the processes associated with digestive and metabolic energetics to yield metabolic water, and the addition of the term for "free existence," which is associated with water loss (e.g., sweating and respiratory loss) to the environment. Overall, it is estimated that metabolic water contributes 5 to 10% of the total requirement. Factorial estimates for maintenance, lactation, and growth are available from Wallace et al. (1972), but they do not separate the maternal water requirement for pregnancy from that of the fetus (or conceptus; NRC, 2007). In addition, there are only a few less reliable estimates of water requirements for young or suckling small ruminants (NRC, 2007) and cattle (NRC, 1996, 2001).

Overall, the water requirements of ruminants are for maintenance, growth, pregnancy, and lactation, with demand increasing proportionately as productivity and water turnover increase. Free drinking water and water associated with the ration supply most of the requirement, although metabolic water can be very important for animals in harsh environments where sufficient free water, feed water, or both are not available. Across ruminant species, less is known about the water requirements of young suckling or growing animals than the water requirements of adults at maintenance or during lactation and gestation.

Water Quality

It is unequivocal that poor water quality can affect the water intake, feed intake, nutrient utilization, health, and productivity of ruminants (NRC, 1996, 2001, 2007). However, it is much less clear which factors (and at which concentrations) elicit undesirable consequences. Under farm conditions, questions about water quality most usually arise only after poor health or productivity is observed or perceived. It is relatively rare for farmers to know actual water intake via metering devices or other measurement, or to have a laboratory analysis for the basic evaluation of the water quality for livestock. Reliable estimates of water intake and quality are the fundamental initial sources of information needed to assess potential water quality or nutrition problems (Beede, 2009).

The definition of water quality typically encompasses physiochemical factors (e.g., turbidity, taste, smell), micro- and macromineral elements, organic matter, and microbial contaminants, as well as potential risk from anthropogenic pollutants and contaminants (Veenhuizen and

Figure 3. Goats drinking water in arid lands of Kenya (source: © 2008 iStockphoto.com/Jurjen Draaijer).

Shurson, 1992; Solomon et al., 1995; NRC, 2001, 2007). Clean (unadulterated or potable) drinking water is critically important for the maximum performance of dairy cattle (Beede, 2006, 2009). For example, on the basis of field experiences, early-lactation cows and young calves are particularly sensitive to poor water quality [e.g., elevated concentrations of total dissolved solids (**TDS**), sulfates, or iron], in turn causing subnormal water consumption, poor growth, or poor lactational performance. It also is possible that an anti-quality factor(s) may interfere with another nutrient or nutrients in the digestive tract to render them less absorbable (e.g., effects of high molybdenum and sulfate on the absorption of copper).

Chemical anti-quality factors in water originate primarily from natural groundwater or from pollutants in the surface or groundwater derived from environmental pollution (e.g., nitrates). Microbial contaminants are mainly from environmental pollution or fecal contamination or from poor cleaning of drinking water receptacles. Deleterious microbes are found in drinking water with some frequency, but the degree of risk is largely undefined (LeJeune and Gay, 2002). Risk factors for microbial contamination of water are beyond the scope of this article but are addressed elsewhere in this issue (McAllister and Topp, 2012).

Table 1 presents a partial compilation of some published water quality guidelines for humans and farm livestock. Information sources were chosen to represent official agency standards [US Environmental Protection Agency (**EPA**), 2009] or published guidelines from authors having databases with sizable numbers of on-farm water sample analyses and considerable knowledge and empirical experience with water quality in livestock operations (Adams and Sharpe, 1995; Socha at al., 2003). As highlighted and emphasized in this issue (Meyer and Casey, 2012), many different guidelines for livestock are suggested from various sources, demonstrating the lack of solid research information to set validated, practical guidelines for ruminants. Additionally, as illustrated in Table 1, there is inconsistency even in the naming of and definitions for water quality standards and their precise meanings. Precise, consistent designations and definitions, such as by the EPA (2009) for humans, would be an improvement also for livestock.

Chemical Constituents

Common elements and compounds in water that are more likely to be important include calcium, chloride, copper, free hydrogen (pH), hydrogen sulfide, iron, magnesium, manganese, nitrate, potassium, sodium, sulfate, zinc, and TDS (the sum of carbonates, chlorides, sulfates, nitrates, sodium, potassium, calcium, and magnesium, primarily). Knowledge of the maximum contaminant concentrations in drinking water for ruminants before problems occur is very limited and is generally extrapolated from information for humans (NRC, 1974; EPA, 2009) or from results of dietary nutrition research in which similar amounts of elements were consumed (NRC, 2005). In most cases, it is unknown whether the chemical form or chemical properties (e.g., valence, salt form, solubility), the concentration (amount), or the medium (drinking water vs. feed) affect absorption of the specific chemical and its effects in the animal. Little research with ruminants has explored possible interactions (e.g., pH of the water by iron valence and availability or potentially excessive absorption of iron by the animal).

Relatively high concentrations of sodium, potassium, calcium, phosphorous, copper, and zinc in natural waters are not considered problematic for cattle and sheep (except for the copper toxicity risk in sheep; NRC, 1974, 2001, 2005, 2007). In addition, current knowledge suggests that water pH within an acceptable range (6.5 to 8.5) is inconsequential to ruminants. Relatively high concentrations (190 ppm) of water hardness (defined as the sum of concentrations of the multivalent metal cations calcium and magnesium primarily, and zinc, iron, and manganese to a lesser extent) did not affect lactating dairy cows (Graf and Holdaway, 1952). However, greater hardness concentrations (as much as 500 to 800 ppm) are found in drinking water in some ruminant farms and the consequences are unknown (D. K. Beede, personal observations).

On the basis of field experience, high TDS in drinking water affected the productivity and health of lactating dairy cows both within the environmental thermoneutral zone and during heat stress (Beede, 2006, 2009). In general, TDS >500 ppm reduced water and feed intake and consequently the physiological and productive performance of the animal. However, the exact mode(s) of action and sequence of physiological reactions to high TDS are largely unknown. Highly saline (sodium chloride) water affected the lactation performance of dairy cows (Solomon et al., 1995). Most often in the field, it is unclear which specific ions or constituents (e.g., high calcium, chloride, iron, or sulfate) within the broader TDS category may be causing specific observed animal responses.

Table 1. General guidelines for assessing drinking water quality for humans and farm livestock[1]

Analyte	Maximum contaminant level[2]	Upper levels for livestock[3]	Maximum upper levels[4]	Expected[5]	Possible cattle problems[6]
Aluminum	(0.05 to 0.2)[7]	5.0	10.0		
Arsenic	0.01	0.2	0.2	<0.05	>0.20
Barium	2.0	1.0	1.0	<1.0	>10 (health)
Bicarbonate		1,000	1,000		
Boron		5.0	30.0		
Cadmium	0.005	0.01	0.05	<0.01	>0.05
Calcium		100	200	<43	>500
Chloride	(250)	100	300	<200	
Chlorine (Cl_2)	4.0[8]				
Chromium	0.1	0.1	1.0	<0.05	
Copper	1.3 (1.0)	0.2	0.5	<0.6	>0.6 to 1.0
Fluoride	4.0 (2.0)	2.0	2.0	<1.2	>2.4 (mottling)
Hydrogen sulfide[9]				<2	>0.1 (taste)
Iron	(0.3)	0.2	0.4	<0.3	>0.30 (taste, veal)
Lead	0.015	0.05	0.1	<0.05	>0.10
Magnesium		50	100	<29	>125
Manganese	(0.05)	0.05	0.5	<0.05	>0.05 (taste)
Mercury	0.002	0.01	0.01	<0.005	>0.01
Molybdenum		0.03	0.06	<0.068	
Nickel		0.25	1.0		
Nitrate	44	89	443	<44	
pH	6.5 to 8.5 (6.5 to 8.5)	6.0 to 8.5	8.5	<6.8 to 7.5	<5.1 to >9.0[10]
Phosphorus		0.7	0.7	<1.0	
Potassium		20	20	<20	
Selenium	0.05	0.05	0.1		
Silica				<10	
Silver	(0.1)	0.05	0.05		
Sodium		50	300	<3	>20 (veal calves)
Sulfate	(250)	50	300	<250	>2,000
Total bacteria, cells/100 mL		1,000	1,000	<200	>1,000,000
Total dissolved solids	(500)	960	3,000	<500	>3,000
Total hardness				<180	
Vanadium		0.1	0.1		
Zinc	(5.0)	5.0	25.0	<5	>25

[1] Values are parts per million (ppm, which is equal to mg/L) unless otherwise indicated.

[2] Adapted from US Environmental Protection Agency (EPA, 2009) as the National Primary Drinking Water Regulations (EPA-regulated concentrations for humans or Treatment Technique action level to require treatment to remove contaminant, or both).

[3] Adapted from Socha et al. (2003) as composite values from several published sources for livestock.

[4] Adapted from Socha et al. (2003). The upper maximum levels are concentrations above which problems likely could occur in livestock.

[5] Adapted from Adams and Sharpe (1995) based primarily on criteria for water fit for human consumption.

[6] Adapted from Adams and Sharpe (1995) based primarily on research literature and field experiences of the authors.

[7] Values in parentheses are EPA National Secondary Drinking Water Regulations nonenforceable guideline concentrations for humans that may cause cosmetic effects (e.g., tooth or skin discoloration) or aesthetic effects (e.g., taste, odor, or color) in drinking water.

[8] Maximum residual disinfectant level allowed in drinking water.

[9] Hydrogen sulfide is very volatile; concentrations must be determined on site with appropriate methodology or values are not accurate.

[10] Values for cows listed in table; for veal calves, 6.0 to 6.4 is recommended.

Most of the variation in water quality guidelines is due to the very limited information about the impact of various concentrations in drinking water on ruminant health or performance. Moreover, greater concentrations of 2 or more of the suspected analytes could have additive effects. More effort should be dedicated to understanding the effects of anti-quality substances in drinking water on animal performance and health. The integrative approach suggested by Meyer and Casey (2012) in the present issue could help take into account these interactions among analytes as well as other environmental factors.

Water Quality Surveys

The largest (>3,600 samples) national (US) survey of water quality on livestock farms was reported by Socha et al. (2003). Mineral element concentrations (a partial monitor of water quality) varied dramatically not only across the country, but also within specific geographical regions. These differences may have considerable influence on total mineral intake and bioavailability from different origins and sources (e.g., water vs. feed) of the essential mineral elements actually consumed. Across regions of the country, overall average concentrations of calcium, chloride, copper, magnesium, sodium, sulfate, and zinc did not exceed the upper levels for livestock suggested by Socha et al. (2003) in Table 1. However, between 15 and 30% of the total samples exceeded the upper levels for calcium, sodium, and sulfate. In addition, iron and manganese concentrations in individual samples exceeded the desired levels in more than 40% of the samples.

Socha et al. (2003) suggested, based on these survey results, that animal performance in many livestock herds could be limited by water quality. However, nutrition advisors were cautioned that research is scant for establishing upper or maximum concentrations for livestock. In addition, the point of water sample collection (e.g., well, surface, spring, or drinking receptacle) was not recorded and may be important in evaluation.

Osborne (2006), in a Canadian survey of water on livestock farms in Saskatchewan (n = 135), Ontario, (n >700), and Prince Edward Island (n = 145), reported great variation in water composition and quality among provinces. Saskatchewan had well water with very great concentrations of TDS (1,580, and 6,590 ppm; average and maximum values), hardness (717 and 3,890 ppm), sulfates (661 and 3,760 ppm), iron (2.1 and 31 ppm), and manganese (0.37 and 2.3 ppm). These levels are much greater than the guidelines in Table 1. In contrast, water from farms on Prince Edward Island had very low concentrations of analytes, whereas the water from farms in Ontario was intermediate. However, both Saskatchewan and Ontario had water with maximum concentrations of sulfate, chloride, magnesium, sodium, iron, and manganese that exceeded the upper levels suggested by Socha et al. (2003) in Table 1.

Based on my anecdotal field observations when trying to solve herd health and productivity problems and from laboratory analyses of more than 200 suspect drinking water samples from dairy farms in the Upper Midwest, Southwest, and High Plains of the United States, the most common potential water quality issues were linked to excess concentrations (typically with high TDS) of iron, sulfate, or both and chloride (Beede, 2006, 2009). Low water and feed intakes, concerns about transition cow health risks (metritis and abomasal displacement), and subnormal milk yield in early lactation are common issues. In some situations in which water treatment (e.g., reverse osmosis or hydrogen peroxide and filtration) was used, dairy producers often perceived improvements in herd health and production (D. K. Beede, personal observations). However, the characterization and quantification of improvements are generally superficial, and the extent of removal of the anti-quality factor(s) needed to achieve the desired improvement is not clear.

As an anthropogenic concern, nitrate appearing in surface and groundwater from cropland fertilization (whether from commercial fertilizers, animal manure, or human septage) is an emerging issue. Nitrate per se is not toxic to ruminants, but the ruminal microbes convert it to nitrite, which is highly absorbable and toxic, causing a deficiency of hemoglobin, a reduced oxygen-carrying capacity of blood, and suffocation. An early study in Wisconsin found that reproductive efficiency was reduced after 35 months when a dairy herd consumed water with 374 ppm of nitrate (supplied as potassium nitrate) compared with 19 ppm (Kahler et al., 1975). In addition, in a large field survey of Iowa dairy farms, greater than normal (but nontoxic, nonlethal) concentrations of nitrate in drinking water were linked to poorer reproductive performance in dairy herd improvement records (Ensley, 2000). The maximum tolerable concentration without subclinical consequences in dairy cattle (or other ruminants) has not been established. Water quality as a potential issue is the least well understood of all aspects of water nutrition, and research is especially scant.

Conclusions

Water is the most important nutrient for all forms of life. In the last century, relatively little attention was given to how drinking water should be provided and managed in ruminant production systems because it was relatively inexpensive and plentiful. However, preservation, conservation, and stewardship of our overall water resources are receiving increasingly more attention nationally and globally. Water is a precious, traded resource in commerce in more and more regions of the developed and developing world. Already on some livestock farms, it is a significant variable cost that will become more prominent in the future. For animal agriculture, the availability (supply of), source, quantity, use, treatment, and conservation of water will be decisive factors dictating (or limiting) farm location, size, sustainability, and profitability. Ruminant livestock producers must be motivated to improve the management and efficiency of use of clean drinking water by carefully utilizing and conserving as much as possible. Doubtless, the viability of ruminant livestock farms in the next century will be dependent much more on efficient use of water to maximize animal performance and health while simultaneously optimizing on-farm use (from irrigation for feed crop production through recycling and conservation) to reduce the overall water footprint of each farm. Given that the global demand for clean drinking water is increasing, yet with the human propensity to contaminate this valuable resource, but still with the potential to remove contaminants (albeit at a cost), one must ask the question, “What will our ruminants drink?”

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