Water for Dairy Production: Where Does it Go and Why Does Quality Matter?

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Introduction

It has been estimated that that 122 gallons of water are required to produce one pound of milk (1, 020 L/kg of milk) (Hoekstra, 2012). This estimate includes water of three categories 1) surface and ground-water, 2) rainwater, and 3) the volume of water needed to dilute pollutants. It is also estimated that most (95-99 %) of this water used to produce milk is needed to produce feed, while less than 1 % of this water is used for drinking (Owusu-Sekyere et al., 2016). Despite the fact that such little water is used for drinking, water plays an important role in milk production; this is because water's importance for sustenance only follows oxygen in the ranking elements of importance for sustenance. Illustrating this are two studies conducted by (Little et al., 1980) who restricted water for 4 and 14 d at a rate of 50% and 90 % of expected voluntary intake. These restrictions resulted in reductions in milk yields by 3 and 74%, respectfully. Because the quality of water varies greatly, and the consumption of water is vital to both life and production, it should be of little surprise that water quality is of critical importance to the commercial dairy industry. The objectives of this work are to review the flux of water through the lactating dairy cow and to review the major factors affecting the quality of drinking water.

Water Intake and Loss

An old rule of thumb is that cows need to drink 2 times more water than the volume of milk they produce, but, in practice, this is likely a bit of an underestimation (Holter and Urban, 1992). As much as 25 % of a cow's total water needs may come from feed. Additionally free water intake (FWI) is also known to be positively associated with feed intake, sodium and potassium content, and increasing humidity and environmental temperatures (NRC, 2001; Appuhamy et al., 2016). Table 1 and Figure 1 summarizes the results of a French study that investigated water intake, excretion and partitioning in Holstein cows placed in climatic chambers either at or above thermoneutrality (Khelil-Arfa et al., 2014). As predicted, the greatest losses of water occurred through fecal routes, followed by losses due to milk production and urine excretion. Increasing the temperature resulted in an increase in evaporated water from 5 to 9 gallons per day or 17 to 32 % of the total water intake (TWI). When expressed per unit of DMI, investigators also observed that increases in evaporative water losses were compensated for by increases in FWI. This increase in FWI is believed to be an adaptive reaction to ameliorate heat stress (Silanikove, 2000).

Water is a source of nutrients. Water can also be an important contributor to the daily intake of minerals in cattle. This is illustrated in a study conducted by in Merced County California in which mineral intake from both water and feed were estimated (Castillo et al., 2013). Of the total minerals analyzed, the proportion coming from water averaged 4 %, but ranged from 0.30 – 20 %. Although this source of minerals is arguably cheap, it may be problematic especially when trying to reduce overall whole-farm mineral balances and also when balancing diets based on dietary cation-anion difference (DCAD); (Beede, 2006; Elrod et al., 2013). Dr. Dave Beede of Michigan State University has created an excellent resource to estimate DCAD intake that accounts for contributions from both the diet and water supplies. This electronic calculator and resource can be found at the following website: https://msu.edu/~beede/extension.html .

Water Quality

High quality water is often easy to spot. It is generally clear and colorless, but it is also easy to overlook the fact that water contains more than just oxygen and hydrogen. Water may also contain pollutants, dangerous microorganisms, and many different types of minerals, all of which affect water quality and possibly production and the health of the lactating dairy cow. The Earth's water moves dynamically above, on, and below the earth's surface. When water moves, it comes into contact with various geological, biological and artificial surfaces that affects its chemical composition (Petersen et al., 2015). It is also important to remember that the composition of drinking water is not only under natural influence but septic tanks, milk-house wastes and industrial drainage or drilling practices (Vidic et al., 2013) may also contribute to these composition problems. It is generally recommended that the water supply for cattle should be evaluated several times a year for coliforms, pH, minerals, nitrate and nitrites, and total bacteria. Expected levels and potential benchmarks of concerns for common water quality tests are given in Table 2.

Source of Problematic Minerals and Compounds. Troubleshooting water problems are not easy, but below is a listing and brief description of problems that may be encountered by a commercial dairy farm. Table 2 is a practical list of average, expected and possible problem concentrations of analytes in drinking water for dairy cattle (Beede, 2012). For a more in-depth review of mineral tolerance and toxicity, readers are referred to the National Research Councils report from Committee on Minerals and Toxic Substances in Diets and Water for Animals (NRC, 2005). Chapter 35 of this publication entitled, "Water as a Source of Toxic Substances," is an excellent summary, while other discussions of water and minerals can be found throughout the publication. The publication notes that sulfur, sodium, iron, magnesium, selenium and fluoride are the minerals that are most likely to reach toxic concentrations in drinking water. Additionally, copper zinc, bromine, bismuth and some rare-earth elements may be added to feed and found in water, and these sources together may resulting in a potential toxicities. When interpreting these guidelines two important points should be made. Firstly, controlled research studies on how these minerals affect animal performance, health, and the foods they produce, is lacking. As a result, except for copper, (0.5 ppm is recommended for livestock, which is lower than the 1.3 ppm in the human drinking water standards) many of these recommendations are made with observations not tested across species. Furthermore, those mineral estimates transposed from human drinking water standards may be conservative when applied to livestock. Secondly, reactivity and toxicity of mineral elements is highly influenced by the chemical form in which they exist. This is a challenge because water analyses and reports focus on the total concentration of a mineral and usually do not report on data related to speciation.

Total Dissolved Solids (TDS) and Salinity. Total dissolved solids (TDS), sometimes referred to as "salinity," is an estimate of inorganic constituents dissolved in a sample of fresh water. Dairy cattle may tolerate some degree of salinity so some caution when interpreting Table 2 and applying results is recommended. The world's growing need for water has brought about greater interest in water desalination (Yermiyahu et al., 2007), while only a small number of studies have sought to evaluate the effects of desalination techniques on dairy cattle. Solomon et al. 1995 reported that desalination increased free water intake by almost 3 gallons, and daily milk yield by over 4.5 pounds. Based on recommendations of the NRC (2001), it is generally believed that water containing 5000 to 7000 ppm of TDS is "reasonably safe" for heifers and dry cows, but producers should avoid offering this water to pregnant or lactating (or both) cattle as production may be impaired. The publication also notes that waters > 7000 ppm of TDS should not be fed to cattle in any stage of production.

Sulfates. Sulfates in ground water usually originate from sulfate-bearing minerals in soils and rocks. The upper safe limit for SO4 is believed to be around 50 ppm with the maximum upper concentration is 300 ppm. A recent study of water samples from the Northern Great Plains observed that 37 % of the samples exceed this upper concentration (Petersen et al., 2015). Sulfates found in drinking water usually include calcium, iron, magnesium, manganese, and sodium salts. Although all of these forms have laxative effects, sodium sulfate is believed to be the most potent. Iron sulfate has been shown to negatively affect free water intake. A major concern with high concentrations of sulfate in drinking water is that in the reducing environment of the rumen. Specifically, most sulfur originating from salts will be reduced to sulfide, and the combined sulfur from feed and water may tie up trace minerals, particularly copper and selenium, making them unavailable to the animal (Socha et al., 2003; NRC, 2001).

Iron. Iron in water is usually found in the ferrous (Fe+2) rather than ferric (Fe+3) form. Recently, Genther and Beede (2013) tested changes in iron concentration, valances [ferrous (Fe+2) or ferric (Fe+3)], and sources (salts) on FWI. Results of this research can be summarized by the three following observations: 1) when the concentration of iron was increased (0, 4 or 8 ppm) with the addition of ferrous lactate [Fe(C3H5O3)2] FWI was reduced at the highest concentrations of iron (8 ppm); 2) valence of iron source was not observed to affect free water intake at concentrations up to 8 ppm; and 3) increasing the concentrations (0, 8 or 12. 5 mg/L) of different salts of Fe [ferrous chloride (FeCl2) or ferric chloride (FeCl3)] did not affect FWI. Consumption of high concentrations of iron may interact with other minerals (i.e. copper and zinc). For example, consumption of high amounts of iron (250 – 1200 ppm) from ferris carbonate has been shown to reduce the absorption of copper in mature cattle (Spears et al., 2003). An additional concern with cows consuming high concentrations of iron, especially in the reduced form, is the increased potential to contribute to oxidative stress. This may of be particular concern in animals with compromised immune systems, like the periparturient cow (Konvičná et al., 2015).

Nitrates. Neither nitrate (NO3-) or nitrite (NO2-) are required by animals. Nitrate poisoning can occur through the consumption of feed or water containing high concentrations (Jones, 1972). Dairy producers should be mindful that rumen microbes reduce nitrates to nitrites; hence, ruminants are more sensitive to toxicities associated with nitrate than are monogastric animals. When absorbed into the bloodstream, nitrites reducing the oxygen carrying capacity of blood. In a survey of 128 Iowa dairy farms, an elevation in the nitrate concentration of drinking water was correlated with increasing calving intervals (Ensley, 2000). The Dairy NRC (2001) recommends that nitrate-nitrogen (NO3-N) not exceed 10 mg/L and nitrate (NO3-) not exceed 44 mg/L. Water testing results which include nitrate and nitrite in mg/L can be converted to nitrogen values by dividing these values by 4.43 and 3.29, respectively (NRC, 2005). It is also known that ruminant animals may adapt to consuming high amounts of nitrate because, in some circumstances, rumen microbes may metabolize it completely rather than convert it to nitrite. This is presumably because ruminants have greater numbers of nitrate metabolizing microbes in the rumen (Lin et al., 2013).

Summary

Drinking water is vital to both the vitality and production of the lactating dairy cow. Although much remains to be learned about water quality and concentration, it is important to test water. By obtaining estimates for water intake, these data may help nutritionists further understand the mineral consumption and DCAD levels of the herd. Furthermore, water testing may indicate problematic constituents of water.

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Table 1. Summary of results of a study in which ambient temperature was increased and the observed effects on water intake and excretions (Khelil-Arfa et al., 2015)

	Thermoneutral[1]	**High temperature[2]**
Dry matter intake, lbs/d	46.9	41.7
Milk Yield, lbs/d	68.1	63.7
% Fat	3.96	3.81
% Protein	3.00	2.79
Body weight, lbs	1408	1384
Free Water Intake, gal	20.4	22.6
Water in feed, gal	8.17	7.25
Total water intake, gal	28.6	29.8
Free Water Intake, lbs	170	188
Water in feed, lbs	68	60
Total water intake, lbs	238	249
Urine output, gal	4.7	5.4
Fecal output, gal	12.6	10.4
Milk Output, gal	7.1	6.7
Evaporated water, gal	5.1	9.1
Metabolic, gal	1.2	1.2
Retained, gal	0.2	-0.4
Free Water Intake, % TWI[3]	71.3	75.8
Water in feed, % TWI[3]	28.6	24.3
Urine output, % TWI[3]	16.4	18.1
Fecal output, % TWI[3]	44.1	34.8
Milk Output, % TWI[3]	24.9	22.0
Evaporated water, % TWI[3]	17.7	30.5
Metabolic, % TWI[3]	4.2	3.9
Retained, % TWI[3]	0.79	-1.34
Free Water Intake, % DMI[4]	3.6	4.0
Water in feed, % DMI[4]	1.5	1.3
Urine output, % DMI[4]	0.8	1.0
Fecal output, % DMI[4]	2.2	1.8
Milk Output, % DMI[4]	1.3	1.2
Evaporated water, % DMI[4]	0.9	1.6
Metabolic, % DMI[4]	0.2	0.2
Retained, % DMI[4]	0.0	-0.1

[1] ambient temperature, relative humidity and unadjusted temperature humidity index (THI) was 60°F, 54.3%, and 59.4% respectively.

[2]ambient temperature, relative humidity and unadjusted THI was 83°F, 28.9%, and 73.2%, respectively.

[3] Total water intake, gallons/gallons

[4]pounds/pounds

Table 2. Average, expected and possible problem concentrations of analytes in drinking water for dairy cattle (*as presented by Beede, 2012*) values are derived from analyses in which most of the water samples were from farms with suspected animal health or production.

Measurement	**Average**[1]	**Expected**[2]	**Possible problems, or caution**[3]
pH, cows	7.0	6.8-7.5	< 5.1 or > 9.0
		Units are mg/L or ppm	
Total dissolved solids, TDS	368	< 500	> 3, 000
Total alkalinity	141	0-400	> 5, 000
Carbon dioxide	46	0-50	-
Chloride[4]	20	0-250	-
Sulfate	36	0-250	> 2,000
Fluoride	0.23	0-1.2	> 2.4
Phosphate	1.4	0-1.0	-
Total hardness	208	0-180	-
Calcium	60	0-43	> 500
Magnesium	14	0-29	> 125
Sodium	22	0-3	> 20 veal calves; > 150 cows
Iron	0.8	0-0.3	> 0.3 (taste, veal)
Manganese	0.3	0-0.05	> 0.05 (taste)
Copper	0.1	0-0.06	> 0.6-1.0
Silica	8.7	0-10	-
Potassium	9.1	0-20	-
Arsenic	-	0.05	> 0.20
Cadmium	-	0-0.01	> 0.05
Chromium	-	0-0.05	-
Mercury	-	0-0.005	> 0.01
Lead	-	0-0.05	> 0.10
Nitrate as NO_3 [5]	34	0-44	> 100
Nitrate as NO_2	0.28	0-0.33	> 4.0-10
Hydrogen sulfide	-	0-2	> 0.1
Barium	-	0-1	>10
Zinc	-	0-5	> 25
Molybdenum	-	0-0.068	-
Total bacteria/100 ml	336,300	< 200	> 1 million
Total coliform100 ml	933	< 1	> 1 calves; > 15-50 cows
Fecal coliform/100 ml[6]	-	< 1	> 1 calves; > 10 cows
Fecal streptococcus/100 ml	-	< 1	> 3 calves; > 30 cows

[1] For most measurements, averages are from about 350 samples; most samples are taken from water supplies in farms with suspected animal health or production problems.
[2] Based primarily on criteria for water acceptable for human consumption.
[3] Based primarily on research literature and field experiences.
[4] Field observations suggest free or residual chlorine concentrations up to 0.5 to 1.0 ppm may not affect ruminants adversely. Municipal water supplies with 0.2 to 0.5 ppm have been used

successfully. Swimming pool water with 1.0 ppm, or 3 to 5 ppm chlorine in farm systems with short contact time have caused no apparent problems for cattle.

Figure 1. Measured flow of water (in gallons per day or as a % of total water intake (TWI)) estimated in cows consuming 47 pounds of dry matter and producing 68 pounds of milk that contained 3.96 % fat and 3.00 protein (Khelil-Arfa et al., 2014).