Water, the Forgotten Nutrient

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Take Home Messages

- Do not discount the value of minerals in drinking water. The major effect could be through negative chelations with other diet ingredients.
- Water budget for lactating dairy cattle can be easily calculated based on 4.1 L of water per kg of dry matter intake or 2.6 L of water per kg of milk produced.
- Check the height of the water fountain; cattle prefer water fountains at least 60 cm high.
- Put a water meter on the water source; it may be your first indication of animal health and diet performance.
- Cattle prefer the temperature of water that approximates body temperature.
- Lactating dairy cattle can have continuous or intermittent access to drinking water with no negative effect on productivity. Major drinking bouts occur after each milking.
- The manipulation of the drinking water of lactating dairy cattle should be part of the overall nutrient management strategy of a dairy operation to optimize animal health and productivity.

Background on Water "The Mega Molecule"

The following quotes give a brief history on how NRC introduced the topic of water requirement for dairy cattle for the past 20 years: "Dairy cattle suffer more quickly and severely from a lack of water than from a deficiency of any other nutrient" (NRC, 1978); " Water is an essential nutrient for dairy cattle" (NRC, 1989); and "Water is the most important nutrient for dairy cattle (NRC, 2001). The escalating prominence of water as a nutrient over the years has clearly reflected the attention given to water as a diminished environmental resource. Water has not been researched to the extent of other nutrients because of its abundance and very little cost relative to other essential dietary ingredients. However, fresh clean water is becoming a limited resource in some countries whereas in others, wasteful water use has lead to environmental pollution. In Canada an estimated 18.8 billion litres of potable water each year is used by lactating dairy cattle. According to the World Water Vision (2000) competition for water will reach a zenith in the next ten years if we do not change the management of our most vital resource.

Dairy cattle consume more water than any other nutrient and it is the largest component of milk (85-88%) and combined excretory products (87.8 %) (Van Horn et al. 1994). The unique chemical structure of water (two hydrogen atoms covalently bound to one oxygen) enables water as a liquid to have physiological relevant properties compared to other liquids. Water relative to other liquids has the highest rank of the following properties: heat of vaporization; fusion and capacity; surface tension and electrolytic dissociation (Quinton, 1979). One other major advantage of water is its low viscosity which allows for the simple and quick movement of metabolites in circulation and better solute diffusion (Quinton, 1979). Water is the primary fluid in the body of a dairy animal and is used for maintenance of heat balance and in all intermediary metabolic processes. Water is the main solvent intracellularly and extracellularly. It is essential in osmotic balance, aids in digestion and adsorption of nutrients and milk secretion (Beede, 1992). The water flux in a lactating dairy cow can be as high as 30% of total body water (Woodford et al. 1984a; Holter and Urban, 1992; Andrew et al. 1995). This flux represents an average of 140 L per day (Figure 1).

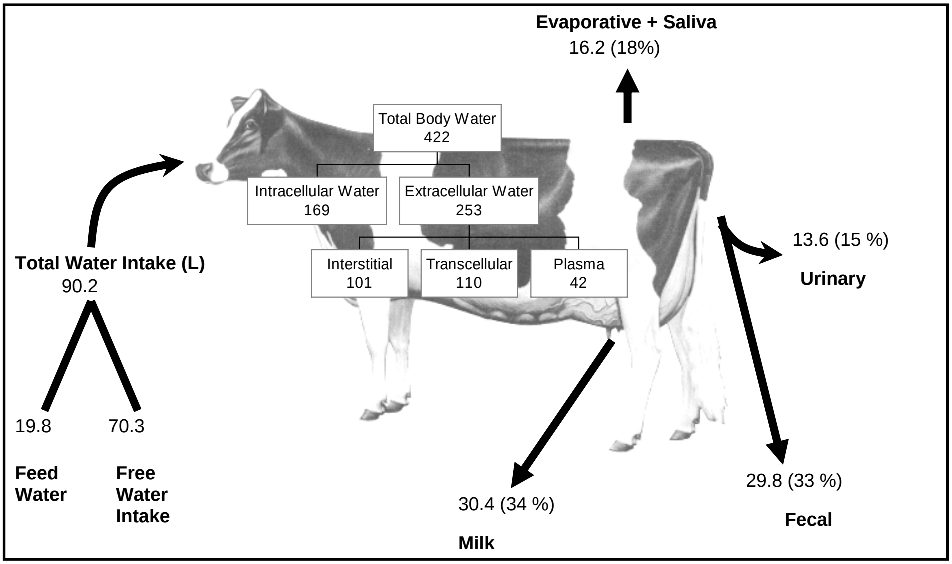

Figure 1. Water distribution (L d-1) and body water pools (L) in a lactating dairy cow (BW=640 kg), consuming 18.7 kg DMI and producing 34.6 kg of milk at 18°C. Milk, fecal, urinary, evaporative and saliva values in brackets are percentage of total water intake. Data adapted from Holter and Urban, (1992) and Woodford et al. (1984a).

Many factors influence the intake of drinking water by dairy cattle including: physiological state, environmental temperature and humidity, diet, dry matter intake, milk yield, body size, breed, water availability, water temperature and disease status (Beede, 1992; Murphy, 1992). However, it is the quality of the water source that ultimately affects intake. Water quality is a comprehensive term that encompasses taste, mineral and organic matter, salinity, solids, bacteria status and the presence of potential contaminants (Veenhuizen and Shurson, 1992; Solomon et al. 1995). I direct the reader to an excellent review article on water assessment for dairy cattle by David Beede at www.msu.edu/~beede/extension. The major problem with assessing water quality particularly with regard to chemical (mineral) properties is the lack of controlled research studies to substantiate any of the maximum tolerable levels. Many questions remain to be elucidated, particularly with how minerals in water invoke their response. Is it a direct osmotic reaction of total salts as a result of a bulk flow of high concentrations, or is it a group or individual ions? What is the bioavailability and is there an alternative route of absorption?

Our laboratory is currently investigating the relationship of how different minerals found in water affect the oral mucosal receptors (smell and taste receptors) of the dairy animal.

Most nutritionists never account for the mineral content of water when formulating rations resulting in potential toxicity levels for some minerals or an unacceptable ratio. Table 1 gives a summary of well water chemical analysis in three different provinces. Figure 2 translates the PEI data into the percent of the daily mineral intake coming from the drinking water source.

The major concern over minerals in water is the possible interactions with other minerals in the diet, particularly with sulphates, iron, manganese, copper, molybdenum and zinc. Iron, copper and zinc are involved in many metabolic pathways. High iron in drinking water is usually in the form of the salt “iron sulfate”. This salt can be absorbed very easily in the small intestine through passive paracellular absorption. Excessive iron is toxic because mammals do not have a metabolic pathway to eliminate excess dietary iron. Iron can inhibit the absorption of copper and zinc resulting potentially in a compromised immune system and retained placenta. The warning level of iron in the drinking water of lactating dairy cattle, in my opinion, is at a concentration of 0.2 ppm.

Table 1. Summary of the chemical analysis of farmstead well water

	Mean			Standard Deviation			Maximum		
Item (mg L^{-1})	**SK[z]**	**ON[y]**	**PE[x]**	**SK**	**ON**	**PE**	**SK**	**ON**	**PE**
pH	7.96	7.59	7.56	0.30	0.51	0.34	8.78	9.30	8.3
TDS[w] (%)	1.58	0.86	0.03	1.02	497	0.06	6.59	9.13	0.71
Hardness	717	315	182	586	387	98	3890	2769	719
Nitrate-nitrogen	2.8	2.81	9.93	5.0	8.76	5.56	32	171	32
Bicarbonate	527	265	192	149	131	67	1160	1114	512
Sulphates	661	186	5	616	393	9	3760	2780	108
Chloride	116	73	32	295	180	80	2100	2290	938
Calcium	156	84	50	110	109	30	514	597	194
Magnesium	79	28	13	83	35	13	683	421	102
Sodium	258	76	19	286	129	40	1390	1519	428
Boron	0.71	0.19	0.03	0.98	0.40	0.02	5.70	5.61	0.11
Copper	0.02	0.01	0.03	0.07	0.05	0.08	0.57	0.90	0.86
Iron	2.1	0.29	0.01	3.6	0.66	0.01	31	28	0.11
Manganese	0.37	0.07	0.02	0.47	0.20	0.07	2.3	2.78	0.59
Silicon	4.58	5.20	3.51	1.64	3.54	0.87	9.90	10.0	6.1
Zinc	0.17	0.05	0.03	0.46	0.13	0.11	4.20	1.30	1.23
Potassium	8.6	8.92	< 0.01	5.5	54	0.00	36	965	0.01
Phosphorus	0.27	12	< 0.01	0.17	27	0.00	0.96	120	0.01

[z] SK = Saskatchewan swine farms (n= 135, McLeese et al. 1991)
[y] ON = Ontario dairy/swine farms (n > 700, Osborne, 2001 and Agri-Lab Services , Guelph, ON ,2005)
[x] PE = Prince Edward Island dairy farms (n= 145, Osborne, 2001)
[w]TDS = Total dissolved solids

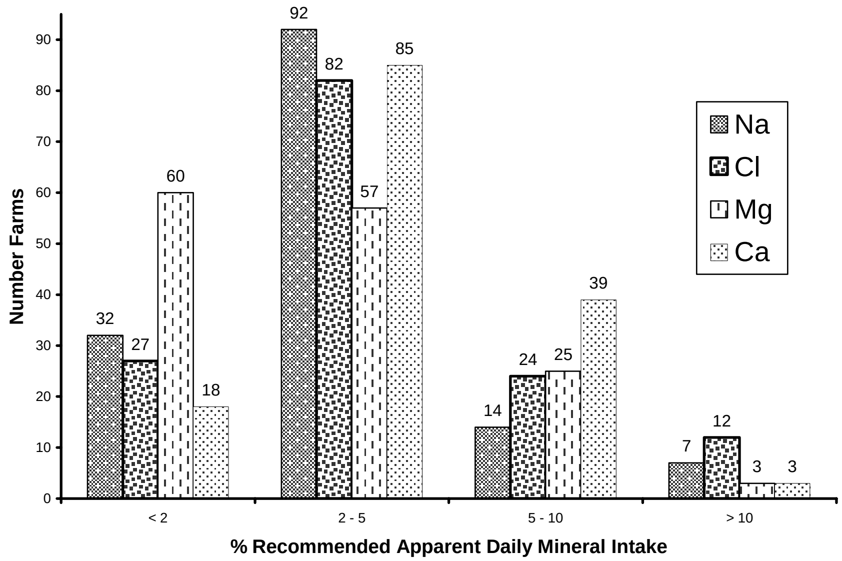

Figure 2. The NRC percent recommended apparent daily mineral intake from the drinking water of lactating dairy cattle. Water intakes based on DHI data and Murphy et al. (1983) prediction equation on 145 dairy farms in PEI.

■ Water Intake

Dairy cattle are suction drinkers and a cow drinks by immersing her lips in water, creating a vacuum in her mouth and delivering the water to the back of the throat by movement of her tongue (Church, 1988). Once water or fluid has passed down the esophagus it can either enter the rumen or by-pass the rumen via the ventricular (reticular, esophageal) groove. The fate of ingested water in the rumen is assumed to equilibrate with ruminal fluid (Cafe and Poppi, 1994). However, data from Woodford et al. (1984b) and Zorrilla-Rios et al. (1990) have shown that 18 to 60% of ingested water bypassed the rumen directly to the abomasum. The level of rumen-fill at the time of drinking could well affect the fate of drinking water in the rumen (Café and Poppi, 1994). More studies are needed to accurately define the route of drinking water in dairy animals under different physiological conditions.

Many water intake prediction equations have been developed. I would refer to David Beede's web site for more information on all the variables that are included; www.msu.edu/~beede/extension. For a quick calculation of the water budget refer to Table 2, which summarizes experiments recording water intakes for lactating dairy cattle. Prediction equations have been developed to estimate the free water intake in dairy cattle with DMI having the greatest influence (Murphy et al. 1983; Holter and Urban, 1992; Dahlborn et al. 1998).

The estimated average ratio of water to DM intake is 4.1 litres. Because most producers have individual milk yield records or bulk tank records a more accurate estimate of herd water intake would be litres of water to milk yield ratio which is estimated from the references cited to be 2.6:1.

Table 2 Recorded individual water intakes for lactating dairy cattle

				Ratio of litres of water per kg	
Reference	**DMI ($kg\ d^{-1}$)**	**Milk yield ($kg\ d^{-1}$)**	**Free water intake ($L\ d^{-1}$)**	**DM**	**Milk**
Little and Shaw ,1978	13.3	21.4	56.5	4.2	2.6
Murphy et al. 1983	19.0	33.1	89.2	4.7	2.7
Woodford et al. 1984	16.2	25.7	65.2	4.0	2.5
Andersson, 1985	17.7	24.5	75.2	4.2	3.1
Nocek and Braund, 1985	18.0	29.0	71.8	4.0	2.6
Andersson, 1987	17.9	29.5	72.6	4.1	2.5
Andersson and Lindgren, 1987	21.2	26.6	89.2	4.2	3.4
Holter and Urban, 1992	18.7	34.6	70.3	3.8	2.0
Dado and Allen, 1994	20.0	28.7	63.2	3.2	2.2
Dado and Allen, 1994	24.8	37.5	89.5	3.6	2.4
Silanikove et al. 1997	22.2	41.5	106.6	4.8	2.6
Dahlborn et al. 1998	18.2	25.1	67.5	3.7	2.7
Osborne, 2001	18.6	36.5	93.0	5.4	2.6
Meyer et al. 2004	20.5	31.1	81.5	3.9	2.6
Average				**4.1**	**2.6**

Cows tend to have peak water intake (40% of daily consumption) during the hour after each milking (Osborne, et al. 2002a) with the remainder of the daily water intake consumed after each feeding (Figure 3). The nocturnal drinking activity of cows is negligible. An additional peak would probably be seen for herds on 3 X milking.

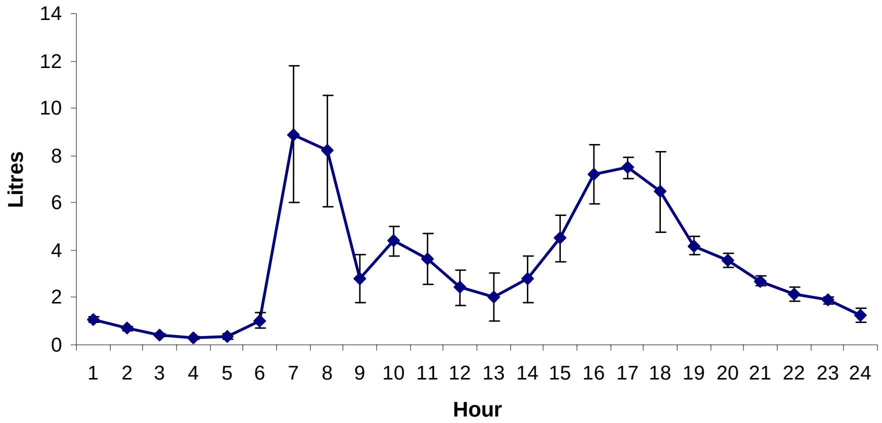

Figure 3. Mean daily water intake of lactating Holstein cows (n=70) was 80.44 L/d. Milking was at 0600 and 1630 h, feeding at 0730 and 1500 h.

Location and height of the drinking fountain are very important. Feed intake is highly correlated to water intake so additional water sources should be made available close to the feed manger. Water volume is important, not pressure, and according to Pinheiro Machado Filho et al. (2004), cattle prefer to drink out of water troughs that are placed at a height of 60 cm. No real data is available on what type of drinking fountain is preferred by cattle (i.e., water bowl or trough). In my opinion there should be both available in a free-stall barn. Troughs can be located on exit alleys from the parlour and crossovers and water bowls in maternity pens and close to feed mangers. Cows are inclined to consume feed and water alternately if given the opportunity (Murphy, 1992). One of the best investments a producer could make is to install water meters. Monitoring drinking water intake is a useful tool to diagnose warning signs of cow health, diet quality and housing issues.

Mammals prefer drinking water temperature that emulates body temperature (Szlyk et al. 1989). Given the preference of dairy cows for warmer drinking water in both a cold (Andersson, 1985) and hot environment (Wilks et al. 1990) we conducted an experiment to investigate the effect of offering continuous heated drinking water on the productive responses of lactating dairy cattle throughout four seasons. Eighteen cows for each experiment were randomly assigned to either an ambient (7 to 15°C) or a continuously heated (30 to 33°C) drinking water treatment.

Table 3. Free water intake of lactating cows given ambient or heated drinking water over four seasons. (Osborne et al. 2002a)

	Treatment				
Season	**Ambient**	**Heated**	**S.E.**	**% Diff.**	**P**
	Free Water Intake (L/d)				
Spring	79.62	82.33	2.77	3.40	< 0.05
Summer	86.09	89.73	3.75	4.23	< 0.05
Autumn	86.99	91.22	2.21	4.86	< 0.001
Winter	87.78	93.00	1.59	5.95	< 0.001

Cattle drank more of the heated water and the difference in treatments increased as the ambient temperature dropped. The economics of heating water for dairy cattle may not warrant a whole herd treatment but may be beneficial for a targeted group, such as transition cows. Heat recovery systems are available in the form of plate cooler technology, jacketing any sources of heat such as vacuum line pumps, the hot water rinse or wash that goes down the drain. Solar heat could also be used to pre-heat drinking water.

▪ Manipulation Of The Drinking Water Of Dairy Cows

In a survey by the National Animal Health Monitoring System (NAHMS), 2002, over 28% of the cattle in the US receive an oral drench with an energy source at the time of calving. Drenching is invasive to the animal and requires extra labour whereas energy supplementation in water is noninvasive and requires no extra labour. The dairy cow is in a nutrient deficit during the periparturient period and the importance of maintaining a constant energy intake would attenuate the use of body reserves. The water intake of a transition dairy cow has been overlooked, yet water has been proven to be a useful strategy to administer nutrients. Water is an excellent solvent in which nutrients can be provided in the form of supplements. Supplements have been included in water as an effective way of ensuring that all animals receive nutrients in extensive grazing conditions (Bowman and Sowell, 1997). If we consider the following variables: the diurnal feed and water intake patterns of dairy cattle; the potential anatomical advantage to rumen by-pass in a full-fed animal; the preference to warm drinking water; the reduced intake behaviour in the transition cow; and the negative energy balance during the first two months of lactation, we should be able to design a economical nutritional therapy based on a water system that delivers nutrients during times of physiological non-steady state. Nutrient water therapy is generally immediate, self medicated, and requires no extra labour for diet mixing or animal handling. The provision of electrolyte (Gortel et al. 1992) and energy (Schaefer et al. 1990) supplementation in the drinking water of market beef bulls exposed to mixing and transport were effective in treating antemortem stress, and losses in live weight and meat quality attributes (Schaefer et al. 1997). Furthermore, the results of Gortel et al. (1992) suggest that intracellular water is conserved at the expense of extracellular water and that an electrolyte mixture emulating interstitial fluid would preserve the integrity of the body water compartments in a non-steady physiological state.

A study done in our laboratory investigated the effects of supplementing glucose in drinking water on the energy and nitrogen status of the transition dairy cow (Osborne et al 2002b). Twenty-four multiparous Holstein dairy cows were randomly assigned to one of three treatments for an experimental period that extended from -7 d prepartum until 21 d postpartum. The treatments included a 0 (control), 1 and 2 % glucose solution metered into the drinking water of transition dairy cows. Milk yield and composition were not affected by treatment. The rumen ammonia levels were reduced (P <0.01) over the lactation period in the glucose treated cows (Table 4). Postpartum blood urea was reduced (P < 0.05) in a linear relationship to glucose inclusion (Table 5).

Table 4. The postpartum treatment by week rumen ammonia concentrations (NH3N, mg/dl) of Holstein cows receiving 0, 1 or 2 % glucose supplemented in the drinking water from -7 to 21 d lactation.

Glucose Treatment	Week 1	Week 2	Week 3	Overall	SE
0 %	9.94	7.16^{a}	9.29^{a*}	8.87^{a**}	0.83
1 %	5.58	5.61^{b}	4.95^{b*}	5.38^{b**}	0.98
2 %	8.88	3.54^{b}	3.29^{b*}	5.32^{b**}	0.76

Table 5. The postpartum by week serum urea concentration (mmol/L) of Holstein cows receiving 0, 1 or 2 % glucose supplemented in the drinking water from -7 to 21 d lactation.

Glucose Treatment	Week 1	Week 2	Week 3	Overall	SE
0 %	5.15	5.68^{a}	5.95^{a}	5.59^{a}	0.12
1 %	4.96	4.50^{b*}	4.82^{b*}	4.76^{b*}	0.12
2 %	4.54	3.76^{b**}	3.84^{c**}	4.04^{c**}	0.11

The BW and BCS loss during the postpartum period was reduced in glucose treated cows. The calculated NE balance and serum glucose, BHBA and NEFA were not affected by glucose treatment.

The major effect of water glucose supplementation was the significantly reduced rumen fluid ammonia and serum urea over the periparturient period demonstrating that the rumen environment can be manipulated with water treatment. Maximizing microbial protein yield by having both a protein and energy source at the optimum time in the rumen may be beneficial not only during transition but also when cattle have to be re-bred. Energy could easily be introduced into the water line of early lactation cattle.

An additional study showed similar serum urea results; neonatal calves supplemented with 5% glucose in their drinking water from birth to 8 wk of age had lower blood urea (3.27 ± 0.12 vs 4.21 ± 0.13 mmol/L, $P < 0.01$) than calves on normal water (Osborne et al. 2002c).

Menhaden oil (Osborne et al. 2002d) has also been successfully administered in the drinking water of lactating dairy cows. Our research has shown that when fish oil was supplemented into the drinking water of dairy cows (2 g/L), DMI was maintained and water intake increased. The results of this trial have led to further studies on alternate energy supplements. We are currently comparing the effects of supplementing glycerol and/or soybean oil into the drinking water of transition cows from -7 to 7 d partum.

Dietary fat largely bypasses the portal venous system and is incorporated into triglycerides in the intestine. The dietary fat can then be used for energy by non-hepatic tissues, thus sparing glucose.

Subacute rumen acidosis (SARA) may also be treated with buffers administered through the water. A study was done to see if cows subjected to SARA would select for water supplemented with sodium bicarbonate (2.5 g/L). Cows selected the bi-carbonated water 40% of the time regardless if they were under SARA or normal rumen pH conditions. The major result of this study was that the largest intake of daily water intake correlated highly with depressed rumen pH (Cottee et al. 2004).

A recent study was completed where we measured the effect of a continuous or restricted source of flavoured water on lactating cow performance. An orange emulsion (0.1%) was supplemented into the drinking water and cows either had continuous access to water or restricted for three hours around milking only (2X). Water restriction had no detrimental effect on cow productivity as seen by Rouda et al. (1994) in beef cattle and by Bjerg et al. (2005) in dairy cattle.

Conclusion

The most important nutrient in dairy cattle nutrition is water (NRC, 2001). However, since water is generally perceived in abundance it receives little research attention.

From previous studies in our lab the manipulation of the drinking water of lactating dairy cattle could be part of the overall nutrient management strategy of a dairy operation to maximize animal productivity. Further research is required to determine the appropriate treatment time and degree of, and what nutrients can be supplemented that are valuable to the cow during the periparturient period. Drinking water intake does not demonstrate the daily variation seen in DMI over the periparturient period.

Milk production is a volume business and any application of technology to reduce the costs of production would greatly help Canadian producers. Supplementation at strategic times and for only short periods may be a more cost effective approach than a traditional supplementation or feeding program. The application of this technology has been widely accepted in the poultry industry and very little retrofitting would be required to apply economical water treatment methods to the dairy industry.

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