The Most Essential Nutrient: Water

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Introduction

An essential nutrient must be supplied via consumption from the ration, air, or a water source because it is not synthesized in sufficient amounts in the animal's body to meet requirements for maintenance, growth, milk production and pregnancy. Of the essential nutrients – oxygen, water, proteins, carbohydrates, fats, minerals, and vitamins – water is second in importance only to oxygen to sustain life and performance of dairy cattle. However, unlike the close and continuous attention given to other essential nutrients supplied primarily in rations, oftentimes water does not receive adequate consideration to ensure optimal nutrition and performance of dairy cattle.

The Future. The availability of abundant, clean drinking water may become a challenge in the future as dairy farms are pushed farther and farther from population centers and relocate. Determining the amount and quality of water (well or municipal) available for nourishment of cattle and milking parlor functions are critical for existing dairies, for dairies considering expansion, or before new dairies are built. Evaluating and determining water supply (amount and maximum flow rate) and quality are paramount to a dairy business's investment. Investors and lenders should require a complete water management plan (e.g., draw, uses/consumption, and recycling) and complete assessment of the chemicals and biological agents carried in the water before any land is purchased or before a new dairy facility is built. Determining the "water status" of a dairy site after-the-fact is poor business. Alarmingly, based on experiences of Roberts and coworkers (http://psc.wi.gov/electric/newsinfo/document/cattle.pdf) in Wisconsin, dairy producers and many professionals advising farmers have poor understanding of water nutrition of dairy cattle. This author finds similar lack of knowledge when assisting dairy producers and nutritionists with water-related problems in dairy farms.

This paper emphasizes basic information about water nutrition of cows and calves, predicting water intake and requirements, evaluation of water quality, factors affecting water intake, and the practical aspects and assessment of water nutrition management in dairy farms. Topics often asked of and encountered by the author in advising dairy producers about quality and provision of the MOST ESSENTIAL ESSENTIAL NUTRIENT to maximize dairy cattle performance are addressed. Citations listed in this paper as well as other references about water nutrition of dairy cattle are provided at: http://www.msu.edu/~beede/ by clicking on "Extension", and then "Water Ref". The NRC (2001) provides a review of the research literature about water nutrition for dairy cattle and current gaps in our knowledge.

Essential Functions of Water

The water requirements per unit of body mass of the high-producing dairy cow are greater than that of any other land-based mammal. This is because she produces a large amount of milk which is 87% water (Woodford et al., 1985). Water is required for digestion and metabolism of energy and nutrients, transport of nutrients and metabolites to and from cells in blood, excretion of waste products (via urine, feces, and respiration), maintenance of proper ion, fluid, and heat balance, and, as a fluid environment for the developing fetus (Houpt, 1984; Murphy, 1992).

Total body water content of adult dairy cattle ranges between 56 and 81% of body weight (Murphy, 1992). Cows in early lactation have more live body weight as water compared with cows in later lactation (69.0 vs. 62.4%); body water content of late pregnant dry cows was 65% of total body weight (Andrew et al., 1995). About two-thirds of water in the body is in the intracellular compartment. The remaining one-third of water is in extracellular spaces around cells and connective tissues, in blood, and as transcellular water or water in the digestive tract.

Water in the digestive tract accounts for 15 to 35% of body weight (Odwongo et al., 1985; Woodford et al., 1984). About 15% of body weight was as water in the digestive tract of dairy cows in early lactation; in late lactation and during the dry period about 10% of body weight was water in the digestive tract (Andrew et al., 1995). Woodford et al. (1984) determined that the residence time of a molecule of water in the rumen of lactating dairy cows was about 1 hour.

Loss of about 20% of total body water is fatal. Loss of water from the body occurs through milk production, urinary and fecal excretion, sweating, and evaporative loss from the lungs. Daily water losses via milk secretion (73 lb/cow per day) represented between 26 and 34% of total water intake (drinking water plus water in feed consumed) (Holter and Urban, 1992; Dado and Allen, 1994; Dahlborn et al., 1998). Water lost in feces of lactating cows ranged from 30 to 35% of total water intake, whereas losses in urine were 15 to 22% (Holter and Urban, 1992; Dahlborn et al., 1998). Fecal water losses are increased by increasing dry matter intake (DMI), dry matter (DM) content of the diet (Murphy, 1992), and with increasing forage content of the diet (Dahlborn et al., 1998). Urinary water excretion is related positively with water availability, amount of water absorbed from the digestive tract, urinary nitrogen, sodium, and potassium excretion, and negatively related with dietary DM content (Murphy, 1992). Holter and Urban (1992) calculated that losses associated with sweat, saliva, and respiratory evaporation accounted for about 18% of total water loss within the thermoneutral zone. However, amounts and proportions of water loss associated with these routes were highly dependent upon environmental temperature (McDowell and Weldy, 1967).

Water Requirements and Predicting Intake of Water

Factors influencing daily water requirements and intake include physiological state, amount of milk yield and feed intake, body size, level and kind of activity, environmental factors such as temperature and air movement, diet composition including types of feedstuffs (e.g., concentrate, fresh forages, fermented forages, and hays) as well as nutrient composition (e.g., dietary sodium, potassium, and crude protein contents), and quality (or anti-quality) factors in a particular water source. Other factors affecting consumption may include frequency and periodicity of watering, temperature of the water, and social and behavioral interactions of animals.

Water requirements of dairy cattle are met mainly from that ingested as drinking (free) water, that found in or on feed consumed, and, a small amount from metabolic oxidation (metabolic water). For all practical purposes drinking water intake plus that associated with the ration represent total water consumption.

Seventy to 97% of total water consumption by lactating dairy cows was from drinking water (Castle and Thomas, 1975; Little and Shaw, 1978; Murphy et al., 1983; Nocek and Braun, 1985; Holter and Urban, 1992; Dado and Allen, 1994; Dahlborn et al. 1998). Dry matter content of the diet also is an important factor affecting total water consumption (Castle and Thomas, 1975; Stockdale and King, 1983; Dahlborn et al., 1998). In totally mixed rations with DM contents ranging from 50 to 70%, Holter and Urban (1992) found relatively small differences in drinking water intake; however, when dietary DM content declined from 50 to 30% (ration moisture content increased from 50 to 70%), drinking water intake declined by 42%. Stockdale and King (1983) estimating drinking water intake of lactating dairy cows on pasture, found that only 38% of total water consumption was as free drinking water.

Diets with high amounts of sodium-containing salts (e.g., NaCl, $NaHCO_3$) or protein (nitrogen *per se*) stimulate water intake (Holter and Urban, 1992; Murphy, 1992). High forage diets also may increase water requirements because of higher excretion of water in feces compared with lower forage diets (Dahlborn et al., 1998).

There is a direct relationship between DMI and water intake in cattle. If water intake is sub-normal, feed DM intake typically will decrease. However, if water intake is normal and sufficient to meet the physiological needs of the animal for maintenance, growth, lactation and pregnancy, there is no evidence to suggest that increasing water intake (e.g., forced-hydration) beyond normal will result in greater feed DMI or performance.

Water Intake of Lactating Cows. Equations developed to predict normal drinking water intake of lactating dairy cows are based on experimental data of water intake and quantifiable independent variables affecting drinking water intake. Three equations for predicting drinking water intake by lactating dairy cows are listed below. Abbreviations represent: MY = milk yield; DMI = dietary dry matter intake; DM% = dietary dry mater percentage; and, JD = Julian Day. Drinking water intake (kg/day) estimated by each equation equals (metric units are preserved to reduce confusion):

(1) Castle and Thomas (1975),
In metric units:
2.53 x (MY, kg/d) + 0.45 x (DM%) - 15.3;

(2) Murphy et al. (1983),
In metric units:
0.90 x (MY, kg/d) + 1.58 x (DMI, kg/d) + 0.05 x (sodium intake, g/d) + 1.20 x (average minimum daily temperature, ^{o}C) + 15.99; and,

(3) Holter and Urban (1992),
In metric units:
0.6007 x (MY, kg/d) + 2.47 x (DMI, kg/d) + 0.6205 x (DM%) + 0.0911 x (JD) - 0.000257 X $(JD)^2$ - 32.39.

Milk yield, DMI, and(or) dietary DM percentage were significant factors for predicting drinking water intake in each equation; minimum environmental temperature or Julian Day (a proxy of environmental factors) are in two equations; and, sodium intake is in one equation. Recently, Roberts and coworkers (http://.wi.gov/electric/newsinfo/document/cattle.pdf) reported that they had used the equation of Murphy et al. (1983) as a reference equation to compare with measured consumption of water (in-line flow meters) by groups of cows in Wisconsin dairy farms. They noted good agreement between predicted and measured drinking water intake. However, to my knowledge the other equations have not been evaluated and compared with other independently collected data.

Table 1 illustrates predicted drinking water intake calculated using each of the three equations when each milk yield, DMI, and dietary DM percentage are varied over typical ranges while holding the other two variables constant at the center point of the range. The equations predict generally similar drinking water intakes over the ranges selected for milk yield, DMI, and DM percentage. Water intake in gallons/day can be calculated by multiplying lb/day x 0.1198.

Table 1. Prediction using three equations of drinking water intake by lactating dairy cows when each milk yield (MY), dry matter intake (DMI), or dietary DM content (DM%) were varied while holding the other two variables constant at the center point of the range.

MY, lb/d	DMI, lb/d	DM, %	Castle and Thomas (1975)	Murphy et al. (1983)[a]	Holter and Urban (1992)[b]
MY varied:	DMI constant:	DM % constant:	- - - Drinking water intake, lb/day (gallons/day)[c] - - -		
55	48	60	165 (19.8)	191 (22.9)	180 (21.6)
66	48	60	194 (23.2)	202 (24.2)	187 (22.4)
77	48	60	220 (26.4)	211 (25.3)	194 (23.2)
MY constant:	DMI varied:	DM % constant:			
66	44	60	194 (23.2)	196 (23.5)	176 (21.1)
66	48	60	194 (23.2)	202 (24.2)	187 (22.4)
66	53	60	194 (23.2)	209 (25.0)	198 (23.7)
MY constant:	DMI constant:	DM (%) varied:			
66	48	50	183 (21.9)	202 (24.2)	174 (20.8)
66	48	60	194 (23.2)	202 (24.2)	187 (22.4)
66	48	70	202 (24.2)	202 (24.2)	200 (24.0)

[a] Sodium intake was set at 44 grams/cow per day; minimum daily environmental temperature was set at 50°F.
[b] Julian day was set at 150.
[c] Water intake in gallons/day equals (lb/day X 0.1198).

It is important for dairy producers and nutritionists to realize that these are only predictions (estimates). Other environmental factors not measured and quantified may influence actual water intake. It is common for water intake measured for groups of cows in farms to vary by as much as ±15 to 20% from predicted values, with no apparent (observable) reasons affecting water intake (personal observation). Use of the equation of Murphy et al. (1983) or of Holter and Urban (1992) are recommended as a starting point to predict drinking water intake and to compare with actual on-farmed measured drinking water intake. Doubtless, more research and developing other prediction equations over practical ranges considering additional significant variables would be useful to help diagnose potential water nutrition problems in the field.

Dry Cows. Holter and Urban (1992) developed a specific equation to predict drinking water intake (kg/day) of dry (non-lactating, pregnant) cows:

<u>In metric units:</u>

2.212 x (DMI, kg/d) + 0.2296 x (DM%) + 0.03944 x (dietary crude protein, %) - 10.34.

Table 2 illustrates expected drinking water intakes of dry cows over practical ranges of DMI, dietary DM content, and dietary crude protein percentages. Increasing DMI from 22 to 30.8 lb/day, while holding dietary DM and crude protein percentages constant, increased predicted drinking water intake by 39%. Increasing dietary DM percentage from 30 to 60%, while holding the other two variables in the equation constant, increased drinking water intake by 29%. Based on analysis of their data, increasing dietary DM percentage above 60% had relatively less influence of drinking water intake or total water consumption (Holter and Urban, 1992). Increasing dietary crude protein content from 10 to 18% (dry basis), while holding DMI and DM percentage constant, increased predicted drinking water intake by 11%.

Table 2. Prediction of drinking water intake by dry dairy cows when each dietary dry matter intake (DMI), dietary DM content (DM%), or dietary crude protein percentage were varied while holding the other two variables constant at the center point of the range.

DMI, lb/d	DM, %	CP, %	Equation of Holter and Urban (1992)
DMI varied:	DM % constant:	CP % constant:	- - - Drinking water intake, lb/day (gallons/day)[a] - - -
22.0	45	14	49.9 (6.0)
26.4	45	14	59.6 (7.1)
30.8	45	14	69.3 (8.3)
DMI constant:	DM % varied:	CP % constant:	
26.4	30	14	52.0 (6.2)
26.4	45	14	59.6 (7.1)
26.4	60	14	67.2 (8.0)
DMI constant:	DM % constant:	CP % Varied:	
26.4	45	10	41.6 (5.0)
26.4	45	14	43.9 (5.3)
26.4	45	18	46.3 (5.5)

[a] Water intake in gallons/day equals (lb/day x 0.1198).

Water Quality: Factors Affecting Animal Performance

Factors typically considered in water quality evaluation include odor and taste, physical and chemical properties, presence of toxic compounds, concentration of macro- and micro-minerals, and microbial contamination. These factors may have direct effects on the acceptability (palatability) of drinking water, or they may affect the animal's digestive and physiological functions, once consumed and absorbed. Table 3 provides a summary of average, expected and possible problem concentrations of analytes in drinking water (adapted from Adams and Sharpe, www.das.psu.edu/teamdairy/). Summary of information from other sources is available elsewhere (Beede and Myers, 2000).

Primary anti-quality factors known to affect dairy cattle include total dissolved solids, sulfur, sulfate and chloride (both being anions), nitrates, iron, and fluoride. Many other potential factors typically listed in water analyses reports and listed as potential risks for humans have not been well-documented in the research literature or under practical conditions to affect dairy cattle performance or health; examples include pH of water (pH between 6 and 9 is assumed acceptable and has very little influence on ruminal pH due to the highly reductive environment in the rumen), total hardness, calcium and magnesium contents. It is always possible that isolated cases of higher than normal concentrations of mineral elements, microorganisms, or other toxic compounds may be present and deleterious to cattle (Table 3). However, typically these cases are extremely difficult to identify and to prove cause and effect.

Table 3. Average, expected and possible problem concentrations of analytes in drinking water for dairy cattle (adapted from Adams and Sharpe, www.das.psu.edu/teamdairy/).

Measurement	Average[a]	Expected[b]	Possible problems[c]
pH for cows	7.0	6.8-7.5	under 5.1 or over 9.0
pH for veal calves		6.0-6.4	
		- - - - - - - parts per million (ppm, or mg/ liter) - - - - - - - -	
Total dissolved solids	368	500 or less	over 3,000
Total alkalinity	141	0-400	over 5,000
Carbon dioxide	46	0-50	
Chloride*	20	0-250	
Sulfate	36	0-250	over 2,000
Fluoride	0.23	0-1.2	over 2.4 (mottling)
Phosphate	1.4	0-1.0	
Total hardness	208	0-180	
Calcium	60	0-43	over 500
Magnesium	14	0-29	over 125
Sodium	22	0-3	over 20 for veal calves
Iron	0.8	0-0.3	over 0.3 (taste, veal)
Manganese	0.3	0-0.05	over 0.05 (taste)
Copper	0.1	0-0.6	over 0.6 to 1.0
Silica	8.7	0-10	
Potassium	9.1	0-20	
Arsenic	---	0.05	over 0.20
Cadmium	---	0-0.01	over 0.05
Chromium	---	0-0.05	
Mercury	---	0-0.005	over 0.01
Lead	---	0-0.05	over 0.10
Nitrate as NO_3[d]	34	0-44	over 100
Nitrite as NO_2	0.28	0-0.33	over 4.0-10.0
Hydrogen sulfide	---	0-2	over 0.1 (smell of rotten eggs, taste)
Barium	---	0-1	over 10 (health)
Zinc	---	0-5	over 25
Molybdenum	---	0-0.068	
Total bacteria/100 ml	336,300	under 200	over 1 million
Total coliform/100 ml	933	Less than 1	over 1 for calves; over 15-50 for cows
Fecal coliform/100 ml[e]	---	Less than 1	over 1 for calves; over 10 for cows
Fecal streptococcus/100 ml	---	Less than 1	over 3 for calves; over 30 for cows

[a] 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.
[b] Based primarily on criteria for water acceptable for human consumption.
[c] Based primarily on research literature and field experiences.
[d] Should not be consumed by human infants if over 44 ppm NO_3 or 10 ppm NO_3-N.
[e] If pollution is from human wastes, fecal coliform should exceed fecal streptococcus by several times. If pollution is from an animal source, strep should exceed coliform in refrigerated samples analyzed soon after sampling.
* Free or residual chlorine concentrations up to 0.5 to 1.0 ppm have not affected 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.

Total Dissolved Solids (TDS). TDS are defined as the sum of inorganic matter dissolved in water (also are known as the salinity of water). Table 4 provides guidelines for the use of waters containing varying concentrations of TDS. Total dissolved solids can be an indicator of poor quality water. High TDS generally are considered an unwanted characteristic. A few studies have tested the effects of salinity on milk production, with conflicting conclusions. Jaster et al. (1978) found that milk production decreased when cows consumed water containing 2500 ppm of NaCl added to tap water (196 ppm of TDS). Challis et al. (1987) found that there was a trend towards decreased milk production during hot weather when cows were given water with 4300 ppm of TDS. Bahman et al. (1993) reported that water with 3500 ppm of TDS did not affect milk production. Solomon et al. (1995) reported results similar to those of Jaster et al. (1978). The more recent studies were carried out in semiarid, hot climates. Also, these studies do not address the possibility that specific substances *per se* (e.g., sulfates) might be the primary problem and more of an issue than TDS alone. Most research has studied added NaCl to a water source to increase the TDS concentration. However, elevated concentrations of NaCl may not be the most unpalatable compound in some natural water sources. In some studies, it is not clear whether TDS or specific mineral elements, such as sulfate, chloride, sodium, or magnesium, were more responsible for poor water quality causing reduced water intake and milk production (Challis et al., 1987; Bahman et al., 1993).

Table 4. Guide for use of waters with different total dissolved solids (TDS) by dairy cattle[a]

TDS (ppm)	Comment
Less than 1,000 [fresh water]	Presents no serious burden to livestock.
1,000 – 2,999 [slightly saline]	Should not affect health or performance, but may cause temporary mild diarrhea.
3,000 – 4,999 [moderately saline]	Generally satisfactory, but may cause diarrhea, especially upon initial consumption.
5,000 – 6,999 [saline]	Can be used with reasonable safety for adult ruminants. Should be avoided for pregnant animals and baby calves.
7,000 – 10,000 [very saline]	Should be avoided if possible. Pregnant, lactating, stressed or young animals can be affected negatively.
>10,000 [approaching brine]	Unsafe, should not be used under any conditions.

[a] TDS and salinity are commonly synonymous terms. NRC (1974).

Sulfur and Sulfates. Sulfur present as hydrogen sulfide, imparting the rotten egg smell, is believed to affect water intake. Water intake increased at least in the short-run when water without the smell was offered (Beede, personal observation). However, it is not known what concentration of hydrogen sulfide or what intensity of smell reduces normal water intake, or if cattle adapt to the smell and have normal water intake rates if that is the only water available.

High concentrations of sulfate in drinking water can reduce water consumption. However, there is some discrepancy as to the maximum tolerable concentration of sulfate. Weeth and Hunter (1971) found that 3493 ppm sulfate as sodium sulfate reduced water intake, weight gain, and DMI of heifers. Weeth and

Capps (1972) found that sulfate tolerance was about 1462 ppm of sulfate. There were three concentrations of sulfate in drinking water given to heifers in that experiment, tap water (110, 1462, or 2814 ppm). They found that regardless of treatment, heifers still gained weight. However, heifers given drinking water with higher sulfate gained less than heifers drinking tap water (110 ppm). They also found that if given a choice, heifers would discriminate against the water containing 1462 ppm of sulfate and rejected water with 2814 ppm. This suggests that the tolerance threshold of sulfate may be around 1450 ppm, at least for young growing heifers.

Digesti and Weeth (1976) did a third experiment to reevaluate the previous tolerance threshold of 1450 ppm and to determine if heifers could tolerate higher chloride or sulfate concentrations in drinking water. They found that neither health nor growth of heifers was compromised when drinking water contained 2500 ppm of sulfate. Heifers rejected high sulfate water (3317 ppm) supplied as sodium sulfate before rejecting high chloride water (5524 ppm) added as sodium chloride. Equal molar sodium was provided from both sulfate and chloride salts.

Recent research from the University of British Columbia showed that drinking water was unpalatable to beef heifers and steers if it contained 3200 or 4700 ppm sulfate from sodium or magnesium sulfates. Animals offered high-sulfate water also changed their pattern of drinking, drinking more often at night compared with animals offered tap water with low sulfate. Also when the poorer quality high-sulfate water was offered, animals showed more aggressive behavior towards each other when trying to drink. However, 1500 ppm sulfate did not reduce water consumption (Zimmerman et al., 2002).

Nitrates. Nitrates are another potential problem when present in excess in drinking water. Nitrates can pollute a water source via contamination of groundwater or runoff into surface waters. Nitrates have been linked to reproductive problems of lactating dairy cows. A 35-month study tested the influence of nitrates on reproductive and productive efficiency in Wisconsin (Kahler et al., 1974). Two groups of cows were given tap water (19 ppm of nitrate) or drinking water containing 374 ppm of nitrate added as potassium nitrate. During the first 20 months of the study, there was no difference in reproductive performance. However, in the last 15 months cows drinking the high-nitrate water had more services per conception, lower first service conception rates, and longer calving intervals. Table 5 lists guidelines for nitrate concentrations in drinking water for livestock.

In a more recent study of 127 dairy farms in northwestern and northeastern Iowa, the nitrate concentrations of drinking water were relatively high (Ensley, 2000). In northwestern Iowa (n = 104 farms) average, minimum, and maximum concentrations of nitrate were 30, 1 and 300 ppm, respectively; comparable values for water samples in northeastern Iowa (n = 23 farms) were 25, 9, and 110 ppm, respectively. In northwest Iowa, shallow wells were most prevalent, whereas in the northeast, the majority of wells were 150 feet or deeper. Dairy herd performance (DHI records) and the relationships with water quality (anti-quality factors) were evaluated. Herds drinking water with highest nitrate concentrations also had the longest calving intervals, similar to the earlier findings of Kahler et al. (1974).

Table 5. Guidelines for nitrate concentrations in drinking water for livestock.[a]

Nitrate (NO_3), ppm	Nitrate-nitrogen (NO_3-N), ppm	Guidelines
0-44	0-10	Safe for consumption by ruminants.
45-132	10-20	Generally safe in balanced diets with low nitrate feeds.
133-220	20-40	Could be harmful if consumed over long periods of time.
221-660	40-100	Cattle at risk and possible death losses.
Over 661	Over 101	Unsafe: possible death losses and should not be used as a source of water.

[a] NRC, 1974.

Iron. Besides sulfate, iron in drinking water is probably the most frequent and important anti-quality consideration for dairy cattle. Whereas, iron deficiency in adult cattle is very rare because of abundant iron in feedstuffs, excess total iron intake can be a problem especially when drinking water contains high iron concentrations. Iron concentrations in drinking water of greater than 0.3 ppm are considered a risk for human health, and are a concern for dairy cattle health and performance (Table 3).

The first concern is that high iron in drinking water may reduce the palatability (acceptability) and therefore consumption. Also, a dark slime formation in plumbing and waterers by iron-loving bacteria may affect water intake.

The predominant chemical form of iron in drinking water is the ferrous (Fe^{+2}) form (e.g., ferrous sulfate). This is the water-soluble form compared with the highly insoluble ferric (Fe^{+3}) form more typically present in feed sources. Highly soluble iron can interfere with the absorption of copper and zinc by interfering with the transport (absorption) system (the ferritin system) in the intestinal wall cells. Also, highly soluble ferrous iron can be readily absorbed by sneaking between cells thus bypassing the normal cellular regulation. Once in the body, the transferrin and lactoferrin systems normally bind iron in blood and tissues to control its reactivity. However, when excess iron is absorbed (e.g., from drinking water) there is an "overload" and all can not be bound. The excess free iron results in reactive oxygen species (e.g., peroxides) and oxidative stress occurs damaging cell membrane structure and functions. Iron toxicity causes diarrhea, reduced feed intake, growth, milk production, and compromised immune function.

Excess iron (greater than 0.3 ppm) in water is much more absorbable and available than iron from feedstuffs, and thus a higher risk for iron toxicity. If high-iron drinking water is present an alternative water source should be found, or a method to remove the iron from water before consumption by cattle and humans should be employed.

Other Factors Affecting Water Intake

Mineral Ion Content of Feeds and Rations. Mineral ion content of feed can influence water intake by cattle. Omer and Roberts (1967) tested the influence of dietary potassium on water intake of beef heifers and found that a high potassium diet (4.24% of dietary DM) caused a significant increase in water consumption compared with 0.61 or 1.71% dietary potassium. Murphy et al. (1983) found that each gram of additional sodium intake, increased water intake by 50 milliliters in lactating cows. If high concentrations of dietary potassium or sodium are present, water intake may be increased. It could be beneficial to either reduce the content of these ions in the diet if possible, or ensure that an adequate supply of drinking water is available.

Dietary Crude Protein Content. Only one study was found that addressed the influence of dietary crude protein on water intake. Holter and Urban (1992) found that raising the crude protein content (e.g., from 12 to 13%), increased water intake about 2.2 lb/day in dry cows. This same sort of relationship was not significant in their dataset for lactating cows.

Environmental Temperature. Warm environmental temperature (e.g., heat stress) is an important factor when evaluating water nutrition. Increased drinking water intake is related positively with increasing environmental temperature. At an environmental temperature of 90°F, cows consumed two to four times more water than did cows in an environmental temperature of 36 to 50°F (McDowell and Weldy, 1967). Earlier research showed that water intake paralleled feed consumption of lactating Holstein and Jersey cows when the environmental temperature ranged between 3 and 81°F; however, once ambient temperature rose above 81°F, water intake increased dramatically regardless of DM content of the diet (Ragsdale et al., 1949; as cited by McDowell and Weldy, 1967). Cows in hot environments increased water intake to replace water lost via sweat, respiratory evaporation, and feces and milk. Water intake increased with increasing environmental temperatures in several other studies (Hoffman and Self, 1972; Shultz, 1984; Richards, 1985; Holter and Urban, 1992). Murphy et al. (1983) found that water intake of Holstein cows increased 1.20 kg/1°C increase in average minimum daily ambient temperature within the range of 8 and 19°C. Andersson (1987) noted similar results. For every 1°C increase in barn temperature, water intake increased 1.11 liters when barn temperature ranged between 7.3 and 16.5°C.

Hoffman and Self (1972) demonstrated the effect of season and presence of shade on water intake in feedlot steers. During the summer, animals drank more water than in the winter (8.2 vs. 5.0 gal/day). This suggested that animals drink more water to compensate for water loss in higher environmental temperatures. The influence of shade on water intake observed in this study also showed that providing overhead shelter to cattle was beneficial. In hot summer months, steers consumed more water (8.7 vs. 8.2 gal/day) when overhead shelter was not provided compared with when shade was provided. There were no influences during the winter months. Shultz (1984) did an observational study with lactating dairy cows in California showing that shade decreased water intake compared with absence of shade. Therefore, it can be concluded that when average daily environmental temperatures exceed 77°F, overhead shelter keeps cattle cooler resulting in less body water loss, and in turn less water intake.

Drinking Water Temperature. The temperature of drinking water available to dairy animals may affect water consumption and animal performance. Most studies were conducted considering moderate to cold vs. warm environmental temperatures.

During <u>cold temperatures</u>, drinking water is typically cold unless artificially warmed. Effects of drinking water temperature on rumination rate, ruminal temperature (and recovery to normal ruminal temperature), body temperature, digestibility of the dietary constituents and ruminal fermentation, feed consumption, milk yield and composition, and live weight change have been studied.

Andersson (1985) suggested that it may be efficacious to warm the drinking water of high-producing dairy cows to improve milk yield. Drinking water temperatures (37, 50, 63, and 73^{o}F) were compared with eight lactating cows (12th to 15th weeks of lactation, averaging 57 lb of 4% fat-correct milk/day) kept in tie-stalls (average daily barn temperature = 59^{o}F). Water intake was lowest (18.8 gal/day) with the 73^{o}C drinking water, and similar when cows were offered drinking water at the other three temperatures (average water intake = 20.1 gal/day). However, average milk yield was lowest for cows consuming 37^{o}F drinking water compared with those consuming 63 or 73^{o}F drinking water. Feed and free-choice salt consumption, live weight change, and rates of rumination were not affected by drinking water temperature. In another study, Himmel (1964) conducted a preference test in which cows were able to choose between 37 and 68^{o}F drinking water during a period of time when environmental temperatures ranged from 30 to 45^{o}F. After a few days, most cows drank more of the warmer water.

Other researchers have studied the effects of drinking water temperature on ruminal fluid temperatures and digestibility. Early studies indicated that the magnitude of depression of ruminal fluid temperature was related to the temperature and amount of cold drinking water given to dairy cows (Dale et al., 1954; Dillion and Nichols, 1955; Dracy et al., 1963); from 70 to 120 minutes was required after ingestion of water before ruminal fluid temperatures returned to pre-drinking values. However, Cunningham et al. (1964) found no effects on dietary DM, energy, and crude protein digestibilities when non-lactating cows were housed at 27 to 54^{o}F and provided drinking water of varying temperatures (34, 57, 64, and 102^{o}F).

It is obvious from the very limited amount of information cited here, that not much is known about the short- and long-term effects of drinking water temperature on preference or performance of high-yielding dairy cows in cold environments. Surprisingly, in the study of Wilks et al. (1990) when lactating cows (average milk yield about 55 lb/day) in a warm climate (summer in College Station, Texas) were given the choice of drinking water of 51 vs. 81^{o}F, they clearly preferred to drink the warmer water. Therefore, one might presume that cows prefer warmer drinking water in cold climates as well. But additional research could prove valuable to demonstrate the optimum water temperature and any possible benefits on performance.

In a series of experiments at high temperatures, the effects of providing chilled drinking water to lactating cows were studied (Stermer, et al., 1986; Lanham et al., 1986; Milam et al., 1986; Baker et al., 1988; Wilks et al., 1990). In these studies, drinking water temperatures typically ranged from about 50^{o}F (chilled) to 81 to 86^{o}F (ground water from local wells in College Station, Texas). Overall, it was possible to reduce cows' body temperature transiently (for a maximum of 2.2 hours) during hot weather by providing chilled drinking water (Stermer et al., 1986). However, chilled water was only somewhat effective in reducing body temperature and the effect was not maintained long enough to keep the body temperature from rising above the upper critical temperature in heat-stressing conditions. In one study, chilled drinking water increased DMI and milk yield (Milam et al., 1986). In another study, no differences in respiration rates, rectal temperatures, ruminal motility, or milk yield were detected, but DMI increased 9% and water intake was lower (Baker et al., 1988).

Cows exhibited preference for warmer water when offered drinking water with a temperature of 51 vs. 81^{o}F in a cafeteria-style experiment during summer (Wilks et al., 1990). Respiration rates and rectal temperatures were reduced by the colder drinking water. However, cows preferred the warmer water given the choice, with over 97% of the total water consumed being the warmer water. Also, 70% of the cows drank only the warmer water. It seems clear from this study, even under warm environmental conditions that cows preferred to drink warmer water.

Two field studies were conducted in large commercial dairies during Florida summers in which lactating dairy cows were offered well water (75 to 81^{o}F) vs. chilled drinking water (52 to 59^{o}F) in insulated troughs (Bray et al., 1990). There were no differences in milk yield (Study 1: 61.4 vs. 61.8 lb/cow per day; Study 2: 63.1 vs. 64.2 lb/cow per day) when cows consumed well or chilled drinking water, respectively.

Overall, there appears to be no real advantage on lactational performance of providing chilled drinking water to lactating dairy cows during high environmental temperatures. The main consideration should be to provide an easily accessible source of clean drinking water in close proximity to cows and feed in a shaded location.

Dietary DM Content. Because feed ingested by a cow is a source of water, the DM content of the diet influences how much water will be ingested via drinking water. Paquay et al. (1970), Little and Shaw (1978), Murphy et al. (1983), and Holter and Urban (1992) reported that as DM content of a diet increased (decreased moisture content), drinking water intake increased to compensate for less feed water intake. The DM percentages ranged from 62 to 88% among experiments, excluding the study of Paquay et al. (1970), in which DM concentration was not reported. Castle and Thomas (1975) tested the influence of forage type on water intake. They found that regardless of what forage was fed, water intake was dependent on the DM content of the feed.

A negative correlation was found between DM content and total water consumption (feed water plus drinking water). Paquay et al. (1970) and Stockdale and King (1983) found that as DM content increased, drinking water intake increased while total water consumption decreased. To illustrate this relationship, Murphy (1992) used an example of a cow eating a diet with 60% DM. If she consumed 187 lb of drinking water and 33 lb of water from feed, total water consumption was 220 lb. If the DM content of the diet was increased to 67% while keeping DMI constant, she consumed 191 lb drinking water and 24 lb water from feed for a total water intake of 215 lb. If this relationship could be exploited without compromising milk yield, then it would be useful in reducing total urine output, thus reducing the amount of liquid waste that dairy producers must manage (Murphy, 1992). Holter and Urban (1992) determined that with dry cows as dietary DM content increased from 30 to 60%, total water consumption decreased by 33 lb/day; however the decline in water intake was only 11 lb/day when DM content was increased from 60 to 90%.

Adequate Water Supplies. The amount of water available for consumption has a marked effect on behavior of dairy cattle. This can influence water intake of an individual cow or a group of cows, thus, impacting production. Several experiments were done to test the effects of water restriction and its effects on drinking behavior as well as on social behavior. Three main questions were addressed in these studies. 1) How does water intake restriction affect milk production? 2) What behavioral changes will be observed if water is restricted? 3) Is flow rate into a water receptacle (e.g., waterer or bowl) a significant factor?

Drinking water intake is correlated positively with milk production. To investigate this relationship, studies were done in which water intake was restricted and milk yield and DMI were measured. Little and Shaw (1978), Murphy et al. (1983), and Holter and Urban (1992) showed that as milk yield increased, more drinking water and dietary DM must be consumed. Because DM and water intake are correlated closely, and DMI and milk yield are correlated, it can be concluded that milk yield is influenced by water intake (Murphy, 1992).

Therefore, restricting water intake may be detrimental to milk production. Little et al. (1984) found that Holstein cows completely deprived of water for 72 hours produced less milk. However, there was a delayed response. On the first day of deprivation, there was no difference in milk yield between the control group (ad libitum drinking water and 48.2 lb milk yield/day) and the group deprived of water (44.7 lb milk yield/day). This represented a 7% reduction in milk yield on day 1 of water deprivation. Water deprivation resulted in a decrease in an average milk production to 24.6 lb on day 2, and to 13.4 lb on day 3. When water was made available to the water-deprived cows, milk production returned to within 4 lb/d of control cows. Little et al. (1976) found a similar delay in milk yield reduction when water was only partially restricted, but did not report recovery period results.

Restricted water intake also influenced drinking behavior. Some aspects of drinking behavior have been addressed but more research would be useful. Andersson (1987) and Andersson and Lindgren (1987) stated that cows like to have water available during feeding. However, if water is not available during feeding cows consumed 60 to 80% of total water consumption within a few hours after eating (Andersson, 1987). Swedish Red and White lactating cows were kept in tie-stalls and fed individually, but pairs of cows shared one water bowl (Andersson and Lindgren, 1987). Treatments were: 1) control, with free access to drinking water, concentrate and hay for 24 hours/day; 2) no drinking water for 1 hour after the main morning and afternoon feedings; and 3) no drinking water available for 2 hours after the main morning and afternoon feedings, but concentrate was offered at the time drinking water was made available. Cows with free access to drinking water drank for the first time within 0.5 hour after eating (average = 15 minutes). They drank about 19% of their total daily water intake during the first hour after the morning plus afternoon feedings. Both cows of the pair drank within 28 minutes on average. After making water available to cows in both drinking water-restricted treatments, the same amounts of water were consumed as by cows in the control treatment, and there was no difference in total daily water consumption among cows in the three experimental treatments. However, cows that had restricted water intake, but were provided drinking water and concentrate after the 2-hour restriction chose to eat the concentrate before drinking. This study showed that cows in tie-stalls preferred having drinking water available at the time of feeding. However, cows still consumed concentrate before they consumed water after a 2-hour restriction. It is imperative to have adequate space and enough water sources in close proximity to feed.

When adequate water is not supplied, competition occurred when water was available. In addition to the water availability preference experiment, Andersson and Lindgren (1987) observed paired cows and recorded which cow was dominant and which was submissive. Dominant cows produced 6.2 lb/day more milk, drank more frequently (29 vs. 26 times per day), and consumed more water (24.2 vs. 22.7 gal/day) than submissive cows. However, there was no difference between drinking water intake of submissive and dominant cows within the first 30 minutes of access to drinking water. They suggested that stress on the submissive cow may play a role in decreased milk yield. Little et al. (1980) also showed that restricted water intake (50% of control group) of lactating Holstein cows in a loose-housing situation reduced milk yield of submissive cows. In addition, Little et al. (1984) showed that lactating Holstein cows given 90% of the control group's water intake resulted in much less competition than 50% restriction, although some aggression was still noted. No differences in milk yield or water intake were observed with 10% restriction. The conclusion was that small restrictions possibly could be detected by confrontations still occurring among cows at the water source. If behavior like this is noted in a dairy operation, the herd may benefit from additional water sources or more watering stations at different locations.

Flow rate into water bowls also may influence water intake. Andersson et al. (1984) studied the influence of three flow rates (0.5, 1.8, and 3.2 gal/minute) on water intake. They found that as flow rate decreased, drinking occurrences increased to compensate. There were no effects on milk yield or water intake. However, there was a tendency for increased milk production when water was delivered at increased flow rates in water bowls. The results suggested that cows adapt to slower flow rates by altering their drinking behavior. With slower flow rates, abundant water sources and (or) increased linear water trough space per cow may be advantageous.

Stray Voltage. Dairy producers concerned about whether or not stray voltage at watering stations (cups, bowls or troughs) may be a problem, or dairy farm consultants trying to discern if stray voltage might be affecting water intake of cows are strongly encouraged to review the writing of Roberts and co-worker et al. (http://wi.gov/electric/newsinfo/document/cattle.pdf). Their article describes considerable field experience working for the Wisconsin Department of Agriculture, Trade and Consumer Protection and Public Service Commission investigating the possible influence of (possible) stray voltage on water intake in dairies. Below are some of the key findings and conclusions from their experiences.

From 1994 to 2002, 285 field investigations were made in dairy farms concerned about possible stray voltage. About 50% of farmers thought that decreased water intake was a symptom of stray voltage in their operations. Investigators found a widespread deficiency of knowledge among farmers and their professional farm consultants about water nutrition and how stray voltage might affect water intake, health and performance of dairy cattle (e.g., lack of rural expertise on water issues). Most troubling was the use of simplistic rules of thumb about what water intake should be (e.g., 4 to 5 lb of water for each lb of feed DM consumed, or 3.0 lb of water intake/lb of milk produced). Often these rules of thumb gave estimates of water intake greater than actual, normal water intake and did not include water from the ration. These rules of thumb implied that water intake was depressed. Unfortunately, conclusions were drawn that stray voltage were (might be) responsible without proper follow-up to determine whether or not water consumption was really meeting cows' requirements or was below normal. Roberts and coworkers successfully used and highly recommend that actual intake of water be measured (e.g., with in-line flow meters) and compared with prediction equations such as described previously in this paper. Also, there often was a false expectation that increasing supposedly low water intake would improve cattle performance, when (possible) stray voltage was eliminated.

There is a widespread, highly popularized misconception that stray voltage typically found in farms caused reduced water intake. Several stray voltage studies have assessed the relationship between stray voltage and water intake (the reader is referred to the writings of Roberts et al. in which 12 such studies are cited). There is no dispute that high enough stray voltage can affect cows' water intake, For instance, experimentally applied 12 milliamps (6 volts through a 500 ohm resistance) shocked cows and made them unapproachable. However, data from 6,000 first-time stray voltage investigations in Wisconsin dairies indicated that the potential for that severity of voltage is rare; in fact, 91.8% of cases had 1 volt or less at cow contact and only 2.7% had over 2 volts. Also, there was wide variation in animal perception in relationship to electrical pathway, level of exposure, and animal sensitivity. One study that demonstrates these ideas was that of Gorewit et al. (1992a) in which the influence of long-term exposure to 0, 1, 2, or 4 volts during a full lactation was evaluated. Only one of 51 cows in the experiment refused to drink when 4 volts were applied. She was removed from the study. In two other studies, there were no differences in milk somatic cell count, milk yield, or water intake when the water source supplied 0 to 1.8 volts of electricity (Southwick et al., 1992), or 0 to 4 volts (Gorewit et al., 1992b).

The popularized notion that stray voltage commonly reduces water intake is dangerously simplistic. Firstly because adaptation is known to occur (to less than 4 volts); and, secondly because if the current on the water bowl or tank is intermittent and the cow learns to avoid exposure, or if there are alternative sources of water for a cow to drink from, then it is likely that water consumption will not be affected.

Additionally in their review of the research literature, Roberts and coworkers noted that cow behavior is a more sensitive indicator to exposure to transient current than water intake. But, unfortunately many common ideas about cow behavior around watering stations and while drinking are not accurate indications of the presence of stray voltage. For example, it has been proven that the characteristic "lapping of water" is not a reliable indicator of stray voltage. Videotaped behavior of eating and drinking in Wisconsin herds under investigation for stray voltage confirmed that lapping was a common characteristic in many herds whether or not stray voltage was present. The only behavior truly indicative of an encounter with stray voltage is the so-called "flinch response" at the watering station. The very first encounter with current at the water source was described as a "startled" response. Typically cows tried to drink again and if not shocked will resume normal behavior. If the shocks persist cows may delay drinking again and(or) hover over the water source. If the level of shock is annoying, but not prohibitive, eventually adaptation and a resumption of normal drinking behavior occurred.

Overall from the research literature and investigative experience, Roberts and coworkers concluded that such behaviors as lapping of water, biting of the water bowl, nose pressing against the water bowl, splashing and throwing water, and blowing blasts of air into the water (blowing bubbles) all have been inaccurately assumed to be animal behavior responses associated with or in response to stray voltage at watering stations. Sufficient research and field investigation have disproved these popularized misconceptions. Stray voltage of less than 4 volts is unlikely to be a major problem for water nutrition in most dairies.

Water Nutrition of Calves

Healthy calves are an essential component of a successful dairy operation. Supplying adequate water is one instance in which a producer can improve calf nutrition. Water is a necessity for maximizing the growth of calves.

Do calves need water in addition to milk or milk replacer they receive? Atkeson et al. (1934) suggested that supplemental water does not seem to be beneficial until the calf is 8 weeks of age. However, Thickett et al. (1981) and Kertz et al. (1984) showed that when calves were fed supplemental water in addition to that provided in milk replacer, they consumed more calf starter or grower and gained more body weight as compared with calves not given supplemental water. Cunningham and Albright (1970) found that calves given supplemental water gained 5.8 lb more from 4 to 40 days of age than calves not receiving water in addition to milk replacer.

There also has been some question about whether or not excess water intake by calves causes scours. Jenny et al. (1978) observed 25 to 50% increases in water intake when calves had scours, but it was unclear whether increased water intake was the cause or the result of scours. Subsequently, it was found that scours caused water intake to increase as a result of dehydration (Thickett et al., 1981; Kertz et al., 1984). An experiment also tested if restricting water intake reduced the incidence of scours. There was no difference in the incidence of scours between restricted water intake and ad libitum intake (Kertz et al., 1984). There is no evidence to support the assumption that water intake causes scours. Therefore, dairy producers always should supply supplemental drinking water to pre-weaned calves.

It is recommended that calves receive additional water as soon after birth as possible. Calves 1 to 5 weeks of age consumed an average of about 17 gal of drinking water per week or nearly 2.5 gal/day in addition to that in milk replacer (Thickett et al., 1981). Therefore, calves should be provided at least this amount of clean water daily. Providing ad libitum intake of drinking water is the best approach. The bucket or trough used to water calves should be cleaned daily to ensure freshness and cleanliness of water. Attention should be used in the winter, as the water source may freeze. Water intake encourages grain or starter intake. Providing adequate water is one management tool that helps ensure that heifers are healthy and growing optimally.

Practical Considerations for Optimal Provision of Water for Dairy Cattle

Too often in modern farms, meeting the water requirements of dairy cattle is not given the practical management consideration it deserves to maximize animal performance. This is probably because water is the least expensive nutrient supplied to dairy cattle, and because some water source nearly always available, it is assumed that sufficient water is being supplied and consumed. This may not always be true. Provision of drinking water to satisfy and maximize the animal's biological drive to consume water is absolutely crucial.

Practical Guidelines of Water Consumption. Readers are encouraged strongly to use the prediction equations presented earlier (e.g., Murphy et al., 1983; Holter and Urban, 1992) and compare with actual, measured water intake (approaches for measuring water intake are described below) to evaluate the sufficiency of water intake by dairy cows in specific groups and farm situations. Common rules of thumb (e.g., 4 to 5 lb of water intake/lb of DMI; 3 lb drinking water/lb of milk yield) are not accurate enough to determine if water intake is sufficient and normal to meet animals' requirements.

Water Sources. Location and the best physical specifications to optimize water intake are facility-dependent. One common problem observed in some remodeled free stall barns is the "dead end" alley where the water source is located (Beede, personal observation). "Boss" cows may stake-out territory in front of the water source, keeping other cows from drinking. Listed below are some common guidelines for location and physical specifications of water sources.

1. Provide 1 to 2 ft of linear trough space per cow in return alleys or breezeways from the milking parlor. Given the choice, cows will consume large amounts of their daily water consumption needs immediately after milking. In field measurements we found that cows drank as much as 50 to 60% of their total daily water intake immediately after milking. A good guideline is to provide enough linear water trough space so that at least half of the cows in the parlor will be provided with 2 ft of linear trough space per cow when exiting the parlor. For example, if the parlor is a double-10 herringbone, there should be at least 20 ft of linear trough space, at a location where cows from both sides of the parlor return to their pens through a common lane. Depending on physical layout and parlor turnover rate during milking, as much as 40 ft of linear water space may be needed to maximize water intake immediately after milking through a double-10 parlor. Cows will line up side-by-side and drink, just like they do at the feed bunk.

   Another consideration is to use warmed water from the heat exchange unit (e.g., plate cooler) as the source for a trough in the exit lane from the parlor. This water likely is warmer than the common water source in most dairies. Field observations indicate that cows prefer to drink this warm water, even in environments with warm ambient temperatures. One must be sure that the plate cooler supply is continuously sufficient to keep the water level high enough in the trough so that no cow is ever deprived of the amount of water she wants to consume in a short period of time. If it is possible that this supply will be insufficient at any time, another water source to automatically supplement the plate cooler water will be required.

2. Provide a minimum of two water sources per group in the areas where cows are housed. Cows should never have to walk more than 50 ft to get a drink of water. Place water sources in close

proximity to the feed bunk. These sources should be protected from the sun. Adequate open space around water sources is crucial. Cross-over alleys in free stall barns should be at least 13.5 ft wide. This allows 1 ft for the width of the water trough, plus 7.5 ft for a cow standing perpendicular to the long dimension of the trough while drinking, plus 5 ft for other cows to pass behind cows that are drinking. With sufficient linear trough space several cows can line-up parallel to drink and they will have sufficient space to back away from the trough after drinking. Also, boss cows may stand near corners of the trough preventing more timid cows for drinking. Boss cows will not be able to guard the entire water trough if sufficient linear trough length and space for other cows to maneuver are provided. In existing facilities, this may require some remodeling to provide ample space around water sources. For example, removing a couple of free stall spaces and re-locating the water trough might be necessary.

3. Cleanliness is crucial! A good rule of thumb is, "Based on appearance of water in the trough, would you be willing to cup your hands and take a drink"? If not, the water is not clean enough for your cows (Beede, 1992). Cleaning water sources daily is very important, so not to limit water intake. Troughs or tanks that can be drained or dumped easily to make the cleaning process quicker and more effective are key.

4. Be certain that the water filling capacity of the system and at each watering source is sufficient so that cows never have to wait for water to be available. If cows ever have to wait for water, changes are needed immediately!

5. Use water receptacles (troughs or tanks) that provide a filled water depth of only 6 to 12 inches. The advantages to relatively shallow troughs are: 1) they prevent stagnant water; 2) they are easier to clean; 3) they will fill rapidly, assuming proper flow rates, so that cows never have to wait to consume water; and, 4) they will necessitate that sufficient linear space be available to accommodate all cows that want to drink at any particular time.

6. Use of water cups or small receptacles (e.g., 12-inch diameter cups or bowls) is discouraged strongly for groups of cows. Rarely are enough cups or space provided around the cups or bowls to meet the needs of all cows in the group (Beede, personal observation). Boss cows can claim a water cup preventing other cows from drinking.

7. In tie-stall barns, one cup for each cow will ensure each cow is able to meet her drinking water needs. Two cows sharing one water cup will result in the submissive cow of the pair not receiving the amount of water needed to maximize her performance potential (Andersson and Lindgren, 1987).

8. Head clearance around water troughs should be at least 2 ft; less than that may impede optimal water consumption.

Trouble-Shooting Water Consumption Questions and Potential Problems. Restricted water consumption may be indicated by abnormally firm manure; reduced urine output; infrequent drinking activity; reduced feed intake and (or) milk production; drinking of urine or other accessible sources of liquids (although this may be indicative of other problems such as a dietary sodium chloride deficiency); dehydration; loss of body weight or condition; and, increased blood packed cell volume, hematocrit and osmolality (Chase, 1988). Abnormally high consumption of water may be indicated by excessive urine output and loose manure. This may be caused by abnormally high dietary concentrations of mineral elements in the ration (e.g., sodium or potassium).

To determine if water intake is sufficient several questions and approaches should be asked and employed jointly. Are there adequate numbers of watering sources available for each group of animals? Are the water sources clean, do they work properly? Is there sufficient water pressure to fill waterers when several cows want to drink simultaneously, even during peak water usage (e.g., during milking)?

In order to truly know if water consumption is sufficient it must be measured. In-line water meters to each water source are needed. No other water sources, other than those routinely used by each group of cows should be available to animals during the measurement period. Additionally, water intake should be measured for at least 5 to 10 days consecutively. Keep track of the numbers and types of animals with access to each water source. If focusing on measurement of water intake by lactating cows, it may be useful to know water intake of individual groups of cows. It may be necessary to subtract estimated water intake for other animals (e.g., dry cows and heifers) if they too have access to water sources used by lactating cows. Determine daily feed intake for the same days that water intake is measured, determine the moisture content of the rations, and calculate the water intake from the ration. Determine total water consumption (from the drinking water source plus water from the ration). Calculate the total water consumption on a per head basis and compare with prediction equations to determine if water consumption is normal. If water intake is deemed sub-optimal, any or a combination of the potential problems noted previously should examined.

Assessing Water Quality. Water quality *per se* could be a cause of low water intake. In such cases, before spending a lot of money trying to solve a drinking water problem two additional assessments are suggested. 1) Provide a sufficient supply of an alternate source of drinking water to a specific group of animals for at least 5 to 10 days; during this time measure water intake. It is a good idea to measure intake of the water source in question for 5 to 10 days before and after the alternate water source is offered. 2) In conjunction with measuring water intake of the alternate water source or after it is determined that intake is sub-optimal, laboratory analysis of the drinking water source should be performed. The water source might contain constituents that cause palatability problems, microbial contamination, or excessive chemicals or toxic compounds.

Water for laboratory analysis should be sampled into a clean plastic container, after repeatedly rinsing with the water to be tested, at the site of discharge into the water trough or bowl, but not at the origin of the water (e.g., the reserve tank). The sample should not be taken by dipping into the tank, because it will be contaminated by feed and saliva. The sample should be sent to a laboratory certified by the appropriate governmental agency. Chemical and microbial measurements are the two main types of tests for drinking water quality. Standard laboratory tests provide concentrations of common mineral elements and some other constituents of interest such as those listed in Tables 3, 4, and 5. A standard water quality analysis is recommended first; that is not very costly. If necessary, more extensive testing can be performed for other compounds such as pesticides. The information in Tables 3, 4, and 5 can serve as reference information for the actual water analyses obtained.

In limited experience, the most common water quality factors found that affect water intake of dairy cattle in the field are high concentrations of sulfate, sodium chloride, and iron. If concentrations of these elements are excessive, water intake and animal performance may be reduced. For example, in several different cases when water sulfate concentrations exceeded 1000 ppm, water and feed intake, health (especially of periparturient cows), and milk production were affected adversely. When the sulfate content was reduced (to about 40 ppm) by reverse osmosis, animal responses and improvements in health were marked. Depressed water consumption by lactating cows also was noted from a highly chlorinated (1500 to 1850 ppm of chlorine) water supply, and water intake increased dramatically when an alternate water source was provided (Beede, personal observation).

Summary

Without question, the MOST ESSENTIAL ESSENTIAL NUTRTIENT for dairy cattle is abundant, easily accessible, and clean drinking WATER!

References

Citations listed in this paper as well as other references about water nutrition of dairy cattle are provided at: http://www.msu.edu/~beede/ by clicking on “Extension”, and then “Water Ref”.