8 Water

Water is the most important nutrient for dairy cattle. It is required for all of life's processes—transport of nutrients and other compounds to and from cells; digestion and metabolism of nutrients; elimination of waste materials (urine, feces, and respiration) and excess heat (perspiration) from the body; maintenance of a proper fluid and ion balance in the body; and provision of a fluid environment for the developing fetus (Houpt, 1984; Murphy, 1992). A loss of 20 percent of the body water is fatal (Houpt, 1984).

The total body water content of dairy cattle is 56 to 81 percent of their body weight (Murphy, 1992). Physiologic stage and body composition affect the body's water content. Cows in early lactation have more body weight in water (69.0 percent) than cows in late lactation (62.4 percent) with late-gestation dry cows intermediate in body water content (64.7 percent) (Andrew et al., 1995). Fat cows have a lower water content than thin lactating cows, and younger, leaner animals have a higher water content than older animals (Murphy, 1992).

Body water is divided into intracellular and extracellular compartments. Intracellular water is the largest compartment, accounting for about two-thirds of the water in the body. The extracellular fluid comprises water around cells and connective tissue, water in plasma, and transcellular water or water in the gastrointestinal tract. Intestinal water accounts for 15-35 percent of body weight (Odwongo et al., 1985; Woodford et al., 1984). Cows in early lactation had about 15 percent of their body weight in gastrointestinal water, while cows in late lactation and in gestation had 10 to 11 percent (Andrew et al., 1995). Resident time of a water molecule in the rumen was estimated to be 61 minutes in sheep (Faichney and Boston, 1985) and 62 minutes in lactating dairy cattle (Woodford et al., 1984).

Loss of water from the body occurs through milk production, urine excretion, fecal excretion, sweat, and vapor loss from the lungs. Water losses through milk of cows producing 33 kg/day were about 34 percent (Holter and Urban, 1992), 29 percent (Dado and Allen, 1994), and 26 percent (Dahlborn et al., 1998) of total water intake (feed plus free water consumed). Fecal water losses are similar to those of milk (30 to 35 percent of total water intake), and urine losses are about half of fecal losses (15 to 21 percent) in lactating cows (Holter and Urban, 1992; Dahlborn et al., 1998). Factors that affect fecal water loss include dry matter intake (DMI), dry matter (DM) content of the diet being fed, and digestibility of the diet (Murphy, 1992). Dahlborn et al. (1998) reported that fecal DM percentage did not change with changing dietary DM, but water loss via feces increased with increasing dietary forage content. Urinary water excretion in cattle is variable at 4.5 to 35.4 L/day in cows producing an average of 34.6 kg/day of milk and 5.6 to 27.9 L/day in dry cows (Holter and Urban, 1992). Urinary water excretion was related positively to water availability, amount of water absorbed from the intestinal tract (total intake minus fecal loss), urinary nitrogen, and urinary potassium excretion and negatively related to dietary DM content (Murphy, 1992). Increasing forage in the diet increased urinary water loss (Dahlborn et al., 1998). Sweat, salivary, and evaporative losses combined account for about 18 percent of water loss (Holter and Urban, 1992).

WATER INTAKE

Cattle require large amounts of water every day. They meet this requirement via three sources: drinking or free water intake (FWI), ingestion of water contained in feed, and water produced by the body's metabolism of nutrients. Metabolic water is an insignificant source compared with the water ingested freely or in feed. The sum of FWI and the water ingested in feed is the total water intake (TWI).

Several factors that affect the amount of FWI of dairy cows each day have been identified. Of studies in which equations were developed to predict daily FWI, DMI was included as a variable in four (Holter and Urban, 1992; Little and Shaw, 1978; Murphy et al., 1983; Stockdale and King, 1983), daily milk production in five (Castle and Thomas, 1975; Dahlborn et al., 1998; Holter and Urban, 1992; Little and Shaw, 1978; Murphy et al., 1983), DM content of the diet (DM percent of diet) in four (Castle and Thomas, 1975; Dahlborn et al., 1998; Holter and Urban, 1992; Stockdale and King, 1983), temperature or environmental factors in two (Holter and Urban, 1992; Murphy et al., 1983) and sodium intake in one (Murphy et al., 1983). Equations for predicting FWI, (kg/day) of lactating dairy cows are shown below:

$$-15.3 + 2.53 \times \text{milk, kg/d} + 0.45 \times \text{DM\% of diet.} \quad \text{(Castle and Thomas, 1975)} \quad (8\text{-}1)$$

$$14.3 + 1.28 \times \text{milk, kg/d} + 0.32 \times \text{DM\% of diet.} \quad \text{(Dahlborn et al., 1998)} \quad (8\text{-}2)$$

$$-32.39 + 2.47 \times \text{DMI, kg/d} + 0.6007 \times \text{milk, kg/d} + 0.6205 \times \text{DM\% of diet} + 0.0911 \times \text{Julian Day(JD)} - 0.000257 \times \text{JD}^2 \quad \text{(Holter and Urban, 1992)} \quad (8\text{-}3)$$

$$12.3 + 2.15 \times \text{DMI, kg/d} + 0.73 \times \text{milk, kg/d} \quad \text{(Little and Shaw, 1978)} \quad (8\text{-}4)$$

$$15.99 + 1.58 \times \text{DMI, kg/d} + 0.90 \times \text{milk, kg/d} + 0.05 \times \text{Na intake g/d} + 1.20 \times \text{min temp C} \quad \text{(Murphy et al., 1983)} \quad (8\text{-}5)$$

$$-9.37 + 2.30 \times \text{DMI, kg/d} + 0.053 \times \text{DM\% of diet} \quad \text{(Stockdale and King, 1983)} \quad (8\text{-}6)$$

Winchester and Morris (1956) indicated that 0.87 kg of water per kilogram of milk was an expected requirement for water based on milk being 87 percent water. The 0.90 coefficient of Murphy et al. (1983) is close to this coefficient with the lower coefficients of 0.73 and 0.6007 reported by Little and Shaw (1978) and Holter and Urban (1992). Thus, because the milk coefficient in the Murphy et al. (1983) equation is biologically closest to the water content of milk (87 percent) and other variables in the equation have been shown to affect water intake, this equation is recommended for predicting FWI.

In studies in which milk production was 33–35 kg/d, FWI was 2.0 kg (Holter and Urban, 1992), 2.3 kg (Dado and Allen, 1994), and 2.7 kg (Murphy et al., 1983) per kilogram of milk produced. Total water intake was 3.0 kg (Dado and Allen, 1994; Murphy et al., 1983) and 2.6 kg (Holter and Urban, 1992) per kilogram of milk produced. In studies (Dahlborn et al., 1998; Little and Shaw, 1978; Castle and Thomas, 1975) with lower milk production (less than 26 kg/d), both FWI (2.6–3.0 kg/kg of milk) and TWI (3.3–4.2 kg/kg of milk) were higher.

Results of seven studies (Castle and Thomas, 1975; Dado and Allen, 1994; Dahlborn et al., 1998; Holter and Urban, 1992; Little and Shaw, 1978; Murphy et al., 1983; Nocek and Braun, 1985) indicated that an average of 83 percent (range, 70–97 percent) of the total water consumed by lactating cows was by drinking. DM content of the diet is one of the major factors affecting FWI. Holter and Urban (1992) reported no difference in FWI of cows fed diets that contained 50 to 70 percent DM, but FWI decreased by 33 kg/d when diets decreased from 50 to 30 percent DM. That observation is supported by other studies (Castle and Thomas, 1975; Dahlborn et al., 1998) and the research of Stockdale and King (1983), in which cattle grazing pasture consumed only 38 percent of their TWI by drinking.

Diets high in salt, sodium bicarbonate, or protein appear to stimulate water intake (Holter and Urban, 1992; Murphy, 1992). Sodium intake alone was found to increase water intake by 0.05 kg/day per gram of sodium intake (Murphy et al., 1983). High-forage diets might also increase water requirements by increasing the loss of water in feces and urine (Dahlborn et al., 1998)

Water is an especially important nutrient during periods of heat stress. The physical properties of water, thermal conductivity and latent heat of vaporization, are important for the transfer of heat from the body to the environment. During periods of cold stress, the high heat capacity of body water acts as insulation conserving body heat. As air temperature increases above the thermal neutral zone, shifts in the amount of water consumed and how water is lost from the body occur. McDowell (1967) reported that increasing temperatures from 18 to 30°C increased water consumption by 29 percent, decreased fecal water loss by 33 percent, but increased water loss via urine, sweating, and respiration by 15, 59, and 50 percent, respectively. The equations of Murphy et al. (1983) and Holter and Urban (1992) contain an environmental variable. Murphy et al. (1983) included a variable associated with minimal daily temperature that increased FWI by about 25 percent as minimal temperatures increased from 0 to 25°C. Holter and Urban (1992) included Julian days in their FWI equation and going from 1 to peak intake at 178 days, increased FWI by about 10 percent. Besides air temperature, the effect of exposure to direct sunlight has been shown to affect FWI. During summer months, cows provided with no shade consumed 18 percent more water per day than cows provided shade (Muller et al., 1994).

Dry Cows

Holter and Urban (1992) developed the following equation to predict FWI of dry cows:

$$\text{FWI, kg/d} = -10.34 + .2296 \times \text{DM\% of diet} + 2.212 \times \text{DMI kg/d} + 0.03944 \times (\text{CP\% of diet})^2 \quad (8\text{-}7)$$

where CP = crude protein.

The major factors affecting FWI of dry cows are DMI and the percentage of DM in the diet. Increasing dietary DM from 30 to 60 percent increased FWI, but increasing dietary DM content above 60 percent had only a minor effect on either FWI or TWI. The increased FWI of dry cows caused by increasing crude protein content of the diet is a physiologic response to dilute and excrete nitrogen in excess of needs.

Calves and Heifers

During the liquid feeding stage, calves receive most of their water via milk or milk replacer. It is recommended water be provided free choice to calves receiving liquid diets to enhance growth and DMI. Kertz et al. (1984) reported calves offered water free choice in addition to the liquid diet gained faster and consumed dry feed quicker than calves provided water only in their liquid diet. Water intakes increased from about 1 kg/day during the first week of life to over 2.5 kg/d during the fourth week of life; with most of the increase occurring during the fourth week.

Drinking Behavior

Water consumption occurs several times per day and is generally associated with feeding or milking. Nocek and Braun (1985) reported that the relationship between feeding frequency and voluntary water intake was not significant; however, cows fed once per day consumed slightly less DM and water than cows fed eight times per day. Peak hourly water intakes were associated with peak hourly intakes of DM. Dado and Allen (1994) reported that lactating cows housed in tie stalls drank an average of 14 times per day. Water intake was correlated positively with both total DMI and number of eating bouts per day. In loose housing with water bowls, lactating cows consumed water an average of 6.6 times per day (Andersson, 1985). Nocek and Braun (1985) and Castle and Watson (1973) indicated that most water is consumed during daylight hours.

Reported rates of water intake vary from 4 to 15 kg/minute (Dado and Allen, 1994; Castle and Thomas, 1975). On the basis of the farm studies of Castle and Thomas (1975), the length of water troughs should be 5 cm/cow with an optimal height of 90 cm. A minimum of one water bowl per 10 cows was recommended.

The temperature of drinking water has only a slight effect on drinking behavior and animal performance. Cooling of drinking water to 10°C had a transient effect on reducing body temperature but did not affect milk production relative to production when water was at 27.7°C (Stermer et al., 1986). In other studies, the chilling of drinking water to 10°C increased milk production (Milam et al., 1986; Wilks et al., 1990) and DMI (Baker et al., 1988; Stermer et al., 1986; Wilks et al., 1990). Responses to chilling of water under most conditions would not warrant the additional cost of cooling water. Given a choice of water temperature, cows prefer to drink water with moderate temperatures (17–28°C) rather than cold or hot water (Andersson, 1987; Lanham et al., 1986; Wilks et al., 1990).

WATER QUALITY

Water quality is an important issue in the production and health of dairy cattle. The five criteria most often considered in assessing water quality for both humans and livestock are: organoleptic properties (odor and taste), physiochemical properties (pH, total dissolved solids, total dissolved oxygen, and hardness), presence of toxic compounds (heavy metals, toxic minerals, organophosphates, and hydrocarbons), presence of excess minerals or compounds (nitrates, sodium, sulfates, and iron), and presence of bacteria. Research information on water contaminants and their effects on cattle performance is sparse. The following attempts to define some common water-quality problems in relation to cattle performance.

Salinity, total dissolved solids (TDS), and total soluble salts (TSS) are measures of constituents soluble in water. Sodium chloride is the first consideration in this category, but other components associated with salinity, TDS, or TSS are bicarbonate, sulfate, calcium, magnesium, and silica (National Research Council, 1974). A secondary group of constituents, found in lower concentrations than the major constituents, consists of iron, nitrate, strontium, potassium, carbonate, phosphorus, boron, and fluoride. Guidelines for TSS in water for dairy cattle are in Table 8-1.

Research at Arizona (Ray, 1986; Wegner and Schuh, 1986) has evaluated the effects of saline water on feedlot

TABLE 8-1 Guidelines for Total Soluble Salts (TSS) in Water for Cattle

TSS (mg/L)	Comments
<1,000	Safe and should pose no health problems.
1,000–2,999	Generally safe but may cause a mild temporary diarrhea in animals not accustomed to the water.
3,000–4,999	Water may be refused when first offered to animals or cause temporary diarrhea. Animal performance may be less than optimum because water intake is not maximized.
5,000–6,999	Avoid these waters for pregnant or lactating animals. May be offered with reasonable safety to animals where maximum performance is not required.
7,000	These waters should not be fed to cattle. Health problems and/or poor production will result.

SOURCE: National Research Council (1974).

steers and lactating dairy cows. Feedlot cattle drinking saline water (TDS, 6,000 mg/L) had lower weight gains than cattle drinking normal water (1,300 mg/L) when energy content of the ration was low and during heat stress. High-energy rations and the cold of the winter months negated the detrimental effects of high-saline water consumption. Likewise, milk production of dairy cows drinking high saline water (TDS, 4,400 mg/L) was not different from that of cows drinking normal water during cool months but was significantly lower during summer months. Cows offered the salty water drank more water per day (136 vs 121 kg/cow) over a 12-month period than cows drinking normal water.

The performance of dairy cows consuming high-saline waters has been variable. In a study that compared water with dissolved solids from sodium chloride at 196 mg/L and 2,500 mg/L, lactating cows consuming water with the high salt content increased water intake by 7 percent and exhibited a tendency for less milk yield and DMI compared with cows consuming low-saline water (Jaster et al., 1978). An Israeli study (Solomon et al., 1995) with Holstein cows producing milk at over 30 kg/day showed that cows consuming desalinated water consumed 11 kg more water per day and produced 2.2 kg more milk per day than cows consuming salty water. Also, both milk protein percentage (2.89 vs 2.84 percent) and lactose percentage (4.50 vs 4.44 percent) were higher for cows consuming the desalinated water. Similar results were observed by Challis et al. (1987) under hot desert conditions. They reduced the TDS of water from about 4,400 to 440 mg/L and obtained a greater than 20 percent increase in milk production, water intake, and feed intake. Cooling of the desalinated water resulted in a small additional increase in milk production. Bahman et al. (1993) offered cows natural water that contained TDS at 3,574 mg/L and desalinated water at 449 mg/L and observed no differences in milk production. The equation of Murphy et al. (1983), which considers sodium intake, predicted intake of high-saline water better than the equations of Holter and Urban (1992).

Sanchez et al. (1994) indicated that high intakes of chloride and sulfate are detrimental to milk production during summer months. Saline water generally contains high concentrations of chloride and sulfate and so would contribute to high intakes of these elements. Likewise, saline waters are high in sodium, but feeding high amounts of sodium does not reduce milk production or lactation performance (Sanchez et al., 1994). The cation-anion differences (CAD, mEq/L) of the high-saline water in studies in which milk production or water intake reductions were observed was −1.9 (Solomon et al., 1995) and −4.4 (Challis et al., 1987). Reductions in milk production or water consumption were not observed in the study of Bahman et al. (1993) when brackish well water with a CAD of −3.0 mEq/L was offered for 196 days.

Hardness is generally expressed as the sum of calcium and magnesium reported in equivalent amounts of calcium carbonate. Other cations in water—such as zinc, iron, strontium, aluminum, and manganese—can contribute to hardness but are usually in very low concentrations compared with calcium and magnesium. Hardness categories are listed in Table 8-2. The hardness of water had no effect on animal performance or water intake (Graf and Holdaway, 1952; Blosser and Soni, 1957).

Nitrate can be used in the rumen as a source of nitrogen for synthesis of bacterial protein, but reduction to nitrite also occurs. When absorbed into the body, nitrite reduces the oxygen-carrying capacity of hemoglobin and in severe cases results in asphyxiation. Symptoms of acute nitrate or nitrite poisoning are asphyxiation and labored breathing, rapid pulse, frothing at the mouth, convulsions, blue muzzle and bluish tint around eyes, and chocolate-brown blood. More moderate levels of nitrate poisoning have been incriminated in poor growth, infertility problems, abortions, vitamin A deficiencies, and general unhealthiness, but research has not always substantiated these claims (Crowley et al., 1974; Stuart and Oehme, 1982).

The general safe concentration of nitrate-nitrogen (NO_3-N) in water is less than 10 mg/L and of nitrate less than 44 mg/L (Table 8-3). In evaluating potential nitrate problems, feeds also should be analyzed for nitrate in that the effects of feed and water nitrate are additive.

Sulfate guidelines for water are not well defined, but general recommendations are less than 500 mg/L for calves and less than 1,000 mg/L for adult cattle. When sulfate exceeds 500 mg/L, the specific salt form of sulfate or sulfur

TABLE 8-2 Water Hardness Guidelines

Category	Hardness (mg/L)[a]
Soft	0–60
Moderately hard	61–120
Hard	121–180
Very hard	>180

[a] 1 grain/gal = 17.1 mg/L.
SOURCE: National Research Council (1980).

TABLE 8-3 Nitrate in Water

Nitrate (NO_3) (mg/L)	Nitrate Nitrogen (NO_3-N) (mg/L)	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
221–660	40–100	Cattle at risk; and possible death
661	100	Unsafe—possible death; should not be used as a source of water

SOURCE: National Research Council (1974).

should be identified. The form of sulfur is an important determinant of toxicity (National Research Council, 1980). Hydrogen sulfide is the most toxic form, and concentrations as low as 0.1 mg/L can reduce water intake. Common forms of sulfate in water are calcium, iron, magnesium, and sodium salts. All are laxative, but sodium sulfate is the most potent. Cattle fed water that is high in sulfates (2,000–2,500 mg/L) show diarrhea initially but appear to become resistant to the laxative effect. Iron sulfate was reported by Horvath (1985) to be a more potent depressor of water intake than other forms of sulfate.

Research from Nevada (Digesti and Weeth, 1976; Weeth and Capps, 1972; Weeth and Hunter, 1971) has shown that cattle can tolerate sulfate at up to 2,500 mg/L in water for short periods (less than 90 days) with no major metabolic problems. At 2,500 mg/L, heifers increased renal filtration of sulfate by 37 percent compared with heifers drinking water that contained 110 mg/L. Heifers also rejected water that contained 2,500 mg/L if lower-sulfate water was available. Research from Canada (Smart et al., 1986) has shown that beef cows drinking water that contained sulfate at 500 mg/L had lower concentrations of copper in plasma and liver than cows consuming water that contained 42 mg/L. No significant differences in health, reproduction, weight changes of cows, or birth weight of calves were reported, but calves of cows that received the high-sulfate water had lower weaning weights than calves of cows that received low-sulfate water. Water and feed with high sulfate contents have been linked to polioencephalomalacia in beef calves (Hibbs and Thilsted, 1983; Gould, 1998).

pH guidelines of water for dairy cattle have not been established. The EPA (1997) recommendation for the pH of human drinking water is between 6.5 and 8.5. No information was found in the scientific literature as to what effects the pH of water has on water intake, animal health, animal production, or the microbial environment in the rumen.

Other nutrients and contaminants are sometimes found in water and can pose a health hazard to cattle. For safe consumption, water contaminants should not exceed the guidelines in Table 8-4. However, many dietary, physiologic, and environmental factors affect these guidelines and make it impossible to determine precisely the concentrations at which problems will occur.

Microbiologic analysis of water for coliform bacteria and other microorganisms is necessary to determine sanitary quality. A common microbiologic analysis is for total coliforms, not specific coliforms. Results from the assay are usually reported as a most probable number (MPN), which is an index of the number of coliforms present (0 MPN = satisfactory; 1–8 MPN = unsatisfactory; over 9 MPN = unsafe). A more specific analysis for contamination is a fecal-coliform test. Coliforms found in human and animal feces can be determined directly, and information as to the source of contamination can be obtained. The effect of coliforms in water on health of cattle or ruminal microorganisms is unknown.

TABLE 8-4 Generally Considered Safe Concentrations of Some Potentially Toxic Nutrients and Contaminants in Water for Cattle

Item	Upper-limit guideline
	(mg/L or ppm)
Aluminum	0.5
Arsenic	0.05
Boron	5.0
Cadmium	0.005
Chromium	0.1
Cobalt	1.0
Copper	1.0
Fluorine	2.0
Lead	0.015
Manganese	0.05
Mercury	0.01
Nickel	0.25
Selenium	0.05
Vanadium	0.1
Zinc	5.0

SOURCE: National Research Council (1974, 1980); Environmental Protection Agency (1997).

SUMMARY

Water availability and quality are extremely important for animal health and productivity. Limiting water availability to cattle will depress production rapidly and severely.

Some water contaminants—such as nitrates, sodium chloride, and sulfates—have been reported to affect animal performance and health. However, most water contaminants have an unknown effect on animal performance. That is particularly true for water that has low concentrations of contaminants and is consumed over a long period.

On the basis of the scientific literature, no widespread specific beef cattle or dairy cattle production problems have been caused by consumption of water of low quality. Water quality might cause poor production or nonspecific diseases and should be one aspect of the procedures used to investigate such problems.

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