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Dry Matter Intake

Dry matter intake (DMI) is fundamentally important in nutrition because it establishes the amount of nutrients available to an animal for health and production. Actual or accurately estimated DMI is important for the formulation of diets to prevent underfeeding or overfeeding of nutrients and to promote efficient nutrient use. Underfeeding of nutrients restricts production and can affect the health of an animal; overfeeding of nutrients increases feed costs, can result in excessive excretion of nutrients into the environment, and at excessively high amounts may be toxic or cause adverse health effects.

Many factors affect voluntary DMI. Individual theories based on physical fill of the reticulorumen (Allen, 1996; Mertens, 1994), metabolic-feedback factors (Illius and Jessop, 1996; Mertens, 1994), or oxygen consumption (Ketelaars and Tolkamp, 1996) have been proposed to determine and predict voluntary DMI. Each theory might be applicable under some conditions, but it is most likely the additive effect of several stimuli that regulate DMI (Forbes, 1996).

Feeds low in digestibility are thought to place constraints on DMI because of their slow clearance from the rumen and passage through the digestive tract. The reticulorumen and possibly the abomasum have stretch and touch receptors in their walls that negatively impact DMI as the weight and volume of digesta accumulate (Allen, 1996). The neutral detergent fiber (NDF) fraction, because of generally low rates of digestion, is considered the primary dietary constituent associated with the fill effect.

The conceptual framework for the metabolic-feedback theory contends that an animal has a maximal productive capacity and maximal rate at which nutrients can be used to meet productive requirements (Illius and Jessop, 1996). When absorption of nutrients, principally protein and energy, exceeds requirements or when the ratio of nutrients absorbed is incorrect, negative metabolic-feedback impacts DMI.

An alternative to the metabolic theory is the theory Ketelaars and Tolkamp (1996) proposed based on oxygen consumption. This theory suggests that animals consume net

energy at a rate that optimizes the use of oxygen and minimizes production of free radicals that lead to aging.

In addition to the complexity and interaction of the physical, metabolic, and chemostatic factors that regulate DMI is the psychologic and sensory ability of animals (Bauumont, 1996). Consistently accurate prediction of DMI in ruminants has been difficult to achieve because a complicated, diffuse, and poorly understood set of stimuli regulate DMI. For additional discussions and reviews on intake, see Baile and McLaughlin (1987); Forbes (1995); Ketelaars and Tolkamp (1992a,b); Mertens (1994); National Research Council (1987).

In lactating dairy cattle, milk production (energy expenditure) usually peaks 4 to 8 weeks postpartum, and peak DMI (energy intake) lags until 10 to 14 weeks postpartum (National Research Council, 1989). It has been debated whether milk production is driven by intake or intake is driven by milk production. On the basis of energy intake regulation theory and others (Baile and Forbes, 1974; Conrad et al., 1964; Mertens, 1987; National Research Council, 1989), cows appear to consume feed to meet energy needs, so intake is driven by milk production.

This increase in energy intake in response to energy expenditure has been clearly shown in the numerous lactation studies with bovine somatotropin where DMI follows milk production (Bauman, 1992; Etherton and Bauman, 1998).

EQUATIONS FOR PREDICTING DMI

Lactating Cows

Earlier editions of *Nutrient Requirements of Dairy Cattle* used various approaches to predict DMI. The 1971 edition (National Research Council, 1971) simply recommended feeding ad libitum during the first 6 to 8 weeks of lactation, and then feeding to energy requirements after that for lactating dairy cows. In 1978 (National Research

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Council, 1978), DMI guidelines were established by using a set of selected studies to create an interpolation table. Body weight and 4 percent fat-corrected milk were factors used to estimate DMI, which ranged from 2 to 4 percent of body weight. The 1989 edition (National Research Council, 1989) predicted DMI on the basis of energy requirement theory and expressed it simply as

$$\text{DMI (kg)} = \frac{\text{NE}_L \text{ required (Mcal)}}{\text{NE}_L \text{ concentration of diet (Mcal/kg)}} \quad (1-1)$$

where net energy of lactation (NE_L) included requirements for maintenance, milk yield, and replenishment of lost weight. Suggested modifications for expected DMI were an 18 percent reduction during the first 3 weeks of lactation and DMI reduction of 0.02 kg per 100 kg of body weight for each 1 percent increase in moisture content of the diet above 50 percent when fermented feeds were being fed. The DMI guidelines in the 1989 publication were based entirely on energy balance (that is, over the long term, energy intake must equal energy expenditure). The method was not designed to estimate daily DMI in the short term. It required accurate estimates of changes in body tissue mass (although the equation was based on changes in body weight, it assumed that body weight changes equaled changes in body tissue mass) and accurate estimates of the concentration of NE_L in the diet. Because of changes in gut fill and inaccurate measurements, short-term changes in body tissue mass and the energy needed or provided because of those changes are difficult to measure accurately, as is the concentration of NE_L in the diet. To improve the utility of this report, the present subcommittee decided to include an empirical equation to estimate short-term DMI.

Several DMI prediction equations have been developed for use in the field, but only a few have been published in the scientific literature and tested for accuracy (Fuentes-Pila et al., 1996; Roseler et al., 1997a). The equations reported in the literature are based on the principle that animals consume dry matter to meet energy requirements or are developed by regression of various factors against observed DMI. DMI prediction equations that include animal, dietary, or environmental factors have been developed by Holter and Urban (1992) and Holter et al. (1997).

In the approach used to develop DMI prediction equations in this edition, DMI prediction is based on actual data with the inclusion of only animal factors, which would be easily measured or known. Dietary components were not included in models for lactating cows, because the approach most commonly used in formulating dairy cattle diets is to establish requirements and a DMI estimate before dietary ingredients are considered. Equations containing dietary factors are best used to evaluate postconsumption rather than to predict what will be consumed.

DMI data published in the *Journal of Dairy Science* from 1988 to 1998 (see Chapter 16 for references) and data from Ohio State University and the University of Minnesota (May, 1994) were used in evaluating and developing an equation for lactating Holstein dairy cows. The data set included 17,087 cow weeks (5962 first lactation and 11,125 second lactation or greater cow weeks), a diverse set of diets, and studies with and without bovine somatotropin and encompassed a 10-year period from 1988 to 1997. Weeks of lactation ranged from 1 to 80; most data were from 1 to 40 weeks. Equations evaluated were those of Roseler et al. (1997b) and May (1994) and an equation reported by Rayburn and Fox (1993) based on DMI values in the 1989 *Nutrient Requirements of Dairy Cattle* (National Research Council, 1989). The best overall prediction equation, based on bias (-0.27 kg/day) and mean square prediction error ($3.31 \text{ kg}^2/\text{day}$) was a combined equation of Rayburn and Fox (1993) and an adjustment for week of lactation developed by Roseler et al. (1997b). The equation for predicting DMI of lactating Holstein cows is

$$\begin{aligned} \text{DMI (kg/d)} = & (0.372 \times \text{FCM} \\ & + 0.0968 \times \text{BW}^{0.75}) \\ & \times (1 - e^{(-0.192 \times (\text{WOL}+3.67))}) \end{aligned} \quad (1-2)$$

where FCM = 4 percent fat corrected milk (kg/day), BW = body weight (kg), and WOL = week of lactation. The term $1 - e^{(-0.192 \times (\text{WOL}+3.67))}$ adjusts for depressed DMI during early lactation. For early lactation cows, Equation 1-2 was compared to those developed by Kertz et al. (1991) using the validation data from Kertz et al. (1991). Dry matter intake predictions for the first 14 weeks of lactation are shown in Figure 1-1. Equation 1-2 predicts DMI very closely to the actual DMI for the first 10 weeks of lactation and then slightly under predicts DMI thereafter compared to the general overall predictions of Kertz et al. (1991).

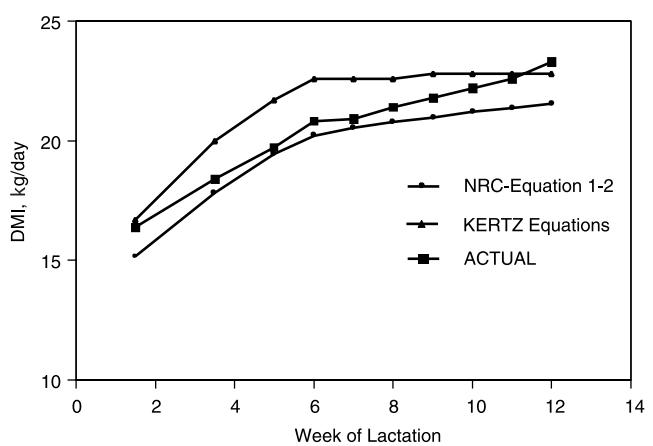


FIGURE 1-1 Dry matter intake prediction of early lactation cows using Equation 1-2 and Kertz et al. (1991) equations.

Equation 1-2 is based entirely on Holstein cows. No published DMI data were available for developing or modifying the current equation for use with breeds other than Holstein. For DMI of Jersey cattle, readers are referred to Holter et al. (1996).

No adjustment to the DMI equation for parity is needed. The bias and mean square prediction error for primiparous (-0.16 kg/day and $3.05 \text{ kg}^2/\text{day}$) and multiparous (0.12 kg/day and $3.20 \text{ kg}^2/\text{day}$) were similar and were not different from the overall combined prediction equation statistics. However, body weight and milk production data appropriate for first and second lactation animals must be used in the equation to estimate DMI accurately for these animals.

The actual DMI, FCM, and body weight data from animals used to develop and validate the lactating cow DMI prediction equation are shown in Figure 1-2. Body

weight change is based on animals becoming pregnant by week 17 of lactation, so later weights reflect cow and conceptus gain during the lactation.

The DMI of lactating cows is affected by environmental conditions outside the thermal neutral zone (5 to 20°C). Both Eastridge et al. (1998) and Holter et al. (1997) have shown DMI decreases with temperatures above 20°C. The equation used for predicting DMI of lactating cows (Equation 1-2) in this edition does not include a temperature or humidity adjustment factor because of insufficient DMI data outside of the thermal neutral zone to validate equation modifiers. However, use of lowered milk production in Equation 1-2 during heat stress periods will reflect the reduction in DMI commonly observed during heat stress periods. Eastridge et al. (1998) suggested the following changes occur in DMI when temperatures are outside of

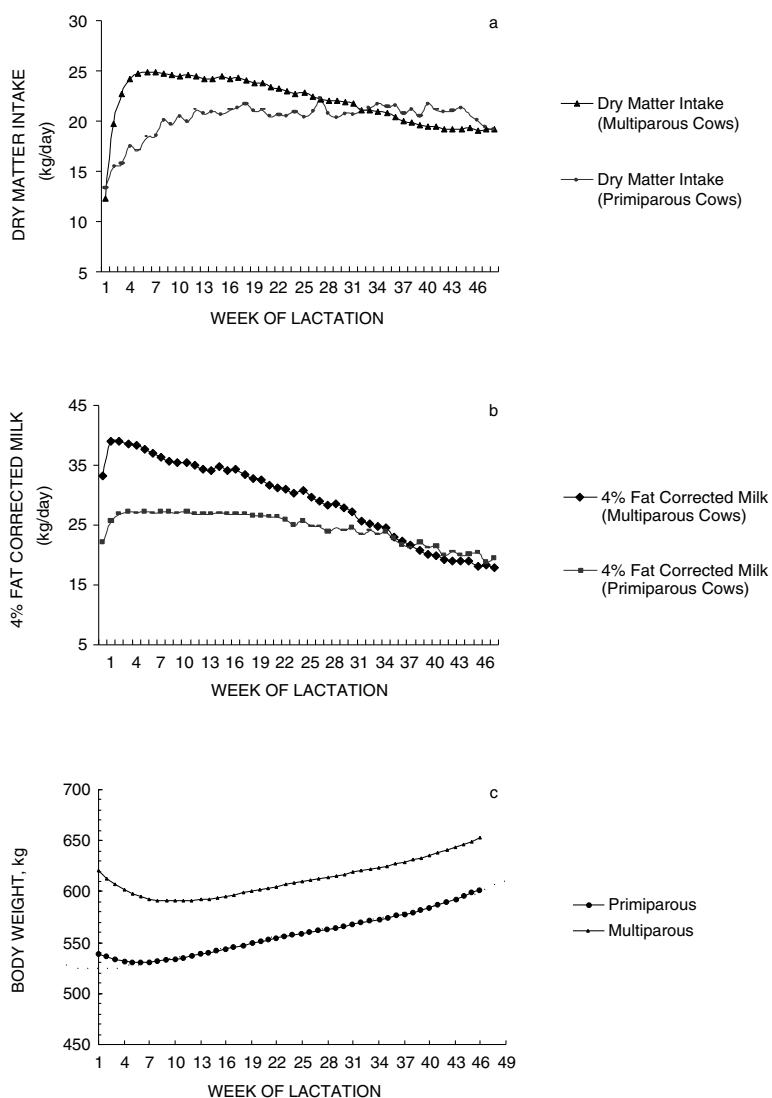


FIGURE 1-2 a) Dry matter intake, b) 4 percent fat corrected milk production, and c) body weight change of primiparous and multiparous cows during 48 weeks of lactation.

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the thermal neutral zone; temperatures $>20^{\circ}\text{C}$, $\text{DMI} \times (1 - ((^{\circ}\text{C} - 20) \times 0.005922))$ and temperatures $<5^{\circ}\text{C}$, $\text{DMI}/(1 - ((5 - ^{\circ}\text{C}) \times 0.004644))$. Application of the Eastridge et al. (1998) adjustment factors to a DMI prediction from Equation 1-2 based on lowered milk production during periods of heat stress may result in an excessively low prediction of DMI.

Growing Heifers

Published data on DMI of growing heifers weighing from 60 to 625 kg are sparse. Most research studies used fewer than 40 animals with a narrow weight range and limited experimental observation period. Dry matter intake equations from Quigley et al. (1986) and Stallings et al. (1985) and calf equation from the *Nutrient Requirements of Beef Cattle* (National Research Council, 1996) were selected for initial evaluation using data from New Hampshire and Minnesota where dietary composition, heifer growth, and DMI were measured over several months. The equation of Quigley et al. (1986) and the *Nutrient Requirements of Beef Cattle* equation (National Research Council, 1996) include dietary energy content and body weight. An equation based only on animal parameters was preferred to one including dietary components, however, the only published heifer DMI equation without dietary components found was from Stallings et al. (1985). On evaluation, the limited animal parameter equation of Stallings et al. (1985) was found to have a much larger prediction error, especially for heifers above 350 kg, than either the Quigley et al. (1986) or the National Research Council's *Nutrient Requirements of Beef Cattle* (1996) equation, which had similar predictive accuracy (Table 1-1).

Because of more current evaluation and a much larger validation data set than Quigley et al. (1986), the equation for beef calves from the 1996 *Nutrient Requirements of Beef Cattle* (National Research Council, 1996) was further validated using a data set from Purina Mills, St. Louis, Missouri. This data set included 2727 observations on growing heifers ranging from 58 to 588 kg and dietary net energy-maintenance concentrations from 1.24 to 1.55 Mcal/kg. Based on the fit of the data from the initial evaluation and the validation (Figure 1-3), the National Research

TABLE 1-1 Validation Statistics for Prediction of Dry Matter Intake by Heifers

Equation source	Bias, kg/d	MSPE, ^a kg ² /d
Quigley et al. (1986)	-0.32	1.47
Stallings et al. (1985)	-1.32	1.90
National Research Council ^b (1996) Calves	-0.51	1.48

^a Mean square prediction error.

^b *Nutrient Requirements of Beef Cattle* (National Research Council, 1996).

Council equation for beef cattle is recommended for predicting DMI of growing, nonlactating Holstein heifers.

$$\begin{aligned} \text{DMI (kg/d)} = & (\text{BW}^{0.75} \times (0.2435 \times \text{NE}_M \\ & - 0.0466 \times \text{NE}_M^2 \\ & - 0.1128)/\text{NE}_M) \end{aligned} \quad (1-3)$$

where BW = body weight (kg) and NE_M is net energy of diet for maintenance (Mcal/kg).

No adjustments for breed, empty body fat, feed additives, or anabolic implant were made. There is a considerable difference in the DMI predicted from the growing heifer equation (Eq. 1-3) during late gestation and the equation used to predict DMI of heifers the last 21 days of gestation (Eq. 9-1, Chapter 9). To avoid a large disconnect in DMI between days 260 and 261 in the model, the following adjustment factor for Equation 1-3 based on days of gestation is applied to Equation 1-3: [1 + ((210 - DG) × 0.0025)]; where DG = day of gestation. The adjustment is applied for utility in model usage and is not validated. Reported information on DMI of growing heifers during the last trimester of pregnancy is nonexistent.

Data for predicting DMI of growing heifers for breeds other than Holstein or adjusting Equation 1-3 to fit other breeds was not found. Likewise, there is a dearth of information for developing adjustments to Equation 1-3 for temperature and other environmental factors. Fox and Tylutki (1998) modified the temperature and mud adjustments listed in the *Nutrient Requirements of Beef Cattle* (National Research Council, 1996) for growing dairy heifers, but did not validate the adjustments because of the lack of data. Hoffman et al. (1994) have shown that season, type of housing, muddy conditions, length of hair, and body condition all affect average daily gain; and adjustments to energy requirements for gain were suggested, but effects on DMI were not evaluated.

NUTRIENTS AND FEEDING MANAGEMENT RELATED TO DMI OF LACTATING DAIRY COWS

Moisture

Studies reviewed by Chase (1979) and included in the 1989 *Nutrient Requirements of Dairy Cattle* (National Research Council, 1989) indicate a negative relationship between DMI and diets high in moisture content. A decrease in total DMI of 0.02 percent of body weight for each 1 percent increase in moisture content of the diet above 50 percent was indicated when fermented feeds were included in the ration. In a study using alfalfa silage to vary dietary DM, Kellems et al. (1991) found a trend of reduction in DMI with increasing moisture in the diet. Holter and Urban (1992) summarized data on 329 lactating

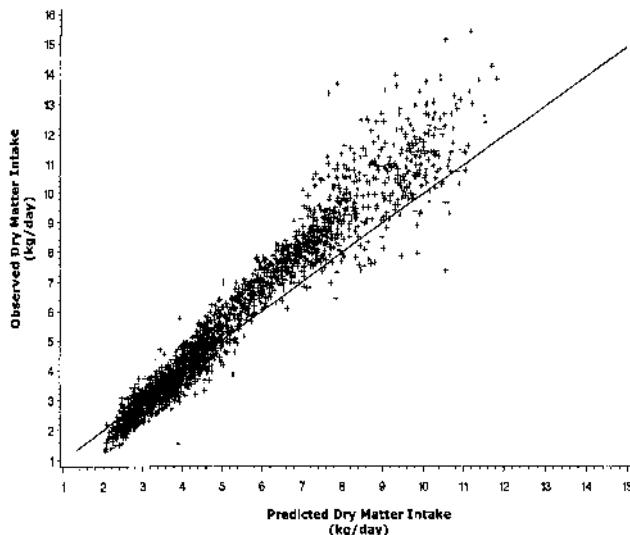


FIGURE 1-3 Observed versus predicted dry matter intake of growing dairy heifers using beef calf equation from *Nutrient Requirements of Beef Cattle* (National Research Council, 1996).

cows fed diets ranging from 30 to 70 percent DM and found that DMI was not decreased when dietary DM decreased to below 50 percent. Most high moisture feeds are fermented, and the decrease in DMI when they are fed is generally thought to result from fermentation end products and not water itself. When cows were given diets identical in composition except for the addition of water (78, 64, 52, or 40 percent DM in diets), DMI of cows increased linearly ($P < 0.01$) as percentage DM in the ration increased (Lahr et al., 1983). However, DMI was not affected by soaking grain mixes in water to achieve a dietary DM of 35, 45, or 60 percent (Robinson et al., 1990). Published reports on the relationship between dietary DM content and DMI are conflicting and no optimum DM content of the diet for maximum DMI is apparent.

Neutral Detergent Fiber

Mertens (1994) suggested that NDF be used to define the upper and lower bounds of DMI. At high NDF concentrations in diets, rumen fill limits DMI whereas, at low NDF concentrations energy intake feedback inhibitors limit DMI. Dado and Allen (1995) demonstrated the fill relationship in cows during early lactation: 35 percent NDF diets restrict DMI because of feed bulkiness and rumen fill, but DMI was not limited when 25 percent NDF diets were fed with or without inert bulk in the rumen. In a review on feed characteristics affecting DMI of lactating cattle, Allen (2000) summarized 15 studies and showed a general decline in DMI with increasing NDF concentrations in diets when diets exceeded 25 percent NDF. At any particular NDF concentration in the diet, however, a considerable range in DMI was observed suggesting the

source or sources of NDF in the diet as affected by particle size, digestibility, and rate of passage from the reticulo-rumen affect DMI.

The use of NDF as a variable in DMI prediction models has been reviewed in two studies. Rayburn and Fox (1993) concluded that DMI prediction was most accurate and least biased when dietary NDF, particularly from forages, was included in a model with BW, FCM, and days in milk. However, in models for predicting DMI of lactating cows fed high energy diets ranging in NDF from 25 to 42 percent of DM, less than 1 percent of the variation in DMI was accounted for by dietary NDF (Roseler et al., 1997a).

Forage to Concentrate Ratio

The ratio of forage to concentrate (F:C) in lactating dairy cow diets has been reported to affect DMI. Many of the study results are probably associated with the amount and digestibility of forage fiber and a propionate limiting effect on DMI as discussed by Allen (2000), rather than a specific ratio of forage to concentrate. In alfalfa or orchardgrass based diets, cows fed concentrate as 20 percent of the dietary DM produced less milk ($P < 0.01$) than cows fed diets that contained 40 or 60 percent concentrate (Weiss and Shockley, 1991). The DMI increased linearly ($P < 0.01$) with increasing concentrate in diets regardless of forage type. Digestible DM also increased linearly ($P < 0.01$) with increasing concentrate in the diet. Because intake of undigested DM was not affected by the amount of concentrate, rates of passage and digestion and physical characteristics of the feedstuffs are probable causes of differences in DMI.

Llamas-Lamas and Combs (1991) fed diets with three ratios of forage (alfalfa silage) to concentrate (86:14, 71:29, and 56:44). DMI was greatest for the diet highest in concentrate but similar for the other two diets. Petit and Veira (1991) fed concentrate at either 1.3 or 1.8 percent of BW and alfalfa silage ad libitum (F:C, 63:37 and 54:46) to Holstein cows during early lactation. Both groups of cows ate similar amounts of silage, but cows consuming the high-concentrate diet gained weight, and animals consuming the low-concentrate diet lost weight. Similar results were observed by Johnson and Combs (1992): cows fed a 74 percent forage diet (2:1 alfalfa silage to corn silage) consumed 2.7 kg less DM per day than cows fed a diet containing 50 percent forage. In general, increasing concentrate in diets up to about 60 percent of the DM increased DMI.

Fat

Assuming that cows consume DM to meet their energy requirements (Baile and Forbes, 1974; Mertens, 1987; National Research Council, 1989), often less DM is consumed when fat replaces carbohydrates as an energy source

in diets (Gagliostro and Chilliard, 1991). Fats may also decrease ruminal fermentation and digestibility of fiber (Palmquist and Jenkins, 1980; Chalupa et al., 1984, 1986) and so contribute to rumen fill and decrease the rate of passage. Allen (2000) also indicated fats may contribute to decreased DMI through actions on gut hormones, oxidation of fat in the liver and the general acceptability of fat sources by cattle.

The response in DMI to the addition of fatty acids in lactating dairy cattle diets is dependent on the fatty acid content of the basal diet and source of added fatty acids (Allen, 2000). For the diets containing 5 to 6 percent total fatty acids, the addition of oilseeds and hydrogenated fatty acids to diets resulted in a quadratic effect on DMI with minimums occurring at 3 and 2.3 percent added fatty acids, respectively. Additions of tallow, grease, and calcium salts of palm fatty acids to diets resulted in a general negative linear decrease in DMI. Smith et al. (1993) reported ruminally active fats have a greater negative effect on DMI, ruminal fermentation, and digestibility of NDF when diets are high in corn silage than when they are high in alfalfa hay.

Palmquist and Jenkins (1980) indicated that increased saturation of fatty acids usually reduces the negative ruminal effects associated with fats. However, Allen (2000) found that as the proportion of unsaturated fatty acids in the fat source increased, DMI generally decreased. Most all of the studies that Allen (2000) cited fed the calcium salts of palm fatty acids. However, total digestible energy intake in many of the studies was not reduced, as digestibility of the calcium salts of palm fatty acids was high and greater than hydrogenated palm fatty acid comparisons.

While the trend is for a reduction in DMI with the addition of fatty acids to diets (Allen, 2000; Chan et al., 1997; Elliot et al., 1996; Garcia-Bojalil et al., 1998; Jenkins and Jenny, 1989; Rodriguez et al., 1997), some studies (Pantoja et al., 1996; Skaar et al., 1989) have reported increases in DMI. Potential reasons for increased DMI with fat addition is a lower heat increment during periods of heat stress and/or a reduction in propionate inhibition on DMI when fat is substituted for grain (Allen, 2000).

COW BEHAVIOR, MANAGEMENT, AND ENVIRONMENTAL FACTORS AFFECTING FEED INTAKE

Eating Habits and Cow Behavior

Dado and Allen (1994) studied eating habits of lactating dairy cows housed in a tie-stall barn. Twelve Holstein cows ranging in milk production from 22 to 45 kg/d were monitored during the ninth week of lactation. The six highest-producing cows averaged 11 kg more milk per day and consumed about 6 kg more DM per day than the lowest-

producing six cows. The time spent eating (average, 300 minutes/day) and the number of meals (average, 11/day) did not differ between the two groups, but the high-producing cows consumed more DM per meal than did the low-producing cows (2.3 vs. 1.7 kg). High-producing cows ruminate fewer times per day (13 vs. 14.5 times/day) but ruminate an average of 5 min more per rumination period than low-producing cows.

Grouping cows according to their nutrient requirements can decrease the variation in DMI among cows within the group. The DMI shown in Figure 1-2 illustrates the difference between primiparous and multiparous cows in total DMI and pattern of DMI during lactation. Primiparous cows do not peak in DMI as early in lactation, but they are more persistent in DMI after peak than are multiparous cows. Thus, primiparous and multiparous cows should be grouped separately because of differences in DMI and social hierarchy. Primiparous cows are usually more timid and of lower social rank in the herd initially, but they gradually rise in social rank as more cows enter the herd or as older cows leave (Wierenga, 1990). Phelps and Drew (1992) reported an increase of 725 kg in milk over a 305-day lactation for first-lactation animals when grouped separately instead of being mixed in with older cows.

Behavior at the feed bunk is often affected by social dominance. Dominant cows, usually older and larger, tend to spend more time eating than do cows with a lower social rank in a competitive situation, such as when bunk space is restricted (Albright, 1993). Socially dominant animals, not necessarily the highest producers, tend to consume more feed at the bunk in these situations (Friend and Polan, 1974). In a situation of competition for feed, cows consume slightly more feed but do it in less time per day than when there is no competition and access to feed is ample (Olofsson, 1999).

In 1993, Albright (1993) recommended at least 46 cm of bunk space per cow. Friend et al. (1977) evaluated bunk spaces of 50, 40, 30, 20, and 10 cm per cow, for early lactation cows with mature equivalent productions of 7,700 to 10,000 kg/year. Average time spent at the feed bunk (3.7 hours/day) did not decrease until only 10 cm of space per cow was available (Table 1-2). When there was 20 or 10 cm per cow, the correlation of dominance to duration of eating periods increased. The optimal or critical feed bunk space needed is probably not a constant number and will depend on competition between cows, the total number of cows having access to the feed space, and the availability of feed over a 24-hour period.

For growing dairy heifers, feed-bunk space requirement varies with age. Longenbach et al. (1999) found that rapid growth in growing heifers fed a total mixed diet could be maintained in young heifers (4 to 8 months old) with 15 cm of bunk space. But, by the age of 17 to 21 months,

TABLE 1-2 Effect of Bunk Space Per Cow on Feeding Behavior and Intake of Early Lactation Cows^a

	Feed Bunk Length Per Cow (cm)				
	50	40	30	20	10
Time at feed bunk, h	3.82	3.73	3.73	3.76	2.57 ^b
Correlation of time with social dominance	0.46	0.32	0.30	0.67 ^c	0.71 ^d
Percentage of time at feed bunk, %	21.5	26.9	34.6	51.9	70.6
Daily feed intake, kg of DM	17.5	17.6	17.8	16.9	15.7

^aFrom Friend et al. (1977).

^bDiffers from 50 cm feed bunk/cow.

^cDiffers from zero ($P < 0.05$).

^dDiffers from zero ($P < 0.01$).

feed bunk space needed to be similar (47 cm) to that recommended for lactating cows.

Cattle prefer mangers that allow them to eat off a smooth surface in a natural grazing position. Albright (1993) cited evidence showing cows eating with their heads down produce 17 percent more saliva than cows eating with their heads in a horizontal position. Feed-wasting activities associated with elevated bunks, such as feed tossing, are eliminated when cows eat with their heads down (Albright, 1993).

Weather

The thermal neutral zone of dairy cattle is about 5 to 20°C, but it varies among animals. Temperatures below or above the thermal neutral range alter intake and metabolic activity. Young (1983) stated ruminants adapt to chronic cold stress conditions by increasing thermal insulation, basal metabolic intensity, and DMI. Rumination activity, reticulo-rumen motility, and rate of passage are also increased (Young, 1983). However, in extreme cold, DMI does not increase at the same rate as metabolism, so animals are in a negative energy balance and shift energy use from productive purposes to heat production.

A rise in ambient temperature above the thermal neutral zone decreases milk production because of reduced DMI. Holter et al. (1997) found pregnant multiparous middle-to late-lactation Holstein cows decreased DMI more (22 percent) than primiparous cows (9 percent) at the same stage of lactation and pregnancy when subjected to heat stress. A decrease in DMI up to 55 percent of that eaten in the thermal neutral zone along with an increase of 7 to 25 percent in maintenance requirement has been reported for cows subjected to heat stress (National Research Council, 1981). Water consumption of cattle increases as ambient temperature increases up to 35°C, but further temperature increases decrease water consumption because of inactivity and low DMI. Similar effects as those observed under high temperature conditions can be seen in cattle

at temperatures as low as 24°C with high humidity (Coppock, 1978).

Feeding Method—Total Mixed Ration vs. Individual Ingredient

The goal of any feeding system or method is to provide the opportunity for cows to consume the amount of feed specified in a formulated diet. Considerations in the choosing of a feeding system should include housing facilities, equipment necessities, herd size, labor availability, and cost. Nutrients can be effectively supplied by feeding either a total mixed ration (TMR) or individual ingredients. A TMR allows for the mixing of all feed ingredients together based on a prescribed amount of each ingredient. When consumed as a TMR without sorting of ingredients, more even rumen fermentation and a better use of nutrients should occur than feeding of separate ingredients. Computerized or electronic feeders reduce the labor involved in individual-concentrate feeding and provide an opportunity to control and regulate concentrate feeding to cows through several small amount feedings each day. Limitations to feeding forages and concentrates separately are the forages as they are usually provided free-choice and the amount fed is usually unknown or individual cow amounts are calculated from a group average intake. Maltz et al. (1992) reported that cows fed a TMR or concentrate by computer feeders did not differ in milk production (32.7 vs. 32.7 kg/d) or differ much in DMI (19.7 vs. 20.4 kg/d) during the first 20 weeks of lactation. Allocation of concentrates through a computer feeder based on milk yield per unit of body weight was more successful in economizing on concentrate feeding without losses in milk production and management of body weight than allocation only by milk yield.

Feeding Frequency

It has been suggested that increasing the frequency of offering feed to cows increases milk production and results in fewer health problems. Gibson (1981) concluded in a review on feeding frequency that changing from one or two offerings of feed per day to four increased average daily gain of cattle by 16 percent and increased feed use by 19 percent. Improvements in gain or feed use were greatest when cattle were fed high-concentrate diets. In a review of 35 experiments on feeding frequency in lactating dairy cows, Gibson (1984) reported that increasing feedings to four or more times per day compared to once or twice increased milk fat percentage by an average of 7.3 percent and milk production 2.7 percent. Higher milk fat concentration with increased feeding frequency also was reported by Sniffen and Robinson (1984). The benefit of increased feeding frequency might be more stable and consistent

ruminal fermentation. When Robinson and McQueen (1994) fed a basal diet two times per day and then a protein supplement two or five times per day, production and composition of milk were not affected by the frequency of feeding protein supplement, but both pH and propionate concentration in the rumen were higher with five than with two feedings per day. Klusmeyer et al. (1990) reported that ruminal fermentation pattern and production of milk and milk components were not improved by increasing feedings from two to four times per day. Similar results were found with the feeding of concentrate two or six times per day as milk production, milk-component yield, DMI, or ruminal fermentation characteristics were not affected (Macleod et al., 1994). Fluctuations in diurnal patterns of ruminal metabolites probably have to affect microbial growth and fermentation adversely before a benefit of increasing feedings to more than two times per day will be seen.

All of the studies reviewed for feeding frequency involved the actual offering of new feed to cattle and not the pushing in of existing feed to the manger. Whether the act of pushing feed in stimulates the same effects as the offering of new feed is unknown. In the study of Macleod et al. (1994), whenever fresh concentrate was offered to the cows fed concentrate six times per day, cows fed concentrate only twice per day would begin eating also, suggesting the act of feeding, or maybe pushing in feed, has a stimulating affect on eating.

Sequence of Feeding

Sniffen and Robinson (1984) hypothesized the following reasons for feeding forages as the first feed offered in the morning before concentrates. The feeding of highly fermentable carbohydrates to cows that have been without feed for over 6 hours could cause acidotic conditions in the rumen depressing feed intake and fiber digestion. Feeding forage(s) as the first feed in the morning before other feedstuffs would allow for the formation of a fiber mat in the rumen and provide buffering capacity in the rumen from both the forage and the increased salivation associated with forage consumption. Forages of medium to long chop length were advocated as they should prolong eating and thereby increase salivation and reduce particle passage from the rumen. However, evidence to support this hypothesis is lacking. In two studies (Macleod et al., 1994; Nocek, 1992) where legume forages were fed before concentrates, no effects on rumen fermentation characteristics, rumen pH or milk production were found. In both studies, feeding forage after concentrates resulted in a numerical increase in DMI compared to feeding forage before concentrate.

Access to Feed

Maximal DMI can only be achieved when cows have adequate time for eating. Data from Dado and Allen (1994) indicated early lactation cows (63 days in milk) producing 23 to 44 kg of milk per day fed a TMR ad libitum ate an average of 5 hours per day. Feed intake occurred during 9 to 13 (average of 11) eating bouts per day that averaged 29 minutes per bout. Mean DMI at each eating bout was about 10 percent of the total daily DMI, which ranged from 15 to 27 kg/day. Cows in this study (Dado and Allen, 1994) were housed in tie-stalls and had access to feed 22 of 24 hours per day. This study demonstrates there is a considerable difference in eating behavior between cows in a non-competitive feed environment and that the accessibility of feed must be considerably more than the 5 hours of actual eating time per day. Martinsson (1992) and Martinsson and Burstedt (1990) found that limiting the access of feed to 8 hours a day decreased milk production of cows averaging about 25 kg/day by 5 to 7 percent compared with cows that had free-choice access to feed.

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