**J. Dairy Sci. 85:3430–3443**


# Animal and Dietary Factors Affecting Feed Intake During the Prefresh Transition Period in Holsteins

**A. Hayirli,* R. R. Grummer,* E. V. Nordheim,† and P. M. Crump‡**
*Department of Dairy Science,
†Department of Statistics, and
‡Department of Computing and Biometry,
University of Wisconsin,
Madison 53706

## ABSTRACT

Parity, body condition score (BCS), and dry matter intake (DMI) data of 699 Holsteins fed 49 different diets during the final 3 wk of gestation (prefresh transition period) were compiled from 16 experiments conducted at eight universities. The objectives of this study were to determine the effects of animal and dietary factors on DMI and to elucidate interactions between animal and dietary factors and among dietary factors on DMI during the prefresh transition period. Animal factors examined were parity and BCS, whereas dietary factors examined were rumen undegradable protein (RUP), rumen degradable protein (RDP), neutral detergent fiber (NDF), and ether extract (EE). DMI decreased 32% during the final 3 wk of gestation, and 89% of that decline occurred during the final week of gestation. Day of gestation, animal factors, and dietary factors accounted for 56.1, 19.7, and 24.2% of explained variation in DMI, respectively, and $R^2$ of this linear multivariable model was 0.18. Cows had higher DMI than heifers. DMI decreased linearly as BCS, RUP, and NDF increased, decreased quadratically as EE increased, and increased quadratically as RDP increased. Moreover, the magnitude of DMI depression as animals approached parturition was affected by characteristics of animals and dietary nutrient composition. There were significant parity × EE, BCS × NDF, RUP × NDF, RDP × NDF, NDF × EE, and RUP × EE interactions on DMI. In conclusion, parity, BCS, and concentrations of organic macronutrients in diets affected DMI during the prefresh transition period, and the magnitude of DMI depression as animals approached parturition.
(**Key Words:** diet, dry matter intake, nutrient, transition cow)

**Abbreviation key: AM** = above the mean, **BM** = below the mean, **EE** = ether extract, **EI** = energy intake (Mcal $NE_L$/d), **H** = high, **L** = low, **M** = moderate or medium, **NFC** = nonfiber carbohydrate, **O** = obese, **T** = thin.

## INTRODUCTION

Recent trends in agriculture are such that the number of dairy cows is decreasing and milk yield per cow per lactation is increasing. However, increased milk production is associated with a greater incidence of health problems that cause milk production loss and reproductive inefficiency in early lactation (Erb et al., 1985; Deluyker et al., 1991; Rajala-Schultz et al., 1999). Without taking economic losses due to suppressed production and reproductive failure into account, health cost was estimated to be five times higher during early lactation than during mid- and late lactation (Young et al., 1985).

The dry period used to be considered a nonprofitable resting period (Van Saun, 1991; Nocek, 1995), and it was assumed that nutrient requirements during the entire dry period did not change (NRC, 1989). However, epidemiological surveys ascertained that dry period nutrition had carry-over effects on milk production and reproductive performance in early lactation and health status during the periparturient period (Curtis et al., 1985; Erb and Grohn, 1988; Correa et al., 1990). Dairy cows undergo tremendous challenges to adapt to the homeorrhetical changes that occur during the periparturient period (Nocek, 1995; Bell, 1996). Moreover, a 20 to 40% gradual decline in DMI during the final 3 wk of gestation (prefresh transition period) may initiate a negative energy balance and compromise the ability of dairy cows to adapt to physiological changes (Van Saun, 1991; Bell, 1995; Grummer, 1995). Therefore, minimizing depression in DMI or increasing the nutrient density of the diet during the prefresh transition period is suggested to maintain body reserves, increase nutrients available for rapid fetal growth, ease metabolic transition from pregnancy to lactation, and acclimate rumen microorganisms to lactation diets (Van Saun, 1991;

Received April 30, 2002.
Accepted June 11, 2002.
Corresponding author: R. R. Grummer; e-mail: rgrummer@facstaff.wisc.edu.

Grummer, 1995; Nocek, 1995). Carry-over effects from this include maintenance of body reserves and support for production of milk and milk components in early lactation (Flipot et al., 1988).

Factors affecting and regulating feed intake of lactating dairy cows are numerous and complex and span cellular to macroenvironmental levels (Forbes, 1996; Roseler et al., 1997; Allen, 2000). Factors affecting DMI in lactating dairy cows and other ruminants may influence DMI in prefresh transition dairy cows as well. Some can be controlled by humans and include animal factors (i.e., age, body condition, breed, physiological stage, and milk yield level), dietary factors (i.e., ingredient and nutrient compositions of diets and physical and agronomic characteristics of feeds), managerial factors (i.e., production, feeding, and housing systems), and climatic factors (i.e., temperature, humidity, and wind). Therefore, determination of factors affecting DMI and quantification of their effects are important for developing new feeding strategies during the prefresh transition period. Identification of all the factors affecting DMI in a single survey or experiment is not plausible. For this study, the objectives were to examine the effects of parity and BCS as animal factors and concentrations of organic macronutrients as dietary factors on DMI of Holsteins during the prefresh transition period based on data collected from a number of studies.

## MATERIALS AND METHODS

### Data Collection and Development of Databases

Parity, BW, BCS, and DMI data of 699 Holsteins fed 49 different diets during the final 3 wk of gestation were compiled from 16 experiments conducted at eight universities during the 1990s. Institutions providing data were Cornell University (Van Saun et al., 1993), Iowa State University (Hayirli, 1997), Michigan State University (VandeHaar et al., 1999; Moore et al., 2000), Oregon State University (Allen et al., 1995; Duncan, 1998), Pennsylvania State University (Dann et al., 1999; Soder and Holden, 1999), Purdue University (Greenfield et al., 2000), the University of Illinois (Grum et al., 1996; Overton et al., 1998), and the University of Wisconsin (Skaar et al., 1989; Bertics et al., 1992; Grummer et al., 1995; Vazquez-Anon et al., 1997; Minor et al., 1998). Daily DMI during the prefresh transition period, and BW and BCS (Edmonson et al., 1989) on d 21 ± 0.8 (mean ± SD) prepartum, were measured for all animals.

Tables 1 and 2 summarize descriptive characteristics of prefresh transition Holsteins and nutrient compositions of diets, respectively. Animal factors included parity and BCS, and dietary factors included concentrations of $NE_L$, CP, RUP, RDP, NDF, nonfiber carbohydrates (**NFC**), ADF, ether extract (**EE**), and ash. Investigators who contributed datasets provided nutrient contents of diets. If a nutrient of interest was not provided for a diet, it was calculated using ingredient composition of the diet and tabular values (NRC, 1989; NRC, 1996) for nutrients in those ingredients. NFC was calculated as 100 – (% CP + % ash + % NDF + % EE). Data from prefresh transition dairy cows that were not Holsteins, that were not fed ad libitum, or that had twins, were excluded before setting continuous and discrete databases for statistical analyses. A continuous database was established by compiling all data in which animal and dietary factors remained continuous (Tables 1 and 2). Discrete databases were developed from the continuous database, in which animal and dietary factors were categorized (Tables 1, 3, and 4). At first, animals were categorized according to parity as heifers (approaching the first lactation) and cows (having at least one previous parturition), and according to BCS as thin (**T**), medium (**M**), or obese (**O**), if BCS ranged from 1 to 3, 3.01 to 4, or 4.01 to 5, respectively. Dietary factors were categorized according to percentile distributions in 49 diets as low (**L**), high (**H**), and moderate (**M**) if concentrations ranged from the minimum to 20% more than minimum, from 20% less than maximum to the maximum, and between L and H, respectively (Table 3). The separation criterion was increased from 20 to 30% to increase the number of animals allocated to L and H levels for EE and ash (Table 3).

In this discrete database (Tables 1 and 3), a sufficient number of animals was allocated to each category of animal factors and to each level of dietary factors to determine their main and polynomial effects and their interactions with time (see Model I below). However, the number of animals in each level of dietary factors was not sufficient to determine interactions between animal factors and dietary factors and among dietary factors (see Model II below); therefore, we generated another discrete database (Table 4). In the second discrete database, animal factors were categorized as described earlier (Table 1), and dietary factors were categorized as below (**BM**) or above the mean (**AM**) if concentrations were below or above the mean value of all experimental diets (Table 4).

### Statistics

DMI was expressed as a percentage of BW in all statistical analyses so that intake could be standardized according to BW. Descriptive statistics of animal and dietary factors were determined using the Means, Freq, Univariate, and Corr Procedures (SAS, 1998) on the continuous database (Steel et al., 1997). With the same database, the GLM Procedure (SAS, 1998) was used to

**Table 1.** Description of animal factors.

| | Descriptive statistics[1] | | | | |
|---|---|---|---|---|---|
| | | BW, kg | | BCS | |
| Factor | n | Mean ± SD | Range | Mean ± SD | Range |
| Parity | | | | | |
| Heifer | 172 | 606 ± 53 | 471 to 811 | 3.6 ± 0.4 | 2.7 to 4.9 |
| Cow | 527 | 733 ± 76 | 514 to 960 | 3.6 ± 0.5 | 2.0 to 5.0 |
| Body condition[2] | | | | | |
| Thin | 96 | 662 ± 83 | 480 to 859 | 2.8 ± 0.2 | 2.0 to 3.0 |
| Medium | 516 | 699 ± 84 | 471 to 960 | 3.6 ± 0.3 | 3.1 to 4.0 |
| Obese | 79 | 779 ± 86 | 546 to 937 | 4.4 ± 0.2 | 4.1 to 5.0 |

[1]Body weights and body conditions were measured (mean ± SD) on d 21 ± 0.8 prepartum.

[2]Thin = if BCS ≤3; medium = if 3 < BCS ≤4; obese = if 4 < BCS ≤5. BCS of eight animals were not reported.

model sources of variation by type III sums of squares. These models contained day of pregnancy, animal factors, and dietary factors as independent variables. Additional models with the Reg Procedure (SAS, 1998) examined BCS as a function of BW and DMI, and energy intake (**EI**) as functions of the ratios NDF/NFC, RDP/RUP, and NFC/RDP. The DMI and EI models were used to determine values of the independent variables that maximized DMI and EI.

The effects of animal and dietary factors (Model I), and interactions between animal and dietary factors and among dietary factors (Model II) on DMI were examined in a stepwise manner using the Mixed Procedure of SAS (SAS, 1998; see below). Other models substituting experiment or diet in place of dietary factors were examined, but they did not yield as high an $R^2$ value and will not be discussed. Model I was applied to the first discrete database (Tables 1 and 3), whereas Model II was applied to the second discrete database (Tables 1 and 4). ANOVA was conducted employing a split-plot design with time (the subplot) viewed as repeated measures. Due to autocorrelations, the first-order autoregressive covariance structure was used for the subplot terms (Littell et al., 1996). Animals nested within experiments, diets, and animal and dietary factors were considered as random terms for corresponding mixed models. In Model I, because categories of animal factors and levels of dietary factors were unequally spaced and replicated (Tables 1 and 3), coefficients to test polynomial effects of dietary factors were calculated according to Carmer and Seif (1963), and probabilities of their significances were obtained from the Satterthwaite approximation (Littell et al., 1996). Statistical significance and tendency towards significance were declared at $P \leq 0.05$ and $0.05 < P \leq 0.10$, respectively. The specific structure of Model I was as follows: $y_{ijklmno} = \mu + P_i + BCS_j + RUP_k + RDP_l + NDF_m + EE_n + WPE + D_o + (P{\cdot}D)_{io} + (BCS{\cdot}D)_{jo} + (RUP{\cdot}D)_{ko} + (RDP{\cdot}D)_{lo} + (NDF{\cdot}D)_{mo} + (EE{\cdot}D)_{no} + SPE$, where P = parity (i = heifer and cow), BCS = body condition score (j = T, M, and O), RUP = rumen-undegradable protein (k = L, M, and H), RDP = rumen-degradable protein (l = L, M, and H), NDF = neutral detergent fiber (m = L, M, and H), EE = ether extract (n = L, M, and H), WPE = whole-plot error, D = day relative to parturition (o = –21 to –1), and SPE = subplot error.

**Table 2.** Description of dietary factors.

| | Descriptive statistics | | | | |
|---|---|---|---|---|---|
| Nutrient[1] | Range | WM ± SD[2] | Median | Mode | Skewness |
| $NE_L$, Mcal/kg | 1.27 to 1.66 | 1.48 ± 0.11 | 1.50 | 1.52 | –0.32 |
| CP, % | 11.8 to 20.3 | 14.7 ± 2.0 | 14.1 | 14.1 | 1.06 |
| RUP, % | 3.2 to 6.6 | 4.9 ± 0.8 | 4.9 | 4.9 | –0.08 |
| RDP, % | 7.5 to 14.1 | 9.9 ± 1.5 | 9.2 | 9.2 | 1.46 |
| NDF, % | 28.0 to 62.2 | 43.5 ± 8.3 | 44.5 | 44.5 | –0.08 |
| ADF, % | 18.6 to 41.1 | 28.8 ± 5.3 | 28.9 | 25.2 | 0.21 |
| NFC, % | 10.5 to 46.2 | 31.8 ± 8.2 | 33.2 | 33.9 | –0.10 |
| EE, % | 1.8 to 6.9 | 3.3 ± 1.2 | 3.0 | 3.7 | 1.60 |
| Ash, % | 3.3 to 11.7 | 6.7 ± 1.7 | 6.8 | 7.0 | 0.04 |

[1]Nutrients are expressed on a DM basis and were obtained from 49 diets. NFC = nonfiber carbohydrate; EE = ether extract.

[2]WM ± SD: weighted mean ± standard deviation. Means were calculated from nutritional information for 49 diets fed in 16 experiments. Means were weighted according to the number of animals fed each diet.

**Table 3.** Characteristics of groups generated from three-way categorization of dietary factors.

| | | Level | | |
|---|---|---|---|---|
| Nutrient[1] | DS[2] | Low | Moderate | High |
| $NE_L$, Mcal/kg | WM ± SD | 1.32 ± 0.03 | 1.45 ± 0.02 | 1.56 ± 0.06 |
| | Range | 1.27 to 1.36 | 1.41 to 1.48 | 1.49 to 1.66 |
| | n | 55-112-26-122-19 | 23-105-28-88-9 | 94-310-42-306-51 |
| CP, % | WM ± SD | 13.3 ± 0.6 | 15.2 ± 0.8 | 17.7 ± 1.5 |
| | Range | 11.8 to 14.1 | 14.2 to 16.2 | 16.3 to 20.3 |
| | n | 38-342-53-292-32 | 39-116-20-101-29 | 95-69-23-123-18 |
| RUP, % | WM ± SD | 3.5 ± 0.2 | 4.5 ± 0.3 | 5.7 ± 0.4 |
| | Range | 3.2 to 3.7 | 3.9 to 4.9 | 5.3 to 6.6 |
| | n | 10-43-17-31-2 | 68-297-46-287-32 | 94-187-33-198-45 |
| RDP, % | WM ± SD | 8.5 ± 0.4 | 9.8 ± 0.7 | 12.9 ± 1.3 |
| | Range | 7.5 to 8.9 | 9.0 to 11.2 | 11.5 to 14.1 |
| | n | 21-213-33-182-19 | 78-274-43-245-56 | 73-40-20-89-4 |
| NDF, % | WM ± SD | 29.7 ± 1.2 | 42.5 ± 5.2 | 53.6 ± 4.1 |
| | Range | 28.0 to 31.6 | 34.6 to 49.5 | 50.0 to 62.2 |
| | n | 32-32-5-43-16 | 123-375-72-373-45 | 17-120-19-100-18 |
| ADF, % | WM ± SD | 20.1 ± 1.1 | 28.0 ± 2.5 | 36.7 ± 2.3 |
| | Range | 18.6 to 21.6 | 24.4 to 32.8 | 33.4 to 41.1 |
| | n | 32-32-5-43-16 | 85-339-52-369-55 | 55-96-39-104-8 |
| NFC, % | WM ± SD | 22.9 ± 3.8 | 32.5 ± 2.8 | 42.1 ± 3.1 |
| | Range | 10.5 to 26.2 | 26.7 to 36.0 | 37.5 to 43.2 |
| | n | 55-177-38-170-24 | 85-201-42-242-17 | 32-149-16-122-38 |
| EE, % | WM ± SD | 2.0 ± 0.2 | 3.2 ± 0.5 | 5.7 ± 1.0 |
| | Range | 1.8 to 2.3 | 2.4 to 4.6 | 4.9 to 6.9 |
| | n | 9-71-9-64-7 | 163-380-71-415-54 | 0-76-16-37-18 |
| Ash, % | WM ± SD | 3.2 ± 0.7 | 6.6 ± 1.0 | 9.4 ± 1.2 |
| | Range | 3.3 to 4.2 | 4.6 to 7.8 | 8.6 to 11.7 |
| | n | 0-41-6-55-4 | 157-433-75-397-62 | 15-53-15-64-13 |

[1]Nutrients are expressed on a DM basis. NFC = nonfiber carbohydrate; EE = ether extract.

[2]DS: descriptive statistics. WM ± SD = weighted mean ± standard deviation. Means were weighted according to the number of animals fed each diet within each level; n = the number of heifers, cows, thin animals, medium animals, and obese animals, respectively, within each level. BCS of eight animals were not reported.

**Table 4.** Characteristics of groups generated from two-way categorization of dietary factors.

| | | Descriptive statistics[1] | | |
|---|---|---|---|---|
| Nutrient[2] | Level[3] | WM ± SD | Range | n |
| $NE_L$, Mcal/kg | BM | 1.38 ± 0.06 | 1.27 to 1.48 | 78-217-54-210-28 |
| | AM | 1.56 ± 0.06 | 1.49 to 1.66 | 94-310-42-306-51 |
| CP, % | BM | 13.5 ± 0.7 | 11.8 to 14.4 | 58-387-64-339-39 |
| | AM | 17.1 ± 1.4 | 15.7 to 20.3 | 114-140-32-177-40 |
| RUP, % | BM | 4.4 ± 0.5 | 3.2 to 4.9 | 78-340-63-318-34 |
| | AM | 5.7 ± 0.4 | 5.3 to 6.6 | 94-187-33-198-45 |
| RDP, % | BM | 8.9 ± 0.6 | 7.5 to 9.8 | 58-396-66-346-39 |
| | AM | 11.6 ± 1.4 | 9.9 to 14.1 | 114-131-30-170-40 |
| NDF, % | BM | 36.6 ± 4.7 | 28.0 to 42.7 | 87-243-45-235-45 |
| | AM | 49.6 ± 4.5 | 44.1 to 62.2 | 85-284-51-281-34 |
| ADF, % | BM | 24.6 ± 2.8 | 18.6 to 27.9 | 84-251-61-267-33 |
| | AM | 33.1 ± 3.5 | 28.9 to 41.1 | 88-276-35-249-47 |
| NFC, % | BM | 24.5 ± 4.4 | 10.5 to 30.8 | 68-255-49-242-29 |
| | AM | 38.0 ± 4.5 | 33.0 to 46.2 | 104-272-47-274-50 |
| EE, % | BM | 2.6 ± 0.4 | 1.8 to 3.0 | 75-251-39-240-44 |
| | AM | 3.9 ± 1.2 | 3.1 to 6.9 | 97-276-57-276-35 |
| Ash, % | BM | 5.4 ± 1.2 | 3.3 to 6.7 | 100-248-34-261-23 |
| | AM | 7.8 ± 1.1 | 6.8 to 11.7 | 72-289-62-255-56 |

[1]Descriptive statistics: WM ± SD: weighted mean ± standard deviation. Means were weighted according to the number of animals fed each diet within each level; n = the number of heifers, cows, thin animals, medium animals, and obese animals, respectively, within each level. BCS of eight animals were not reported.

[2]Nutrients are expressed on a DM basis. NFC = nonfiber carbohydrate; EE = ether extract.

[3]Level: BM = below the mean; AM = above the mean.

For Model II, the whole-plot factors were two animal factors (parity and BCS), four dietary factors (RUP, RDP, NDF, and EE), 56 possible interactions between these two groups of factors. The subplot factors were day of gestation and whole-plot factors by day of gestation interactions. This complex model was then simplified by stepwise backward hierarchical elimination of insignificant independent variables ($P > 0.10$) (Snedecor and Cochran. 1989). During the simplification process, the degree of fit was evaluated with different penalty systems, including iterative convergence criterion, Akaike's information criterion, and Schwarz's Bayesian criterion (Littell et al., 1996).

Model II (iterative convergence criterion = 9047.1, Akaike's information criterion = –4525.5, and Schwarz's Bayesian criterion = –4530.1) was subjected to 17 backward hierarchical elimination steps to yield a reduced form (iterative convergence criterion = 8747.2, Akaike's information criterion = –4375.6, and Schwarz's Bayesian criterion = –4380.1). The whole-plot and subplot variances were 0.1148 and 0.08738 for the full, and 0.1148 and 0.08721 for the reduced forms, respectively. No substantial improvements were noticed in model-fitting criteria or decreases in the whole-plot and subplot variances during the course of simplification, suggesting that eliminated independent variables were unimportant. The whole-plot and subplot utilized 29 and 400 df out of possible 698 and 13,960 df, respectively, indicating that over-parameterization was avoided.

## RESULTS AND DISCUSSION

### Overview of the Model-Building Process

Our eventual goal is to develop a mathematical model that precisely and accurately predicts DMI during the prefresh transition period. The selection of independent variables defining the nature of a response variable is important in planning and developing a model. This preliminary approach has allowed us to evaluate animal and dietary factors that may be used to develop a model predicting DMI during the prefresh transition period.

***Animal factors.*** Cows were 127 kg heavier than heifers, but their BCS were similar (Table 1). The mean BCS were 2.8, 3.6, and 4.4 for T, M, and O animals, respectively (Table 1). Because of differences in body surface area, a unit increase in BCS was associated with 55 and 79-kg BW increases in heifers (BW = 405.6 + 54.9·BCS, $R^2$ = 0.21, and $P < 0.0001$) and in cows (BW = 453.3 + 78.5·BCS, $R^2$ = 0.23, and $P < 0.0001$), respectively. When BCS increases, fat deposition in rib, lumbar spine, pelvic, and tailhead areas increase and muscle mass increases (Reid et al., 1986).

***Selection of dietary factors.*** Factors affecting DMI of ruminants are not limited to those examined for this study. For example, few researchers measured concentrations of the major inorganic nutrients (i.e., Ca and P) in these experiments; therefore, they were not considered as dietary factors in the models. Similarly, sources of organic macronutrients were highly variable across diets. Therefore, we were unable to consider ingredient composition of diets as factors affecting DMI.

Due to multicolinearity (Table 5), it was necessary to select dietary factors with biological and statistical relevance for incorporation into the models. There were strong correlations between concentrations of $NE_L$ and major organic nutrients (Table 5). Because of this, and because energy is not a nutrient and is usually estimated from organic macronutrients, models did not include $NE_L$.

Evaluating DMI responses to dietary CP concentration is not as specific as those to dietary concentrations of RDP and RUP. However, CP is measured directly in the laboratory and indicates total amount of nitrogen. Estimates for RUP and RDP can be erroneous and vary depending on ruminal passage rate (NRC, 2001). Therefore, we evaluated the effects of CP on DMI in a separate model in which CP replaced RUP and RDP.

There are numerous measurements for carbohydrate fractions in the diet that could be considered for incorporation into models. The only carbohydrate fraction included in the model was NDF. NDF represents the fibrous carbohydrate fraction in feed. Because the proportion of NDF in the diet is larger than the proportions of CP, EE, and ash, and because CP, EE, and ash are relatively constant among diets, the NDF concentration also reflects the NFC concentration (r = –0.94, $P < 0.0001$; Table 5). As expected, dietary concentrations of NDF and ADF were highly correlated (r = 0.77, $P < 0.0001$; Table 5) because their chemical compositions overlapped. Therefore, NDF was the only carbohydrate fraction included in the models.

***Relationship between DMI and animal and dietary factors.*** Animal or dietary factors highly correlated with DMI may be important determinants of DMI. DMI (% of BW) was positively correlated with parity (r = 0.12, $P < 0.0001$), and negatively correlated with BCS (r = –0.12, $P < 0.0001$) (Table 5). There was a relatively high correlation between EI (Mcal/d) and parity (r = 0.33, $P < 0.0001$) because cows consumed more DM (kg/d) than heifers. Because of the negative correlation between DMI and BCS, there was only a slight correlation between EI and BCS (r = 0.02, $P < 0.004$; Table 5).

There was no significant correlation between DMI and dietary concentrations of CP, RUP, and RDP (Table 5). DMI was positively correlated with the concentration of NFC (r = 0.14, $P < 0.0001$), and negatively corre-

**Table 5.** Correlation among animal factors, dietary factors, and feed intake.[1]

| | NEI, Mcal/d | Parity | BCS | $NE_L$, Mcal/kg | CP, % | RUP, % | RDP, % | NDF, % | ADF, % | NFC, % | EE, % | Ash, % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DMI, % of BW | 0.88** | 0.12** | –0.12** | 0.09** | 0.002 | –0.002 | 0.004 | –0.12** | –0.13** | 0.14** | –0.05** | –0.08** |
| NEI, Mcal/d | 1.00 | 0.33** | 0.02** | 0.34** | –0.09** | –0.03** | –0.10** | –0.29** | –0.33** | 0.35** | 0.07** | –0.26** |
| Parity | | 1.00 | –0.05** | 0.05** | –0.32** | –0.23** | –0.29** | 0.18** | 0.03** | –0.06** | 0.14** | –0.30** |
| BCS | | | 1.00 | 0.05** | 0.09** | 0.16** | 0.02** | –0.11** | –0.16** | 0.08** | –0.11** | 0.09** |
| $NE_L$, Mcal/kg | | | | 1.00 | –0.10** | 0.14** | –0.20** | –0.78** | –0.88** | 0.81** | 0.36** | –0.44** |
| CP, % | | | | | 1.00 | 0.67** | 0.92** | –0.19** | –0.01** | –0.09** | –0.26** | 0.37** |
| RUP, % | | | | | | 1.00 | 0.32** | –0.33** | –0.28** | 0.15** | –0.24** | 0.21** |
| RDP, % | | | | | | | 1.00 | –0.06** | 0.13** | –0.20** | –0.20** | 0.36** |
| NDF, % | | | | | | | | 1.00 | 0.77** | –0.94** | –0.17** | 0.17** |
| ADF, % | | | | | | | | | 1.00 | –0.82** | –0.03** | 0.38** |
| NFC, % | | | | | | | | | | 1.00** | 0.11** | –0.44** |
| EE, % | | | | | | | | | | | 1.00 | –0.09** |
| Ash, % | | | | | | | | | | | | 1.00 |

[1]Pearson correlation coefficients and their significance were obtained from 13,299 observations in the continuous database. Nutrients were on a DM basis. NEI = net energy intake (Mcal/d); NFC = nonfiber carbohydrate; EE = ether extract.

**$P < 0.01$.

lated with concentrations of NDF ($r = –0.12$, $P < 0.0001$) and EE ($r = –0.05$, $P < 0.0001$). The concentration of $NE_L$ was positively correlated with concentrations of NFC ($r = 0.81$, $P < 0.0001$) and EE ($r = 0.36$, $P < 0.0001$), and negatively correlated with the concentration of NDF ($r = –0.78$, $P < 0.0001$). Supplementing highly fermentable carbohydrates (Lawrence, 1988) and fat (Palmquist and Jenkins, 1980) are common approaches to increase energy density of the diet. Energy intake was strongly correlated with concentrations of NFC ($r = 0.35$, $P < 0.0001$) and NDF ($r = –0.29$, $P < 0.0001$) and slightly correlated with the concentration of EE ($r = 0.07$, $P < 0.001$), indicating that increasing EE may not increase EI if DMI is compromised.

***Contributors to variation in DMI.*** Depression in DMI during the prefresh transition period is common, but the causes are largely unknown. The $R^2$ of a multivariable model developed from the continuous database to evaluate the proportion of variation in DMI due to day of gestation and animal and dietary factors was 0.18. Type III sums of squares revealed that variation in DMI accounted for by day of gestation was 56.1% ($P < 0.0001$), by animal factors was 19.7% (10.0%, $P < 0.0001$ for parity and 9.7%, $P < 0.0001$ for BCS, respectively), and by dietary factors was 24.2% (15.3%, $P < 0.0001$ for NDF; 6.4%, $P < 0.0001$ for EE; 1.3%, $P < 0.04$ for RUP; and 1.2%, $P < 0.06$ for RDP, respectively), respectively (Figure 1). When the model included CP in place of RUP and RDP, CP accounted for 1.6% of the variation ($P < 0.53$) in DMI due to all dietary factors (20.1%). Using the principal component approach, Roseler et al. (1997) evaluated the relationship of numerous factors to variability in DMI of lactating dairy cows and reported that BCS and nutritional factors (including diet composition) accounted for 6 and 22% of variations in DMI, respectively. However, in that study, the amount of variation explained by the model was not reported. Despite being statistically significant, contributions of RUP and RDP to variation in DMI were relatively minor compared with those of NDF and EE. Substantial variation contributed by NDF is expected because forages constitute a large proportion of most diets offered during the dry period. Chemical composition and physical properties of forages also vary greatly (Allen, 2000), which causes variation in DMI. Although EE constitutes a small portion of ruminant diets, the

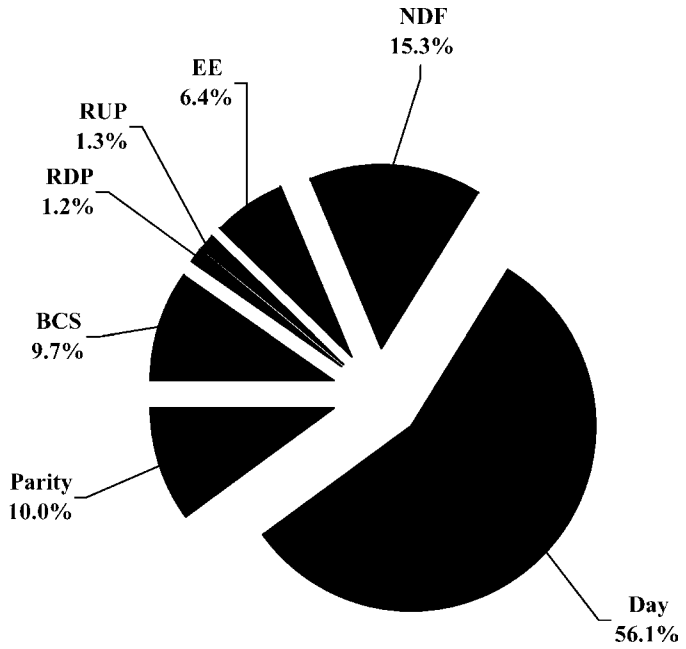


**Figure 1.** Proportion of variation (%) in DMI of prefresh transition Holsteins accounted for by day of gestation, animal factors, and dietary factors. $R^2$ of multivariate model = 0.18. EE = ether extract.

DMI of lactating cows is responsive to the type and amount of fat (Palmquist and Jenkins, 1980; Allen, 2000).

***Statistical approach.*** Assessment of correlations among independent variables is a prerequisite of multivariable ANOVA and multiple regression analysis (Snedecor and Cochran, 1989; Chatterjee and Price, 1991). Incorporation of collinear independent variables into a regression model results in biasing least square estimates and underestimating variation and standard error of the regression coefficients (Chatterjee and Price, 1991). Moreover, interpretation of the algebraic signs of regression coefficients depends on the assumptions that independent variables are not strongly correlated (orthogonal), and that other variables remain unchanged, in the case of removal or addition of one variable. If we had addressed the objectives of this study by a multiple regression analysis approach, results would have been ambiguous and inferences would have been conditional. Because of multicolinearity, concentrations of organic macronutrients in the diet cannot be set to a constant level when the level of one nutrient changes. However, creation of discrete databases by categorizing independent variables reduces imbalance in animal numbers within categories of animal and dietary factors, but does not eliminate multicollinearity. Therefore, we used a multivariable ANOVA approach on discrete databases to accomplish the objectives of this study.

## Effects of Animal and Dietary Factors on DMI

Data in Table 3 indicate that researchers tended to formulate diets to provide higher concentrations of nutrients for the prefresh transition period than those recommended by the NRC (1989) at the time trials were conducted. Eastridge et al. (1998) indicated exceeding NRC (1989) nutrient recommendations, especially for the prefresh transition period, was also a common feeding recommendation by some commonly used ration software programs. Mean nutrient densities of diets categorized as L for Model I (Table 3) are close to previous recommendations by NRC (1989) for dry cows: 1.25 $NE_L$ (Mcal/kg), 12% CP, a minimum of 27% ADF and 35% NDF, and 3% EE. Those values are also similar to what the new NRC (2001) would suggest prior to the depression in DMI during the prefresh transition period. Table 6 summarizes main and polynomial effects of category of animal and dietary factors and interactions of factors with time.

***Time effect.*** Average DMI for all animals was 1.91 and 1.30% of BW on d 21 and 1 prepartum, respectively. DMI decreased 32.2% during the final 3 wk of gestation, and 88.9% of that decline occurred during the final week of gestation ($P < 0.0001$, figure not shown).

***Parity effect.*** Average daily DMI during the final 3 wk of gestation for cows was greater than for heifers (1.88 vs 1.69% of BW, respectively, $P < 0.0001$; Table 6). One could expect greater DMI in heifers than in cows when DMI is expressed as a percentage of BW, because younger animals would have greater nutrient requirements for growth. However, cows had at least one prior lactation, and the capacity of digestive tract increases with lactation (Smith and Baldwin, 1974). If this carries over to the dry period, it may facilitate greater DMI.

The magnitude of DMI depression for heifers and cows was different as they approached parturition (parity × time interaction, $P < 0.0001$; Figure 2A). DMI of cows gradually decreased from 2.06 to 1.36% of BW during the final 3 wk of gestation. The DMI of heifers remained more constant, at about 1.8 to 1.7% of BW from 3 to 1 wk before parturition, and then sharply decreased to 1.23% of BW during the final week of gestation. Marquardt et al. (1977) reported 25 and 52% decreases in DMI for heifers and cows, respectively, during the final 2 wk of gestation. The greater extent of DMI depression during the prefresh transition period of cows compared with that of heifers suggests a greater decrease in energy balance, which may relate to their greater predisposition to postpartum health problems (Curtis et al., 1985).

***Body condition effect.*** BCS score affected DMI ($P < 0.005$; Table 6). DMI was decreased linearly as BCS increased ($P < 0.0007$), and was 1.84, 1.83, and 1.68% of BW for T, M, and O animals, respectively (Tables 1 and 6). As indicated earlier, an increase in BCS was associated with an increase in BW. However, as a percentage of fat-free BW, digestive tract capacity of O cows does not differ from T cows (Doreau et al., 1985). This suggests that differences in DMI due to BCS are probably not related to gut fill and reflect the ratio of body mass to digestive tract capacity.

The magnitude of DMI depression differed by BCS as animals approached parturition (BCS × time interaction, $P < 0.006$; Figure 2B). DMI of O animals continuously and gradually decreased during the final 3 wk of gestation, whereas DMI of T and M animals remained relatively constant from 3 to 1 wk before parturition, and then decreased sharply during the final week of gestation. Total DMI depression during the final 3 wk of gestation was 28, 29, and 40% for T, M, and O, respectively. Body condition at parturition may impact postpartum health, lactation, and reproduction (Treacher et al., 1986). Thin animals may experience inefficient reproductive performance (Heuer et al., 1999) and have low peak milk yield (Frood and Croxton, 1978). Lack

**Table 6.** Effect of animal and dietary factors on DMI during final 21 d of gestation in Holsteins.[1]

| | Animal and dietary factors | | | | | |
|---|---|---|---|---|---|---|
| Category or level | Parity | BCS | RUP | RDP | NDF | EE |
| | DMI, % of BW | | | | | |
| Heifer | 1.69 ± 0.04 | — | — | — | — | — |
| Cow | 1.88 ± 0.04 | — | — | — | — | — |
| Thin | — | 1.84 ± 0.05 | — | — | — | — |
| Medium | — | 1.83 ± 0.04 | — | — | — | — |
| Obese | — | 1.68 ± 0.05 | — | — | — | — |
| Low | — | — | 1.83 ± 0.06 | 1.73 ± 0.04 | 2.03 ± 0.06 | 1.93 ± 0.05 |
| Moderate | — | — | 1.80 ± 0.04 | 1.84 ± 0.04 | 1.68 ± 0.03 | 1.71 ± 0.03 |
| High | — | — | 1.72 ± 0.03 | 1.78 ± 0.05 | 1.64 ± 0.04 | 1.72 ± 0.05 |
| Statistical significance, $P$[2] | | | | | | |
| Main effect | <0.0001 | 0.005 | 0.06 | 0.02 | <0.0001 | <0.0001 |
| Interaction with time | <0.0001 | 0.006 | 0.003 | <0.0001 | 0.14 | 0.09 |
| Linear effect | — | 0.0007 | 0.02 | 0.45 | <0.0001 | 0.04 |
| Quadratic effect | — | 0.06 | 0.60 | 0.005 | 0.0002 | <0.0001 |

[1]Data were generated using Model I and the discrete database in which nutrients were categorized as low, moderate, and high. Time effect was $P < 0.0001$. Whole-plot and subplot variances were 0.13 and 0.09, respectively. Values for animal and dietary factors are least square means ± SE.

[2]Probability values were by Satterthwaite approximation.

of mobile fat reserves force T animals to meet nutrient demands by increasing voluntary intake (Garnsworthy and Topps, 1982; Holter et al., 1990). Treacher et al. (1986) reported that sluggish appetites of O animals continued during early lactation and consequently, greater fat mobilization occurred, which may predispose them to metabolic disorders (Curtis et al., 1985).

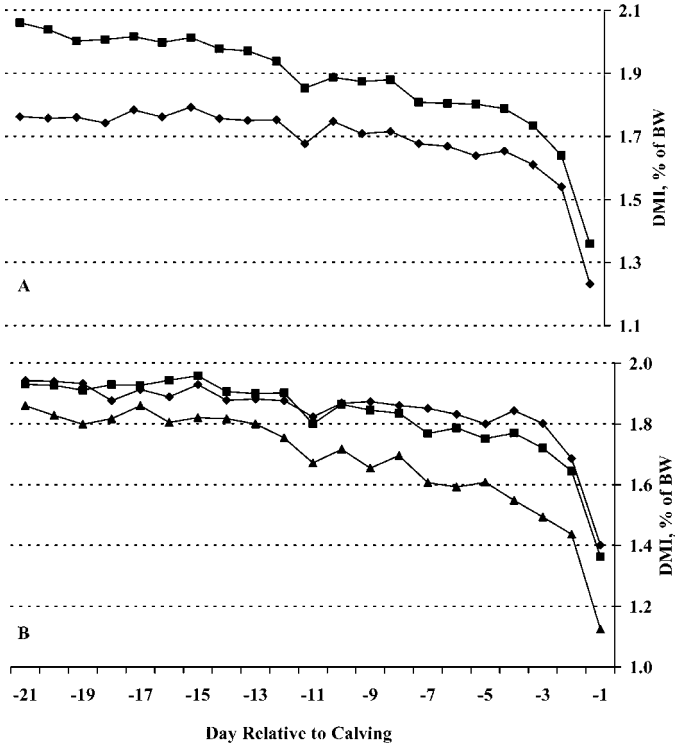


**Figure 2.** Daily DMI (% of BW) of (A) prefresh Holstein heifers (n = 172, ▲) and cows (n = 527, ■), and of (B) prefresh transition Holsteins with BCS (mean ± SD) of 2.84 ± 0.23 (n = 96, ◆), 3.57 ± 0.25 (n = 516, ■), and 4.36 ± 0.22 (n = 79, ▲).

***Protein effect.*** There were no main ($P < 0.38$), linear ($P < 0.18$), or quadratic ($P < 0.68$) effects of CP on DMI when CP replaced RUP and RDP in Model I (data not shown). DMI was 1.73, 1.74, and 1.79% of BW for animals fed diets categorized as L, M, and H CP, respectively (Table 3). The magnitude of DMI depression as animals approached parturition tended to decrease with increasing level of CP (CP × time interaction, $P < 0.09$; figure not shown), and was 34, 27.4, and 29.9% for animals fed diets categorized as L, M, and H CP, respectively.

Dietary RUP concentrations tended to affect DMI ($P < 0.06$; Table 6). DMI decreased linearly as level of RUP increased ($P < 0.02$), and was 1.83, 1.80, and 1.72% of BW for animals fed diets categorized as L, M, and H RUP, respectively (Tables 3 and 6). An interaction between RUP and time indicated that the linear effect of RUP on DMI diminished as parturition approached ($P < 0.003$; Figure 3A). The linear decrease in DMI by increasing level of RUP may suggest that feeding animals diets containing L RUP (3.5 ± 0.2%) is sufficient to meet AA requirements for fetal and maternal tissues during the final 3 wk of gestation. Alternatively, diets high in RUP may be less palatable.

Dietary RDP concentrations affected DMI ($P < 0.02$; Table 6). DMI increased quadratically as level of RDP increased ($P < 0.005$), and was 1.73, 1.84, and 1.78% of BW for animals fed diets categorized as L, M, and H RDP, respectively (Tables 3 and 6). Similarly, an interaction between RDP and time indicated that the qua-

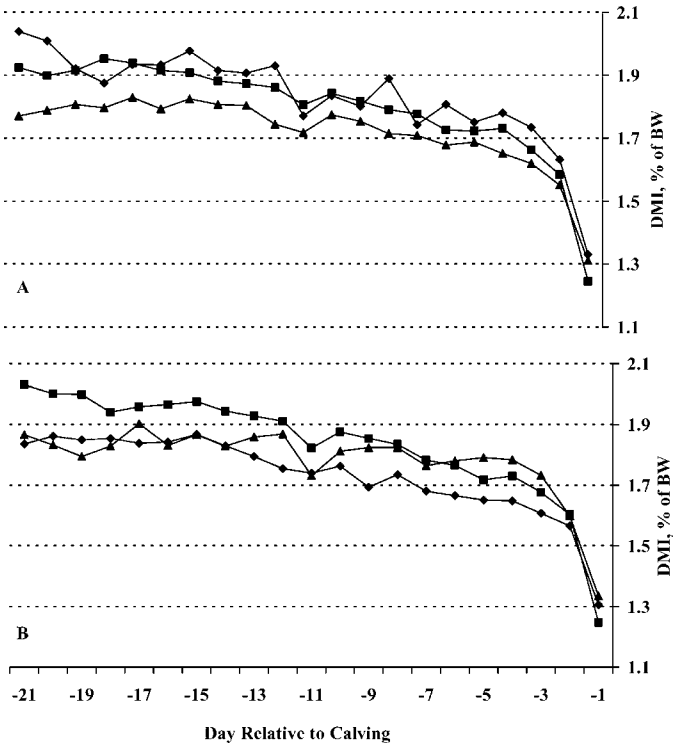


**Figure 3.** Daily DMI (% of BW) of (A) prefresh transition Holsteins fed diets containing (mean ± SD) 3.5 ± 0.2 (n = 53, ◆), 4.5 ± 0.3 (n = 365, ■), and 5.7 ± 0.4% (n = 281, ▲) RUP, and (B) those fed diets containing 8.5 ± 0.4 (n = 234, ◆), 9.8 ± 0.7 (n = 352, ■), and 12.9 ± 1.3% (n = 113, ▲) RDP.

dratic effect of RDP on DMI diminished as parturition approached ($P < 0.0001$; Figure 3B). The quadratic increase in DMI by increasing level of RDP may indicate that feeding animals diets containing M RDP (9.8 ± 0.7%) during the final 3 wk of gestation optimizes microbial protein synthesis and meets nitrogen demand for rumen microbes. Feeding animals higher amounts of RDP may result in increased rumen ammonia concentration that may detrimentally affect rumen fermentation and adversely influence DMI (Cameron et al., 1991; Choung and Chamberlein, 1995).

Efficient protein nutrition in ruminants depends on consumption of RUP and RDP to support optimal rumen fermentation and microbial protein yield and provide metabolizable protein for utilization by body and fetal tissues (Leng and Nolan, 1984). Results of protein nutrition studies are often inconclusive and ambiguous, mainly because of confounding effects when changing RUP or RDP concentration of diets while maintaining a constant level of CP. Putnam and Varga (1998) fed prefresh transition cows isoenergetic diets containing 10.6, 12.7, and 14.5% CP (4.0, 4.8, and 5.5% RUP and 6.6, 7.9, and 9% RDP, respectively). They reported that increasing protein concentration did not affect DMI (both kg/d and % of BW), and that increased nitrogen intake was associated with increased urinary and fecal excretion, increased maternal retention, and decreased efficiency of nitrogen utilization. In another study, Putnam et al. (1999) reported no difference in DMI (both kg/d and % of BW) between prefresh transition cows fed a diet containing 17.8% CP (6.7% RUP and 11.1% RDP) and those fed a diet containing 13.3% CP (4.8% RUP and 8.5% RDP). Wu et al. (1997) offered isonitrogenous diets (14% CP) and showed that there was no difference in DMI between prefresh transition cows fed a diet containing 4.7% RUP and 9.3% RDP and those fed a diet containing 5.8% RUP and 8.2% RDP. Hartwell et al. (2000) examined the effects of RUP without the confounding effects of decreased RDP and reported no change in DMI of prefresh transition dairy cows fed diets containing either 4.0% RUP (14.1% CP and 10.0% RDP) or 6.2% RUP (16.2% CP and 9.9% RDP). They also showed that animals previously fed the diet containing high RUP had lower DMI and milk yield during early lactation than those previously fed the diet containing low RUP.

***Carbohydrate effect.*** Dietary NDF concentrations affected DMI ($P < 0.0001$; Table 6). DMI decreased linearly ($P < 0.0001$) and quadratically ($P < 0.0002$) as level of NDF increased and was 2.03, 1.68, and 1.64% of BW for animals fed diets categorized as L, M, and H NDF, respectively (Tables 3 and 6). A tendency for a NDF × time interaction suggests that DMI depression before parturition may be physiologically mediated and partially independent from the rumen-filling effect of increasing dietary NDF concentration ($P < 0.14$; Figure 4A).

Flipot et al. (1998) offered concentrates as 75 or 25% of TMR to dairy cows during the dry period and reported greater intake by animals fed diets containing 75% concentrate. Olsson et al. (1998) reported higher DMI prepartum and postpartum by dairy cows fed a diet containing 27.4% NDF than by those fed a diet containing 31.5% NDF during the final week of gestation. Increasing dietary NDF concentrations can adversely affect DMI by limiting gut fill (Forbes, 1996; Allen, 2000). Greater DMI of animals fed diets categorized as L NDF (29.7 ± 1.2%) or H NFC (42.1 ± 3.1%) could be related to elimination of rumen distention. Feeding highly fermentable carbohydrates may favor greater intake by stimulating papillae (Dirksen et al., 1985) and microbial growth (Forbes, 1996; Allen, 2000). Papillae growth increases surface area and VFA absorptive capacity of the rumen epithelium (Dirksen et al., 1985). This possibly prevents accumulation of VFA, decreased ruminal pH, adverse affects on rumen microflora and fermentation, and feed intake.

An optimal dietary NDF concentration for prefresh transition dairy cows has not been defined. In this study, EI was at maximum when the NDF:NFC ratio in the diets was equal to 0.78 (EI, Mcal/d = 23.50 − 4.30·[NDF:NFC] + 0.39·[NDF:NFC]$^2$, $R^2$ = 0.11, $P$ < 0.0001, and DMI, % of BW = 1.87 − 0.09·[NDF:NFC], $R^2$ = 0.15, and $P$ < 0.0001). Feeding cows diets with insufficient NDF may compromise rumen function and possibly lead to displaced abomasum (Cameron et al., 1998), acidosis (Nocek, 1997), laminitis (Clarkson et al., 1996), mammary gland edema (Greenhalgh and Gardner, 1958; Emery et al., 1969), and parturient paresis (Emery et al., 1969).

***Fat effect.*** Dietary EE concentrations affected DMI ($P$ < 0.0001; Table 6). DMI decreased linearly ($P$ < 0.04) and quadratically ($P$ < 0.0001) as the level of EE increased, and was 1.93, 1.71, and 1.72% of BW for animals fed diets categorized as L, M, and H EE, respectively (Tables 3 and 6). The difference in EE concentrations between L (2.0 ± 0.2) and M (3.2 ± 0.5) was much less than that between M (3.2 ± 0.5) and H (5.7 ± 1.0). However, the difference in DMI response for the former interval was much greater than for the latter interval (Tables 3 and 6). Dietary EE concentrations tended to affect the magnitude of DMI depression differently as gestation advanced (EE × time interaction, $P$ < 0.09; Figure 4B). Depression in DMI during the final 3 wk of gestation was 19, 27, and 32% for animals fed diets categorized as L, M, and H EE, respectively.

Effects of supplemental fat on DMI are typically negative and have been extensively studied in numerous studies involving lactating cows (Palmquist and Jenkins, 1980; Allen, 2000). Mechanisms by which supplemental fat decreases DMI, particularly in prefresh transition dairy cows, have not been elucidated. Devendra and Lewis (1974) reported that fat feeding may adversely affect DMI by coating fiber, and consequently, preventing bacteria from being in close proximity for fiber digestion; adversely affecting growth of fiber-digesting microbes; and causing formation of insoluble calcium soaps, which decrease the availability of calcium for microbial activity and fiber degradation. Feeding fat may also influence acceptability of diet, gut motility, and hormonal status (i.e., insulin and cholecystokinin as summarized for lactating cows (Palmquist and Jenkins, 1980; Allen, 2000).

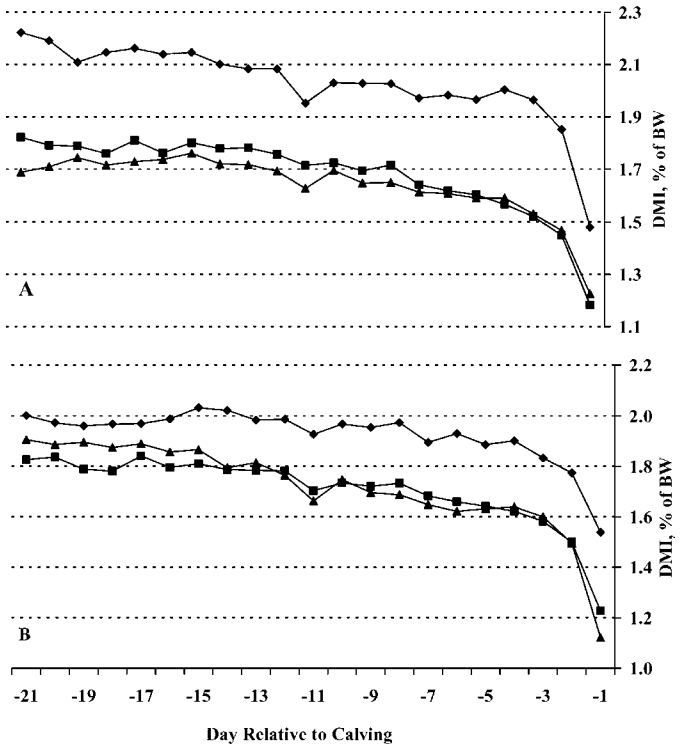


**Figure 4.** Daily DMI (% of BW) of (A) prefresh transition Holsteins fed diets containing (mean ± SD) 29.7 ± 1.2 (n = 128, ◆), 42.5 ± 5.2 (n = 498, ■), and 53.6 ± 4.1% (n = 137, ▲) NDF, and (B) those fed diets containing 2.0 ± 0.2 (n = 80, ◆), 3.2 ± 0.5 (n = 543, ■), and 5.7 ± 1.2% (n = 76, ▲) ether extract.

## Interactions Between Animal and Dietary Factors and Among Dietary Factors

The second discrete database, in which dietary factors were categorized as BM and AM, was used for Model II to determine interactions between animal and dietary factors and among dietary factors. In the reduced form of this model, there were no significant interactions involving more than three factors. Significant three-way interactions were BCS × RUP × NDF ($P$ < 0.006), NDF × RUP × RDP ($P$ < 0.001), and RUP × NDF × EE ($P$ < 0.03). Unless reported below, there were no other significant interactions between animal and dietary factors and among dietary factors obtained in the whole-plot of Model II. Significant three-way interactions were difficult to interpret and were not helpful for explaining two-way interactions. Therefore, they will not be discussed.

***Interactions between animal and dietary factors.*** There was an interaction between parity and level of EE ($P$ < 0.001; Figure 5A). Increasing EE from BM to AM caused a more dramatic decrease in DMI for heifers than for cows. DMI of heifers and cows was 1.71 and 1.81% of BW, respectively, when they were fed diets categorized as BM EE. DMI of heifers and cows was 1.25 and 1.70% of BW, respectively, when they were fed diets categorized as AM EE. To our knowledge, such an interaction has not been previously reported in the literature. Because feeding fat is more common during lactation than during heifer growth, cows are more likely than heifers to have been previously exposed to

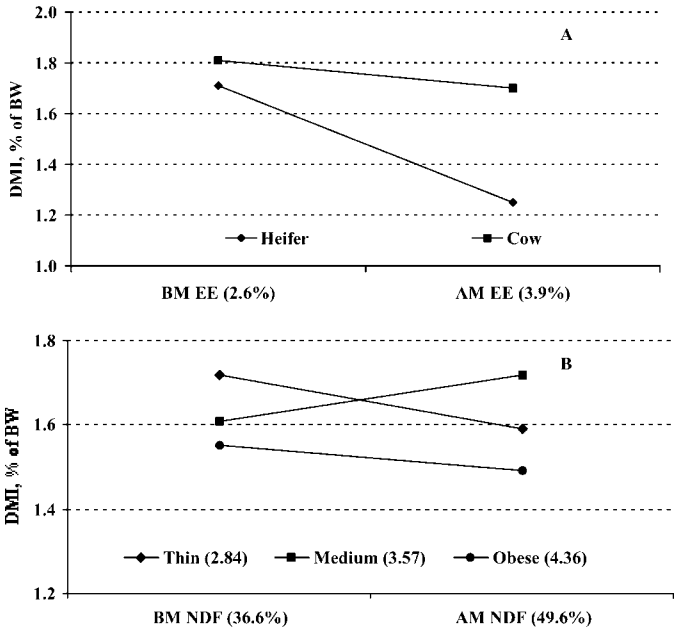


**Figure 5.** Effects of interactions between (A) parity and dietary ether extract (EE) concentration (n = 75 and 251 for heifers and cows fed diets categorized as below the mean (BM) EE, and 97 and 276 for heifers and cows fed diets categorized as above the mean (AM) EE, respectively), and (B) between BCS and dietary NDF concentration (n = 45, 235, and 45 for thin, moderate, and obese animals fed diets categorized as BM NDF and 51, 281, and 34 for thin, moderate, and obese animals fed diets categorized as AM NDF, respectively) on DMI during the final 3 wk of gestation in Holsteins.

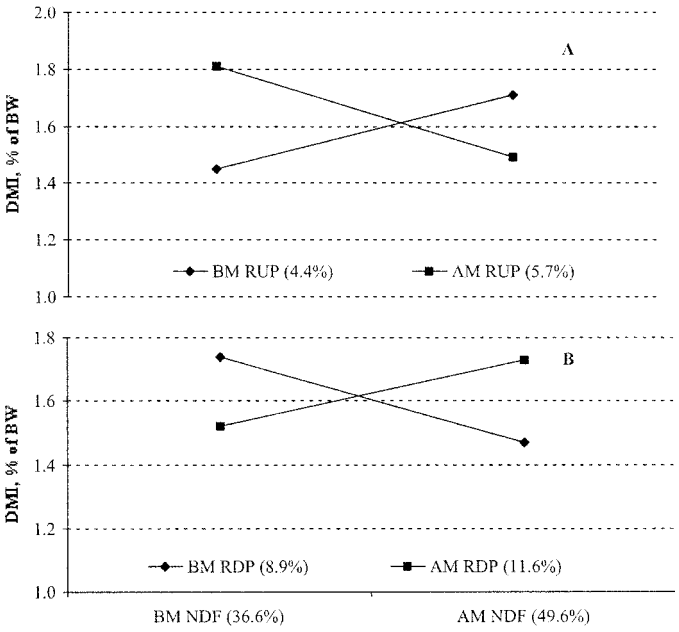


**Figure 6.** Effects of interactions between (A) dietary concentrations of RDP and NDF (n = 180, 274, 150, and 95 for animals fed diets categorized as below mean (BM) RDP–BM NDF, BM RDP–above mean (AM) NDF, AM RDP–BM NDF, and AM RDP–AM NDF, respectively), and (B) between dietary concentrations of RUP and NDF (n = 151, 267, 179, and 102 for animals fed diets categorized as BM RUP–BM NDF, BM RUP–AM NDF, AM RUP–BM NDF, and AM RUP–AM NDF, respectively) on DMI during the final 3 wk of gestation in Holsteins.

supplemental fat. Therefore, the greater decrease in DMI by heifers than cows when increasing EE may reflect differences in acceptability of the EE. Palmquist and Conrad (1978) fed Holsteins and Jerseys diets containing 3.18, 5.73, 5.93, or 10.80% EE, and reported that DMI, expressed as a percentage of BW, declined to a greater extent in Jerseys than in Holsteins as dietary EE concentration increased. Although breed was a confounding factor in their study, the data may indicate that energy intake is more likely to be limited by feeding supplemental fat to small-framed cows compared with large-framed cows.

As reported earlier, DMI decreased linearly as BCS increased ($P < 0.0007$, Table 6). However, there was an interaction between BCS and level of NDF ($P < 0.01$; Figure 5B). Increasing NDF from BM to AM decreased DMI for T and O animals from 1.72 to 1.59 and from 1.55 to 1.49% of BW, respectively, and increased DMI for M animals from 1.61 to 1.72% of BW. We have no explanation for this interaction.

***Interactions among dietary factors.*** There was an interaction between levels of NDF and RUP ($P < 0.00001$; Figure 6A). When the diets contained BM NDF, DMI of animals fed diets categorized as BM and AM RUP was 1.45 and 1.81% of BW, respectively. When the diets contained AM NDF, DMI for animals fed diets categorized as BM and AM RUP was 1.71 and 1.49% of BW, respectively.

The interaction pattern between dietary NDF and RDP levels was the opposite of that between dietary NDF and RUP levels ($P < 0.0001$; Figure 6B). When the diets contained BM levels of NDF, the DMI of animals fed diets categorized as BM and AM RDP was 1.74 and 1.52% of BW, respectively. When the diets contained AM NDF, the DMI for animals fed diets categorized as BM and AM RDP was 1.47 and 1.73%, respectively.

Balancing rations for carbohydrate and protein is important to optimize rumen fermentation and synchronize microbial protein synthesis (Hoover and Stokes, 1991). Interactions between RDP and RUP with NDF observed in this study contradict the expectation that low NDF and high RDP may increase microbial protein synthesis and DMI (Clark et al., 1992). Casper and Schingoethe (1989) reported that increasing solubility of carbohydrate and CP increased DMI and milk yield. Stokes et al. (1991) fed lactating cows isonitrogenous diets (18.4% CP) containing 9.0, 11.8, and 13.8% RDP

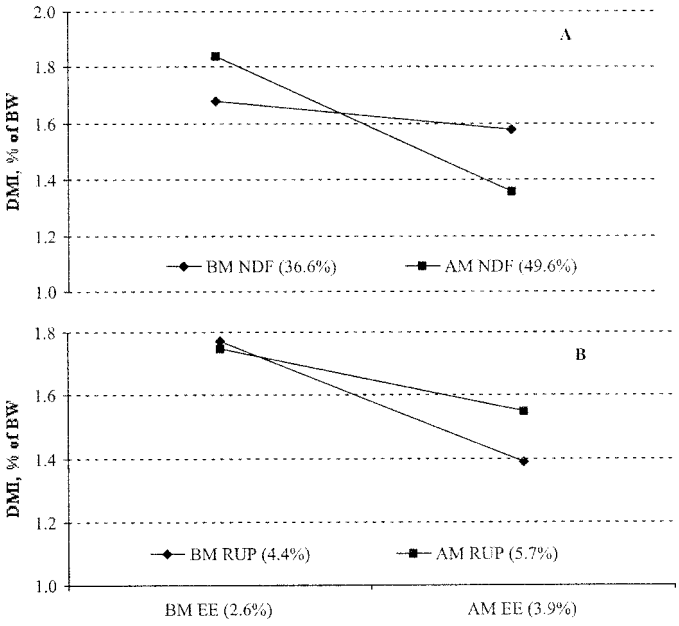


**Figure 7.** Effects of interactions between (A) dietary concentrations of NDF and EE (n = 117, 209, 213, and 160 for animals fed diets categorized as below mean (BM) EE-BM NDF, BM EE-above mean (AM) NDF, AM EE-BM NDF, and AM EE-AM NDF, respectively), and (B) between dietary concentrations of RUP and EE (n = 216, 110, 202, and 171 for animals fed diets categorized as BM EE–BM RUP, BM EE–AM RUP, AM EE–BM RUP, and AM EE–AM RUP, respectively) on DMI during the final 3 wk of gestation in Holsteins.

and 39.9, 33.1, and 27.4% NDF. There was no RDP × NDF interaction on DMI, but feeding diets containing more than 9% RDP and less than 39.9% NDF maximized microbial protein flow from the rumen. Zimmerman et al. (1992) also reported no RUP × NDF interaction on DMI of lactating cows fed diets containing 28.2 and 35.8% NDF and 5.3 and 7.8% RUP. The reason for inconsistencies among our results and those of others is unknown. Gastrointestinal tract fill is greater, turnover rates of liquids and solids are slower, and ruminal retention times are longer in dry cows than in lactating cows (Pond et al., 1984), suggesting that strategies to manipulate protein and carbohydrate fermentation for optimal microbial protein synthesis may differ by physiological state.

There was an interaction between levels of EE and NDF ($P < 0.0001$; Figure 7A). When the diets contained BM EE, the DMI of animals fed diets categorized as BM and AM NDF was 1.68 and 1.84% of BW, respectively. When the diets contained AM EE, the DMI for animals fed diets BM and AM NDF was 1.58 and 1.36% of BW, respectively. Adverse effects of fat feeding on fiber degradation in lactating dairy cows have been summarized in several review articles (Palmquist and Jenkins, 1980; Allen, 2000). Moreover, studies involving lactating dairy cows showed that EE × NDF interaction changes depending upon fat type (Palmquist and Jenkins, 1980; Wu et al., 1994) and source of forage (Adams et al., 1995). It was proposed that adverse effects of fat supplementation may decrease as dietary NDF increases (Palmquist and Jenkins, 1980). In contrast, our results indicated that increasing EE depressed DMI to a greater extent when animals were fed diets containing AM NDF (49.6 ± 4.5%) compared to when animals were fed diets containing BM NDF (36.6 ± 4.7%). Elliott et al. (1995) reported a similar interaction pattern when lactating cows were fed diets containing 33.7 and 44.5% NDF and 2.8 and 5.5% EE.

There was an interaction between levels of EE and RUP ($P < 0.03$; Figure 7B). When the diets contained BM EE, the DMI of animals fed diets categorized as BM and AM RUP was 1.77 and 1.75% of BW, respectively. When the diets contained AM EE, the DMI for animals fed diets categorized as BM and AM RUP was 1.39 and 1.55% of BW, respectively. Palmquist et al. (1993) reported that supplementation of 5% of tallow depressed microbial protein synthesis. However, addition of an 8% mixture of blood meal and hydrolyzed feather meal (1:1) compensated for depressed microbial protein synthesized in the rumen by increasing total nitrogen intake, duodenal AA nitrogen flow, and absorption of Ile, Leu, Met, and Lys. Feeding a higher level of RUP may be necessary to maintain AA flow to the duodenum when animals are fed supplemental fat if there is a decrease in fiber digestion, microbial protein synthesis, or DMI.

## CONCLUSIONS

Day of gestation, parity, BCS, and concentrations of organic macronutrients were systematically evaluated as potential factors that may influence DMI during the prefresh transition period. Of the factors we studied, day of gestation, parity, BCS, and concentrations of NDF and EE in the diet accounted for the greatest proportion of variation in DMI. However, the $R^2$ of the multivariate model was only 0.18. Variation among experiments in methodologies for body condition scoring and determination of nutrient content of diets may partially account for the low $R^2$. DMI decreased by 32.2% during the final 3 wk of gestation and 88.9% of that decline occurred during the final week of gestation. Cows consumed greater DMI than heifers. DMI was not affected by CP; linearly decreased by BCS, RUP, NDF, and EE, and quadratically increased by RDP. Increasing NDF for O and T animals and EE for heifers caused lower DMI. Moreover, NDF × RUP and NDF × RDP interactions on DMI were the opposite of those observed in lactating cows. Increasing dietary EE was

accompanied by greater DMI when the diets contained AM RUP or BM NDF. Factors and interactions that affect DMI identified by this study may be helpful when developing feeding strategies for prefresh transition dairy cows.

## ACKNOWLEDGMENTS

The authors would like to thank D. K. Beede, M. J. VandeHaar, L. H. Kilmer, J. K. Drackley, D. J. Carroll, L. A. Holden, G. A. Varga, S. S. Donkin, R. J. Van Saun, and C. J. Sniffen for providing data sets used for this study.

## REFERENCES

Adams, A. L., B. Harris Jr., H. H. Van Horn, and C. J. Wilcox. 1995. Effects of varying forage types on milk production responses to whole cottonseed, tallow, and yeast. J. Dairy Sci. 78:573–581.

Allen, M. S. 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. J. Dairy Sci. 83:1598–1624.

Allen, S. K., D. J. Carroll, and B. A. Barton. 1995. The effects of the sources of supplemental energy pre- and postpartum on lactation and reproductive performance of dairy cattle. J. Dairy Sci. 78 (Suppl 1):164. (Abstr.)

Bell, A. W. 1995. Regulation of organic nutrient metabolism during transition from late pregnancy to early lactation. J. Anim. Sci. 73:2804–2819.

Bell, A. W. 1996. The transition cow: The actualized homeorrhesis. Pages 150–157 in Proc. Cornell Nutr. Conf. Feed Manuf. Ithaca, NY.

Bertics, S. J., R. R. Grummer, C. Cadorniga-Valino, and E. E. Stoddard. 1992. Effect of prepartum dry matter intake on liver triglyceride concentration and early lactation. J. Dairy Sci. 75:1914–1922.

Cameron, R. E. B., P. B. Dyk, T. H. Herdt, J. B. Kaneene, R. Miller, H. F. Bucholtz, J. S. Liesman, M. J. VandeHaar, and R. S. Emery. 1998. Dry cow diet, management, and energy balance as risk factors for displaced abomasum in high producing dairy herds. J. Dairy Sci. 81:132–139.

Cameron, M. R., T. H. Klusmeyer, G. L. Lynch, J. H. Clark, and D. R. Nelson. 1991. Effects of urea and starch on rumen fermentation, nutrient passage to the duodenum, and performance of cows. J. Dairy Sci. 74:1321–1336.

Carmer, S. G., and R. D. Seif. 1963. Calculation of orthogonal coefficients when treatments are unequally replicated and/or unequally spaced. Agron. J. 55:387–389.

Casper, D. P., and D. J. Schingoethe. 1989. Lactational response of dairy cows to diets varying in ruminal solubilities of carbohydrate and crude protein. J. Dairy Sci. 72:928–941.

Chatterjee, S., and B. Price. 1991. Regression Analysis by Example. 2nd ed. John Wiley & Sons Co., New York, NY.

Choung, J., and D. G. Chamberlain. 1995. Effects of intraruminal infusion of propionate on the concentrations of ammonia and insulin in peripheral blood of cows receiving an intraruminal infusion of urea. J. Dairy Res. 62:549–557.

Clark, J. H., T. H. Klusmeyer, and M. R. Cameron. 1992. Microbial protein synthesis and flows of nitrogen fractions to the duodenum of dairy cows. J. Dairy Sci. 75:2304–2323.

Clarkson, M., D. Downham, W. Faull, J. Hughes, F. Manson, R. Murray, W. Russell, J. Sutherst, and W. Ward. 1996. Incidence and prevalence of lameness in dairy cattle. Vet. Rec. 138:563–567.

Correa, M. T., C. R. Curtis, H. N. Erb, J. M. Scarlett, and R. D. Smith. 1990. An ecological analysis of risk factors for postpartum disorders of Holstein-Friesian cows from thirty-two New York farms. J. Dairy Sci. 73:1515–1524.

Curtis, C. R., H. N. Erb, C. J. Sniffen, R. D. Smith, and D. S. Kronfeld. 1985. Path analysis of dry period nutrition, postpartum metabolism and reproductive disorders, and mastitis in Holstein cows. J. Dairy Sci. 68:2347–2360.

Dann, H. M, G. A. Varga, and D. E. Putnam. 1999. Improving energy supply to late gestation and early postpartum dairy cows. J. Dairy Sci. 82:1765–1778.

Deluyker, H. A., J. M. Gay, L. D. Weaver, and A. S. Azari. 1991. Change of milk yield with clinical diseases for a high producing dairy herd. J. Dairy Sci. 74:436–445.

Devendra, C., and D. Lewis. 1974. The interaction between dietary lipids and fibre in the sheep. Anim. Prod. 19:67–76.

Dirksen, G., H. Liebich, and K. Mayer. 1985. Adaptive changes of the ruminal mucosa and functional and clinical significance. Bov. Prac. 20:116–120.

Doreau, M., J. Robelin, and A. Lestrade. 1985. Effects of physiological state and body fatness on digestive-tract weight and composition in the dairy cow. Lives. Prod. Sci. 12:379–385.

Duncan, J. S. 1998. Role of phosphoenolpyruvate carboxykinase in periparturient and ketotic dairy cows. M.S. Thesis, Oregon State University, Corvallis.

Eastridge, M. L., H. F. Bucholtz, A. L. Slater, and C. S. Hall. 1998. Nutrient requirements for dairy cattle of the National Research Council versus some commonly used ration software. J. Dairy Sci. 81:3049–3062.

Elliott, J. P., J. K. Drackley, G. C. Fahey, Jr., and R. D. Shanks. 1995. Utilization of supplemental fat by dairy cows fed diets varying in content of nonstructural carbohydrates. J. Dairy Sci. 78:1512–1525.

Erb, H. N., R. D. Smith, P. A. Oltenacu, C. L. Guard, R. B. Hilman, P. A. Powers, M. C. Smith, and M. E. White. 1985. Path model of reproductive disorders and performance, milk fever, mastitis, milk yield, and culling in Holstein cows. J. Dairy Sci. 68:3337–3349.

Erb, H. N., and Y. T. Grohn. 1988. Epidemiology of metabolism disorders in the periparturient dairy cow. J. Dairy Sci. 71:2557–2571.

Edmonson, A. J., I. J. Lean, L. D. Weaver, T. Farver, and G. Webster. 1989. A body condition scoring chart for Holstein dairy cows. J. Dairy Sci. 72:68–78.

Emery, R. S., H. D. Hafs, D. Armstrong, and W. W. Snyder. 1969. Prepartum grain feeding effects on milk production, mammary edema, and incidence of diseases. J. Dairy Sci. 52:345–351.

Flipot, P. M., G. L. Roy, and J. J. Dufuour. 1988. Effect of peripartum energy concentration on production performance of Holstein cows. J. Dairy Sci. 71:1840-1850.

Forbes, J. M. 1996. Integration of regulatory signals controlling forage intake in ruminants. J. Anim. Sci. 74:3029-3035.

Frood, M. J., and D. Croxton. 1978. The use of condition-scoring in dairy cows and its relationship with milk yield and live weight. Anim. Prod. 27:285–291.

Garnsworthy, P. C., and J. H. Topps. 1982. The effect of body condition of dairy cows at calving on their food intake and performance when given complete diets. Anim. Prod. 35:113–119.

Greenfield, R. B., M. J. Cecava, T. R. Johnson, and S. S. Donkin. 2000. Impact of dietary protein amount and rumen undegradability on intake, peripartum liver triglyceride, plasma metabolites, and milk production in transition dairy cattle. J. Dairy Sci. 83:703–710.

Greenhalgh, J. F. D., and K. E. Gardner. 1958. Effect of heavy concentrate feeding before calving upon lactation and mammary gland edema. J. Dairy Sci. 41:822–829.

Grum, D. E., J. K. Drackley, R. S. Younker, D. W. LaCount, and J. J. Veenhuizen. 1996. Nutrition during the dry period and hepatic lipid metabolism of periparturient dairy cows. J. Dairy Sci. 79:1850–1864.

Grummer, R. R. 1995. Impact of changes in organic nutrient metabolism on feeding the transition dairy cow. J. Anim. Sci. 73:2820–2833.

Grummer, R. R., P. C. Hoffman, M. L. Luck, and S. J. Bertics. 1995. Effect of prepartum and postpartum dietary energy on growth and lactation of primiparous cows. J. Dairy Sci. 78:172–180.

Hartwell, J. R., M. J. Cecava, and S. S. Donkin. 2000. Impact of dietary rumen undegradable protein and rumen-protected choline on intake, peripartum liver triglyceride, plasma metabolites, and

milk production in transition dairy cows. J. Dairy Sci. 83:2907–2917.
Hayirli, A. 1997. Effects of protein nutrition during the periparturient period on milk yield and health status of dairy cows. M.S. Thesis, Iowa State University, Ames.
Heuer, C., Y. H. Schukken, and P. Dobbelaar. 1999. Postpartum body condition score and results from the first test day milk as predictors of disease, fertility, yield, and culling in commercial dairy herds. J. Dairy Sci. 82:295–304.
Holter, J. B., M. J. Slotnick, H. H. Hayes, C. K. Bozak, W. E. Urban Jr., and M. L. McGilliard. 1990. Effect of prepartum dietary energy on condition score, postpartum energy, nitrogen partitions, and lactation responses. J. Dairy Sci. 73:3502–3511.
Hoover, W. H., and S. R. Stokes. 1991. Balancing carbohydrates and proteins for optimum rumen microbial yield. J. Dairy Sci. 74:3630–3644.
Lawrence, T. L. J. 1988. Feeding value of cereals and concentrates. World Anim. Sci. 4:129-150.
Leng, R. A., and J. V. Nolan. 1984. Nitrogen metabolism in the rumen. J. Dairy Sci. 67:1072–1089.
Littell, C. R., G. A. Milliken, W. W. Stroup, and F. D. Wolfinger. 1996. SAS System for Mixed Models. SAS Inst., Inc., Cary, NC.
Marquardt, J. P., R. L. Horst, and N. A. Jorgensen. 1977. Effect of parity on dry matter intake at parturition in dairy cattle. J. Dairy Sci. 60:929–934.
Minor, D. J., S. L. Trower, B. D. Strang, R. D. Shaver, and R. R. Grummer. 1998. Effects of nonfiber carbohydrate and niacin on periparturient metabolic stats of lactation dairy cows. J. Dairy Sci. 81:189–200.
Moore, S. J., M. J. VandeHaar, B. K. Sharma, T. E. Pilbeam, D. K. Beede, H. F. Bucholtz, J. S. Liesman, R. L. Horst, and J. P. Goff. 2000. Effects of altering dietary cation-anion difference on calcium and energy metabolism in peripartum cows. J. Dairy Sci. 83:2095–2104.
National Research Council. 1989. Nutritional Requirements of Dairy Cattle. 6th rev. ed. Natl. Acad. Sci., Washington, DC.
National Research Council. 1996. Nutritional Requirements of Beef Cattle. 7th rev. ed. Natl. Acad. Sci., Washington, DC.
National Research Council. 2001. Nutritional Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Sci., Washington, DC.
Nocek, J. E. 1995. Nutritional aspects of the transition cow. Pages 121–137 in Proc. Cornell Nutr. Conf. Feed Manuf. Ithaca, NY.
Nocek, J. E. 1997. Bovine acidosis: Implications on laminitis. J. Dairy Sci. 80:1005–1028.
Olsson, G., H. Emanuelson, and H. Wiktorsson. 1998. Effects of different nutritional levels prepartum on the subsequent performance of dairy cows. Livest. Prod. Sci. 53:279–290.
Overton, T. R., J. K. Drackley, G. N. Douglas, L. S. Emmert, and J. H. Clark. 1998. Hepatic gluconeogenesis and whole-body protein metabolism of periparturient dairy cows as affected by source of energy and intake of the prepartum diet. J. Dairy Sci. 81(Suppl. 1):295. (Abstr.).
Palmquist, D. L., and H. R. Conrad. 1978. High fat rations for dairy cows: Effects on feed intake, milk and fat production, and plasma metabolites. J. Dairy Sci. 61:890–901.
Palmquist, D. L., and T. C. Jenkins. 1980. Fat in lactation rations: Review. J. Dairy Sci. 63:1–14.
Palmquist, D. L., M. R. Weisbjerg, and T. Hvelplund. 1993. Ruminal, intestinal, and total digestibilities of nutrients in cows fed high in fat and undegradable protein. J. Dairy Sci. 76:1353–1364.
Pond, K. R., L. Goode, E. S. Leonard, and D. L. Mann. 1984. Intake, digesta fill, and flow kinetics pre- and postpartum. Can. J. Anim. Sci. 64(Suppl.):68–70.
Putnam, D. E., and G. A. Varga. 1998. Protein density and its influence on metabolite concentration and nitrogen retention by Holstein cows in late gestation. J. Dairy Sci. 81:1608–1618.
Putnam, D. E., G. A. Varga, and H. M. Dann. 1999. Metabolic and production responses to dietary crude protein and exogenous somatotropin in late gestation dairy cows. J. Dairy Sci. 82:982–995.
Rajala-Schultz, P. J., Y. T. Grohn, and C. E. McCulloch. 1999. Effects of milk fever, ketosis, lameness on milk yield in dairy cows. J. Dairy Sci. 82:288–294.
Reid, I. M., C. J. Roberts, R. J. Treacher, and L. A. Williams. 1986. Effect of body condition at calving on tissue mobilization, development of fatty liver, and blood chemistry of dairy cows. Anim. Prod. 43:7–15.
Roseler, D. K., D. G. Fox, L. E. Chase, A. N. Pell, and W. C. Stone. 1997. Development and evaluation of equations for prediction of feed intake for lactation Holstein dairy cows. J. Dairy Sci. 80:878–893.
SAS User's Guide. Statistics, Version 7 Edition. 1998. SAS Inst., Inc., Cary, NC.
Skaar, T. C., R. R. Grummer, M. R. Dentine, and R. H. Stauffacher. 1989. Seasonal effects of prepartum and postpartum fat and niacin feeding on lactation performance and lipid metabolism. J. Dairy Sci. 72:2028–2038.
Smith, N. E., and R. L. Baldwin. 1974. Effects of breed, pregnancy, and lactation on weight of organs and tissues in dairy cattle. J. Dairy Sci. 57:1055–1060.
Snedecor, W. G., and W. G. Cochran. 1989. Statistical Methods. 8th ed. Iowa State University Press, Ames, IA.
Soder, K. J., and L. A. Holden. 1999. Dry matter intake and milk yield and composition of cows fed yeast prepartum and postpartum. J. Dairy Sci. 82:605–610.
Steel, G. D. R., H. J. Torrie, and A. D. Dickey. 1997. Principles and Procedures of Statistics: A Biometrical Approach. 3rd ed. McGraw-Hill Inc., New York, NY.
Stokes, S. R., W. H. Hoover, T. K. Miller, and R. Blauweikel. 1991. Ruminal digestion and microbial utilization of diets varying type of carbohydrate and protein. J. Dairy Sci. 74:871–881.
Treacher, R. J., I. M. Reid, and C. J. Roberts. 1986. Effect of body condition at calving on the health and performance of dairy cows. Anim. Prod. 43:1–6.
VandeHaar, M. J., G. Yousif, B. K. Sharma, T. H. Herdt, R. S. Emery, M. S. Allen, and J. S. Liesman. 1999. Effect of energy and protein density of prepartum diets on fat and protein metabolism of dairy cattle in the periparturient period. J. Dairy Sci. 82:1282–1295.
Van Saun, J. R. 1991. Dry cow nutrition: The key to improve fresh cow performance. Vet. Clin. N. Am. 7:599–620.
Van Saun, J. R., S. C. Idleman, and C. J. Sniffen. 1993. Effect of undegradable protein amount fed prepartum on postpartum production in first lactation Holstein cows. J. Dairy Sci. 76:236–244.
Vazquez-Anon, M., S. J. Bertics, and R. R. Grummer. 1997. The effect of dietary energy source during mid to late lactation liver triglyceride and lactation performance of dairy cows. J. Dairy Sci. 80:2504–2512.
Wu, Z., J. T. Huber, S. C. Chan, J. M. Simas, K. H. Chen, J. G. Varga, F. Santos, C. Fontes Jr., and P. Yu. 1994. Effect of source and amount of supplemental fat on lactation and digestion in cows. J. Dairy Sci. 77:1644–1651.
Wu, Z., R. J. Fischer, C. E. Polan, and C. G. Schwab. 1997. Lactational performance of cows fed low or high ruminally undegradable protein prepartum and supplemental methionine and lysine postpartum. J. Dairy Sci. 80:722–729.
Young, C. W., V. R. Erdman, and J. K. Reneau. 1985. Animal health and management and their impact on economic efficiency. J. Dairy Sci. 68:1593–1602.
Zimmerman, C. A., A. H. Rakes, T. E. Daniel, and B. A. Hopkins. 1992. Influence of dietary protein and supplemental niacin on lactational performance of cows fed normal and low fiber diets. J. Dairy Sci. 75:1965–1978.