Predicting Ad Libitum Dry Matter Intake and Yields of Jersey Cows[1]

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ABSTRACT

Two data files were used that contained weekly mean values for ad libitum DMI of lactating Jersey cows along with appropriate cow, ration, and environmental traits for predicting DMI. One data file (n = 666) was used to develop prediction equations for DMI because that file represented a number of separate experiments and contained more diversity in potential predictors, especially those related to ration, such as forage type. The other data file (n = 1613) was used primarily to verify these equations. Milk protein yield displaced 4% FCM output as a prediction variable and improved the R^2 by several units but was not used in the final equations, however, for the sake of simplicity. All equations contained adjustments for the effects of heat stress, parity (1 vs. >1), DIM >15, BW, use of recombinant bST, and other significant independent variables. Equations were developed to predict DMI of cows fed individually or in groups and to predict daily yields of 4% FCM and milk protein; equations accounted for 0.69, 0.74, 0.81, and 0.76 of the variation in the dependent variables with standard deviations of 1.7, 1.6, 2.7, and 0.084 kg/d, respectively. These equations should be applied to the development of software for computerized dairy ration balancing.

(**Key words**: intake prediction, Jersey, lactation, dry matter)

Abbreviation key: **DOY** = day of year, **MINTHI** = minimum (nighttime) THI, **THI** = temperature-humidity index.

INTRODUCTION

Dairy ration balancing, whether for individual cows or for a group fed a TMR, first requires an accurate estimate of ad libitum DMI. The ruminant is adapted to forage utilization, and forage NE_L is nearly always cheaper than concentrate NE_L, especially when part of the forage is corn silage; thus, ration balancing must take advantage of the maximum DMI of each cow to maximize forage intake. Improvement of forage quality by decreasing its fiber content not only increases DMI, but also reduces the proportion of concentrate that must be fed. Computing the ratio of required nutrients to ad libitum DMI and then grouping cows based on this criterion minimizes misfeeding individual cows when total mixed diets are fed to a group of cows for ad libitum intake.

In developing equations to predict DMI, one should first decide whether equations will be used to predict DMI for individual cows or to predict for an average (e.g., $\overline{X}$ + 1 SD) cow in a group fed a TMR. Variables selected for possible use must include only those significant predictors for which the value is likely to be known, based on the individual cow in question. Otherwise, users must substitute a mean or general value, thereby converting a prediction variable into a constant; in such case, only the DMI of a few cows, for which that mean or general value was correct, would be predicted correctly.

Roseler et al. (15) recently summarized most of the factors known to affect ad libitum DMI of dairy cows and some of the prominent equations used to compute it. Numerous characteristics of the cow (i.e., ration, management, and environment) affect DMI. Some of these characteristics are not easily quantifiable, and others are not practically available to dairy producers. However, most of the useful predictors of DMI are correlated, to a greater or lesser degree, with other characteristics that may affect DMI, which gives some flexibility in the selection of possible predictors. For example, energy density of the ration affects ad libitum DMI, but energy density also is

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correlated with, and determined by, grain to forage ratio, ration fiber content, and the percentage of forage DM that is corn silage; consequently, when DMI is estimated for individual cows in a herd and the first three traits are not known, the latter measure might be substituted as a general predictor of energy density. Correlations among the multiple predictors possibly could present significant difficulties in model building that could be alleviated only partially by using data from diverse sources or experiments.

Some of the variables more commonly used in prediction equations for DMI of lactating dairy cows are BW and 4% FCM yield (2, 3, 6, 8, 11, 14, 18), milk protein yield (15), DIM (2, 6, 8, 14), week of lactation lag factor (15, 18), ration NDF (14), crude fiber (2), percentage of forage DM that is silage or corn silage (6), BW change (18), ambient temperature (3), and season of year (2, 6).

The DMI of dairy cows may be depressed about 3.3%/C° above 20 to 25°C, and these effects are enhanced by high relative humidity (7, 10). Heat stress occurs in dairy cows when the daily high temperature-humidity index (**THI**) exceeds 72 (1).

Harlan et al. (4) reported that the maximum DMI of forages fed to nonlactating dairy cattle was not very predictable ($r^2 = 0.09$ to 0.46) from dietary fiber; except for legumes, ADF had somewhat higher r^2 than NDF for predicting DMI.

Our objective was to develop equations to predict ad libitum DMI of lactating Jersey cows for use when balancing rations both for individual cows and for groups and to predict 4% FCM and milk protein yields. We chose to work with Jersey data because DMI predictions apparently have not been published for this breed and because suitable data files were available for our use.

MATERIALS AND METHODS

A total of 666 weekly mean observations (105 from primiparous cows) from 58 Jersey cows from the University of Georgia Coastal Plain Experiment Station were used. Of the total observations, 32% were from a bST trial (20), 26% were from a study (19) to test the effect of 0 to 30% wet brewers grains in the ration, and 2% were from a trial to compare cation-anion balances ranging from −79 to 324 meq/kg of Na + K − Cl in dietary DM (21); in addition, 23% were from an unpublished study (J. W. West, 1995, unpublished data) to examine the supplementation of a control diet based on corn silage (4% ether extract) with whole cottonseed (added 3.2% fat), protected fat (added 2% fat), or both (added 5% fat). The remaining unpublished data from the same source (17%) were from a trial in which 0, 19, 38, or 57% of forage DM was from bermudagrass hay in a diet based on corn silage, ground corn, soybean meal, and whole cottonseed.

Cows were fed for ad libitum intake once daily using electronic gate feeders (American Calan, Inc., Northwood, NH). Rations were provided as TMR using a self-propelled, self-unloading, drum mixer with onboard computer, weigh cells, and an orts vacuum (Data Ranger®; American Calan, Inc.). Cows were housed in total confinement with access to individual free stalls. During hot weather, all cows were shaded but had no additional mechanical cooling.

The variables in Table 1 (except NE_L), their square, and (except for characteristics of ration or forage) their natural logarithm were submitted to the multiple regression procedure with stepwise backward elimination (16); a difference of $P < 0.05$ was needed for a variable to stay. Treatment category (1 = none or 2 = bST) also was included in the model. The NE_L variable was not used because of regional differences in the method of computing NE_L of forages. Models were constructed on the assumptions that milk protein content might not always be measured and that feeds are tested for ADF or NDF but usually not for both. Variables used, except THI, generally were those that were available or might be computed easily from DHI, feed analyses, and ration-balancing reports. We also assumed that users would prefer to record only one environmental temperature per day rather than both minimum and maximum temperatures.

Equation [1] (Table 2) was developed first for use in predicting DMI of individually fed, lactating Jersey cows; therefore, variables having to do with the nutrient composition of the final ration of individual cows (e.g., CP, fat, and ADF) were not submitted as possible predictors. Nutrient composition of the diet would vary among individual cows and would not be quantified until DMI was computed and the ration was balanced. Then, Equation [1] was used to predict ad libitum DMI of each cow in the database. Next, we computed the difference in kilograms per day for observed DMI minus predicted DMI and expressed the observed DMI as the percentage of predicted DMI. Equation [2] (Table 2) was constructed in the same way by substituting ration fiber, fat, and CP and forage fiber percentages in place of variables having to do with the percentage of forage DM that was corn silage or any silage (including corn silage). In Equation [3], which predicted 4% FCM yield, the more general (silage) variables were excluded as in Equa-

TABLE 1. Mean and range for variables that were used to develop prediction equations for DMI and significant Pearson correlation coefficients among variables.

Variable	$\overline{X}$	Range	Variable number																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1 DMI, kg/d	15.1	6.4–24.0		−0.37	−0.55	0.21	0.72	0.81	−0.55	−0.62	NS[1]	NS	0.52	0.55	−0.33	−0.38	NS	−0.20	0.41
2 DIM	184	38–356		. . .	0.52	0.31	−0.41	−0.40	0.41	0.36	NS	NS	0.41	0.33	0.14	0.21	0.17	0.23	0.22
3 Day of year	188	102–248			. . .	NS	−0.50	−0.60	0.72	0.71	NS	NS	0.58	0.51	0.36	0.43	0.14	0.27	−0.46
4 BW, kg	443	319–566				. . .	NS	0.16	NS	NS	−0.14	0.17	NS	NS	−0.16	NS	0.29	NS	0.13
5 4% FCM, kg/d	21.0	8.5–43.4					. . .	0.91	−0.38	−0.48	NS	NS	−0.48	−0.47	−0.57	−0.56	0.22	NS	0.59
6 Milk protein, kg/d	0.69	0.34–1.22						. . .	−0.51	−0.60	NS	NS	−0.57	−0.54	−0.52	−0.53	NS	−0.21	0.57
7 MAXTHI[2]	84	70–90							. . .	0.92	NS	NS	0.53	0.49	0.13	0.21	0.15	0.26	−0.26
8 MINTHI[3]	71	55–75								. . .	NS	NS	0.51	0.48	0.25	0.32	NS	0.17	−0.36
9 CP, % of DM	17.5	14.0–19.1									. . .	−0.30	−0.15	0.24	0.27	NS	−0.61	NS	−0.23
10 Fat, % of DM	5.0	3.2–9.0										. . .	NS	−0.23	NS	NS	0.35	−.27	0.53
11 ADF, % of DM	22.2	16.8–26.0											.	0.85	0.51	0.56	0.18	0.48	−0.69
12 NDF, % of DM	38.2	26.3–50.1												. .	0.46	0.48	−0.18	0.35	−0.64
13 Forage ADF, % of DM	12.6	9.0–16.9													.	0.91	−0.34	NS	−0.95
14 Forage NDF, % of DM	21.6	17.3–26.5														. .	−0.32	−0.18	−0.89
15 Corn silage, % of forage DM	87	43–100															. . .	0.54	0.22
16 Silage, % of forage DM	96	43–100																. . .	NS
17 NE_L, Mcal/kg of DM	1.70	1.52–1.82																	. . .

[1] $P > 0.001$.

[2] Maximum daily temperature-humidity index (7) = °F − (0.55 − 0.55 × relative humidity/100) × (°F − 58).

[3] Minimum daily temperature-humidity index.

tion [2]. The model for Equation [4], used to predict milk protein yield, however, was constructed in a manner similar to the model for Equation [1].

Unfortunately, day of year (**DOY**) could not be used as a prediction variable because it was confounded with DIM in the seasonally bred herd used for the development of the database. Equations were selected for further testing based on criteria used by Roseler et al. (15) of high R^2 and low bias. Bias, as used here, was the variance of predicted DMI expressed as a percentage of the variance of the actual (observed) DMI. About two-thirds of predicted DMI observations should fall in the range of the mean and 1 standard deviation.

Each equation then was applied to a Jersey verification database (n = 1613) from Pell et al. (12); means and ranges for variables in this file are presented in Table 3. The difference between observed and predicted DMI or yields was computed as described previously. This difference then was regressed on parity category (1 vs. 2) and the interaction of parity category by treatment (bST) using the larger verification database; the resulting variables and coefficients were added to the original equation. Although the Georgia database generally contained greater breadth of prediction variables, no parity 1 cows were treated with bST. Hence, we had to use the verification file to develop coefficients for the effects of parity and parity by bST treatment on DMI and on yields of FCM and milk protein. Finally, the equation including these parity variables was used to predict DMI or yields of 4% FCM and milk protein, and the difference between actual and predicted values was computed and evaluated for variance and divergence from zero.

RESULTS AND DISCUSSION

The range in each variable (Table 1) except DOY was sufficient for regression analysis. Data <38 DIM were not available, which was not considered to be a handicap because DHI input information often is not available to producers before approximately 16 to 20 DIM on average. Because of seasonal breeding, our measurement of season effect (DOY) was correlated with DIM (r = 0.52); we elected not to use DOY for prediction because THI also was in the model and was correlated (r = 0.71) with DOY and because the range in DOY was too narrow.

As noted also by Roseler et al. (15), milk protein yield was correlated more closely with DMI than was FCM (r = 0.81 vs. 0.72). Ration NDF exhibited a slightly higher correlation with DMI than did ADF (r

TABLE 2. Regression equations[1] for predicting ad libitum DMI (kilograms per day) of lactating Jersey cows when fed individually (Equation [1]) and when fed a total mixed diet in groups (Equation [2]) and equations for predicting yields (kilograms per day) of 4% FCM and milk protein.

	Regression coefficients			
Item[2]	DMI	DMI	4% FCM	Milk protein
Equation number	[1]	[2]	[3]	[4]
Intercept	−4715.60	−6854.49	5906.22	340.2709
(1 vs. 2)	−0.552	−0.6106	1.791	0.0541
Trt (1 = none; 2 = bST)	−1.557	−1.184	3.431	0.07372
L × Trt	0.559	0.544	−1.480	−0.02627
DIM	−0.022	−0.01865	. . .	. . .
(DIM)^2	. . .	. . .	−0.00003564	−0.00000078
ln DIM	3.679	3.595	. . .	. . .
BW, kg	. . .	−1.0326	2.5284	0.1302
(BW)^2	0.00001571	0.000626	−0.001563	−0.00007765
ln BW	. . .	214.58	−506.34	−26.909
FCM, kg/d	0.3274	0.3730		
(FCM)^2	. . .	. . .		
ln FCM	. . .	. . .		
Corn silage	0.2458			0.008259
(Corn silage)^2	−0.001547			−0.00004532
Silage	−0.03388			−0.001373
(Silage)^2	. . .			. . .
Forage ADF			−0.2174	
(Forage ADF)^2			. . .	
ADF		−5.153	4.178	
(ADF)^2		0.1133	−0.09096	
FAT		−1.840	4.135	
(FAT)^2		0.1406	−0.3453	
MINTHI	−57.328	−68.634	43.284	2.6232
(MINTHI)^2	0.2255	0.2618	−0.1685	−0.010368
ln MINTHI	1790.71	2226.57	−1380.79	−82.629
DMI, kg/d			2.0892	0.05788
ln DMI			−15.084	−0.3527
P	<0.02	<0.02	<0.05	<0.04
R^2	0.69	0.74	0.81	0.76
Bias, %	0.4	−5.0	−4.3	−7.4
MINTHI, default range	<56, >72	<59, >72	. . .	. . .
Observations, no.	1613 (666)[3]	1613 (666)	1613 (666)	1617 (666)
100 × DMI/predicted DMI	98.5 (103.3)	90.8 (103.8)	108.9 (101.0)	99.0 (95.6)
SE	0.5 (0.5)	0.6 (0.5)	2.9 (0.5)	0.6 (0.5)
SD	18.9 (12.3)	22.7 (11.8)	117.9 (13.5)	23.1 (12.1)
10 to 90% Range	77–121 (88–118)	59–118 (90–118)	. . .	70–127 (81–111)
DMI minus predicted DMI, kg/d	−0.47 (0.46)	−2.0 (0.52)	<0.01 (0.26)	<0.0001 (−0.030)
SE	0.06 (0.07)	0.11 (0.06)	0.11 (0.11)	0.0036 (0.0032)
SD	2.59 (1.74)	4.24 (1.63)	4.47 (2.74)	0.1436 (0.0838)
Dependent variable mean, kg/d	14.7 (15.1)	14.7 (15.1)	18.9 (21.0)	0.65 (0.69)

[1] Variables and functions of these variables with blank space in coefficient column were not used in the model; spaces with ellipses were deleted by stepwise backward elimination (16).

[2] L = Lactation number category (1 vs. ≥2), Trt = treatment with bST, corn silage = percentage of forage DM consisting of corn silage, silage = percentage of forage DM that was not air-dried, forage ADF = percentage of forage ADF in ration DM, ADF = percentage of ADF in ration DM, FAT = ether extract plus soaps of fatty acids as a percentage in ration DM, MINTHI = minimum (nighttime) temperature-humidity index (7), and 10 to 90% range means that the middle 80% of observations were within the range indicated.

[3] Values in parentheses were derived using the data file from which the equation was developed or the verification data file.

= −0.55 vs. −0.52), but ADF was more closely related to NE_L and therefore to yields of FCM and milk protein. Plegge and Goodrich (13) reported that ration energy density exerted a quadratic effect on maximum DMI of beef cattle; peak DMI occurred when metabolizable energy was 2.52 Mcal/kg of DM.

The THI based on minimum (nighttime) temperature (**MINTHI**) was correlated more closely (r = −.0.62 vs. −0.55) with DMI (Table 1) than was the THI based on maximum (daytime) temperature; this finding was consistent with the conclusions of Roseler et al. (15), who reported that daytime heat stress had less effect on DMI when there was at least a temporary nighttime respite. Murphy (9) also noted that minimum ambient temperature was correlated more closely than maximum temperature with ad

TABLE 3. Verification database (12) with 1613 observations (441 from parity 1; 653 from bST cows) from 46 Jersey cows for lactation numbers 1 to 6.

	Mean	SE	Minimum	Maximum
DIM	145	2	1	365
Day of year	163	3	3	361
BW, kg	421	1	290	596
DMI, kg/d	14.7	<0.1	2.7	26.2
4% FCM, kg/d	18.9	0.2	3.6	43.7
Milk protein, kg/d	0.65	<0.01	0.14	1.30
Milk, kg/d	16.2	0.1	3.0	34.5
Fat, %	5.13	0.02	2.34	8.36
Protein, %	4.03	<0.01	2.94	4.87
MAXTHI[1]	58.6	0.6	39.4	82.0
MINTHI[2]	58.0	<0.1	56.0	70.2
Ration composition, % of DM				
CP	16.9	<0.1	13.6	19.3
Fat[3]	4.63	<0.01	3.70	4.80
ADF	23.4	<0.1	13.8	33.7
NDF	38.1	<0.1	35.9	44.9
Forage ADF	19.1	<0.1	16.2	28.8
Forage NDF	26.9	0.1	22.8	41.7
Corn silage, % of forage DM	42.5	<0.1	30.8	45.1
All silages, % of forage DM	100	. . .	100	100
NE_L, Mcal/kg of DM	1.61	<0.01	1.37	1.70

[1] Maximum (daytime) temperature-humidity index (THI) = °F − (0.55 − 0.55 × relative humidity/100) × (°F − 58).

[2] Minimum (nighttime) THI.

[3] Ether extract plus soaps of fatty acids.

libitum water intake by lactating cows. Thus, MINTHI was selected for use as a measure of heat stress.

The CP percentage of the ration (Table 1) was not correlated closely in a linear fashion with DMI or with other predictors, except for the percentage of forage DM that was contributed by corn silage ($r = -0.61$), a low protein ingredient of the diet. Fat in the ration (ether extract plus fatty acid soaps) was not correlated closely with other variables (Table 1), except NE_L ($r = 0.53$) and the percentage of forage DM coming from corn silage ($r = 0.35$). Lack of significant linear correlation, however, does not rule out a significant curvilinear relationship, for example, the relationship between dietary fat concentration and DMI. The relationships between chemical composition of the ration and the proportion of forage from corn silage, as noted previously, might explain the usefulness (6) of the latter for predicting ad libitum DMI.

Ration ADF and NDF were correlated more closely with DMI than were forage ADF and NDF (Table 1). The opposite was true for the relationship of fiber with FCM. These results were compatible with the concept that forage quality is more critical for high milk energy yield than is the ratio of concentrate to forage.

Final regression equations from the development database (Table 2) accounted for 69 to 74% of the variation in DMI. Ranges of MINTHI over which MINTHI exerted a depressing effect on maximum DMI are shown; applications using those equations should be programmed so that MINTHI is within these ranges. Although a three-degree polynomial expression fit the MINTHI data base, extension of the curve beyond its peak and nadir represents a mathematical artifact that has no biological basis. The lowest MINTHI in the range gives no DMI correction, and the highest MINTHI in the range gives maximum DMI depression.

The negative coefficients (Table 2, Equations [1] and [2]) for the effect of bST treatment and for its interaction with parity category suggested that, when all other significant predictors were in the model, parity had virtually no effect on the prediction of DMI of cows that were not treated with bST. In cows that were treated with bST, however, the effects of treatment on DMI were −1.0 and −0.6 kg/d for parity 1 cows and −0.4 and −0.2 kg/d for older cows using Equations [1] and [2], respectively. We interpreted this result to mean that, especially for young, growing, lactating cows, the use of bST increased FCM proportionally more than it increased DMI (i.e., the increase in DMI per unit increase in 4% FCM was less than the regression coefficients for 4% FCM) (Table 2). This finding probably was related to the well-established diversion of body fat calories to milk synthesis when bST was administered, thus reducing somewhat the energy demand from the diet compared with that of an untreated cow yielding equal FCM. We do not think the negative coefficient for bST treatment was related to the lag of increase in DMI after increased FCM, because so few observations corresponded with the first 2 wk of bST treatment.

Figure 1 illustrates the separate effects of each prediction variable in Equation [1] (Table 2) with all other independent variables in the model. Therefore, interpretation is tempered by the unavoidable correlations, in some cases, among right-side terms of the prediction equation. Both FCM and BW exerted essentially linear positive effects on DMI as has been noted by others (2, 3, 8, 11, 14, 15). After calving, DMI increased abruptly until about 60 DIM, and then increased gradually until the peak at 150 DIM; DIM then declined slightly until the end of lactation as reported also by Brown et al. (2). Because we had no observations for <38 DIM (Table 1), Equation [1] obviously underestimated DMI during the first 15 to 20 DIM; thus, we recommend that programmers precede our equations for DMI with the following statement: if DIM <15, then DIM = 15. This flaw is of no practical consequence because DHI data <15 to 20 DIM generally are not available for use in ration balancing. Furthermore, cows vary greatly in the rate at which their DMI rebounds soon after calving. During the first 3 wk of lactation, it may be preferable to offer a forage mixture for ad libitum intake plus concentrate at the rates of 0.3 and 0.5 kg/kg of milk for primiparous and pluriparous cows, respectively (5).

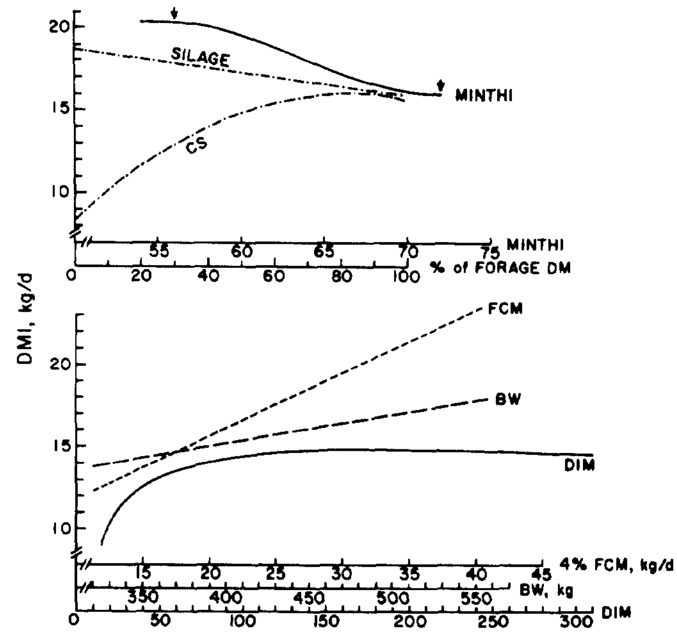

Figure 1. Effects of DIM, 4% FCM, BW, minimum (nighttime) temperature-humidity index (MINTHI) (7), and percentages of forage DM consisting of corn silage (CS) or silage (including CS) on DMI by Jersey cows; Equation [1]: $R^2 = 0.69$; bias = 0.4%; $P < 0.02$. Arrow indicates range over which MINTHI affected DMI.

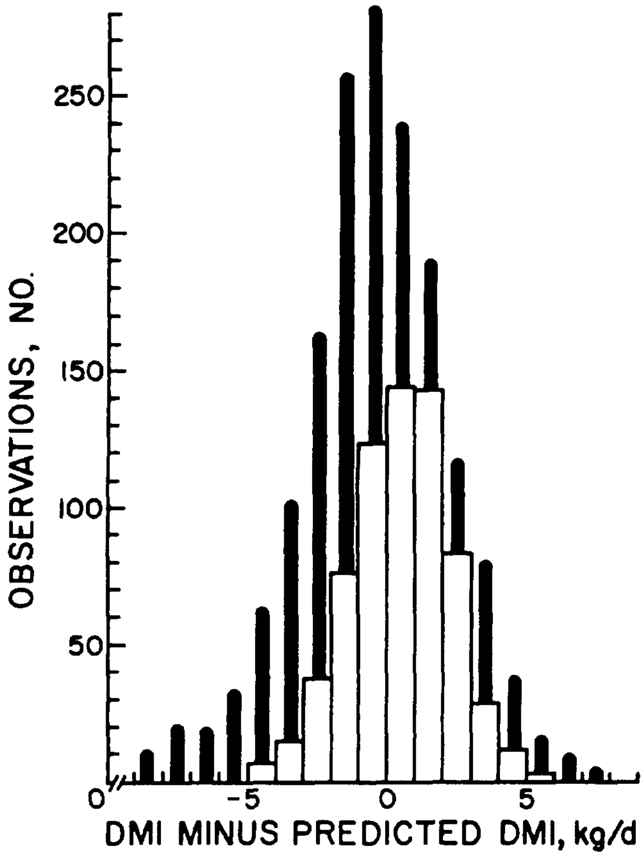

Figure 2 Frequency distribution of differences between observed and predicted DMI of lactating Jersey cows using Equation [1] and either development (open bars; n = 666) or verification (solid lines; n = 1613) data files.

Percentages of corn silage and all silages in the forage DM portion of the ration are useful predictors of DMI because dairy producers generally know these values before rations have been balanced with concentrates and because these values are somewhat related to total percentages of dietary nutrients (Table 1), including energy and moisture. When silage curves are interpreted (Figure 1), the percentage of total silage must equal or exceed the percentage of corn silage, and 100 minus the percentage of total silage must equal the percentage of air-dried forage (hay). Thus, when the forage mixture consists of air-dried hay and corn silage, changing the ratio from 100:0 to

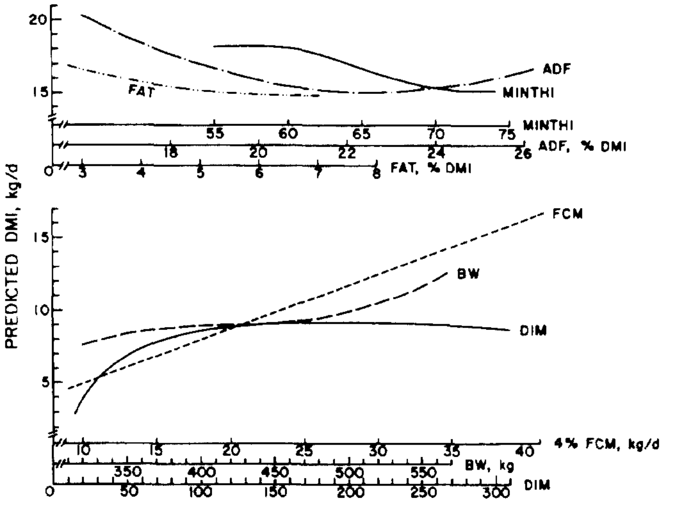

Figure 3. Effects of DIM, 4% FCM, BW, minimum (nighttime) temperature-humidity index (MINTHI) (7), and percentages of ration DM comprising ADF and ether extract plus fatty acids (FAT) on DMI by Jersey cows; Equation [2]: $R^2 = 0.74$; bias = –5.0%; $P < 0.02$.

0:100 would increase the ration DMI from 13.5 to 15.8 kg/d (Figure 1), and 100% haycrop silage would reduce DMI to about 12 kg/d, which is 1.5 kg/d less than if forage were all hay. The curve for percentage of corn silage essentially was a mirror image of the crude fiber curve derived from the equation of Brown et al. (2). The DMI increased as the percentage of corn silage in the forage portion of the diet increased up to about 80% corn silage and then declined slightly. Brown et al. (2) found that DMI increased as crude fiber declined from 32 to 16% of dietary DM and then decreased as crude fiber dropped further to 6%.

Depression of DMI (Figure 1) caused by heat stress, as indicated by MINTHI, commenced when MINTHI rose above 56 to 57 and continued until MINTHI reached about 72; corresponding maximum (daytime) THI would be approximately 71 and 85, respectively. Armstrong (1) indicated that THI ≥72 caused symptoms of heat stress in lactating dairy cows; presumably THI was based on maximum daytime temperatures. Total extent of depression in DMI was about 4.4 kg/d, a 22% reduction in ad libitum feed intake. This extent of depression in DMI was greater than that (13%) suggested by Roseler et al. (15) when cows were exposed to hot, humid conditions without at least 4 h of night cooling below 10°C, but was close to observations in Florida of B. L. Harris, Jr. (1994, personal communication).

Equation [1] represents the simplest and therefore most widely applicable prediction equation for DMI because all predictors, except MINTHI, are routinely available to most producers. The R^2 of 0.69 is based on observations of individual cows and thus is not necessarily inferior to much higher R^2 of 0.99 as reported by Rayburn and Fox (14) using treatment means from the literature rather than observations of individual cows. For Equation [1] (Table 2), bias was low, and mean DMI was underestimated by 0.46 kg/d using the development database and was overestimated by 0.47 kg/d using the verification database. Standard deviations indicated that two-thirds of observations were between 91 and 116% of predictions (SD = 12.3 percentage units) for the development database but between 80 to 117% of predictions for the verification file. However, the distribution of deviations of observed DMI from predicted DMI (Figure 2) indicated that the verification data file was skewed to the negative, which could occur during part of lactation if some cows only consumed limited

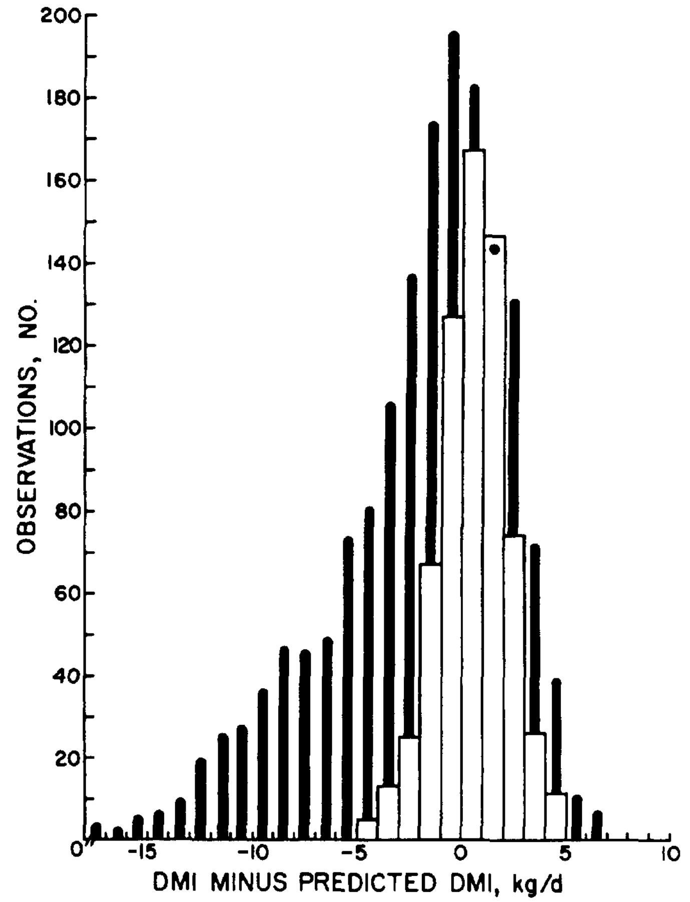

Figure 4. Frequency distribution of differences between observed and predicted DMI of lactating Jersey cows using Equation [2] and either development (open bars; n = 666) or verification (solid lines; n = 1613) data files.

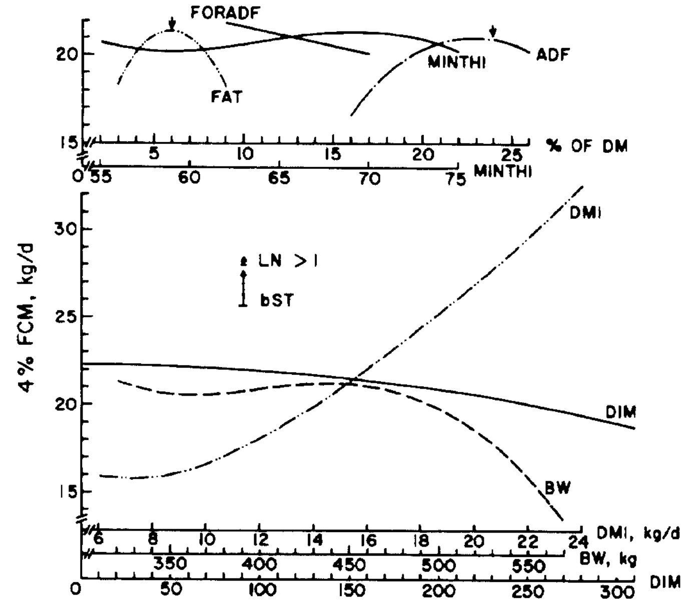

Figure 5. Changes in 4% FCM yield of Jersey cows as affected by DMI, DIM, BW, percentages of ADF, forage ADF (FORADF), and FAT (ether extract plus fatty acids) in ration DM, minimum (nighttime) temperature-humidity index (MINTHI) (7), bST treatment, and lactation number (LN); Equation [3]: $R^2 = 0.81$; bias = –4.3%; $P < 0.05$; arrow = peak.

amounts of their ration. Weekly DMI and milk yield data indicated occasional, temporary bouts of cows being off-feed, despite ad libitum diets. Such an occurrence would explain why the mean deviation was <0.

Equation [2] (Table 2) was developed for use when ration composition is known prior to DMI prediction, such as when TMR are fed to cows in groups. Thus, CP, ADF, and fat content of ration DM were substituted for the silage contents of forage DM used in Equation [1]. Ration ADF was superior to forage ADF as a predictor, and substitution of NDF for ADF measures did not improve prediction R^2. Effects of DIM and FCM on DMI (Figure 3) were similar to those in Equation [1]; BW exerted its largest (positive) influence on DMI >450 kg in contrast to its nearly linear effect in Equation [1]. Perhaps BW accounted for some of the variation in DMI based on parity category. Heat stress, as indicated by MINTHI, depressed DMI about 17% starting when MINTHI exceeded 59 (approximately 69 to 73 maximum THI). Perhaps the apparently lower DMI depression (17% vs. 22%) in Equation [2] versus Equation [1] could be attributed to the larger regression coefficient for FCM in Equation [2], which would account for more of the decline in DMI. Increased fat content of the diet decreased DMI about 1.8 kg/d from 3.0% to about 6 or 7% fat in the diet. Ad libitum DMI was related negatively to ration ADF content as ADF increased from 16 to 22%. The increase in DMI (1.6 kg/d) as ADF further increased from 22 to 26% of ration DM might be attributed to the ADF in concentrate ingredients such as soybean hulls (17). Crude protein was not a useful predictor of DMI, perhaps because of its insufficient range (14 to 19%) and its relationship to other right-side terms of the equation; this result was in contrast to the finding of Weiss (18), who observed that DMI increased with CP up to 19% CP in dietary DM.

Mean difference (observed DMI minus predicted DMI) for the developmental database (Table 2) was 0.52 kg/d, indicating that Equation [2] slightly underestimated DMI; however, use of the verification database resulted in a difference of –2.0 kg/d, a large apparent overestimation. Figure 4 illustrates the distribution of observations in regard to deviations of predicted DMI from observed DMI; data are severely skewed to the negative side for the verification data file, which decreased the mean difference (–2.0 vs. 0.52 kg/d). The largest category of observations for the verification file (Figure 4) was not at the mean difference (–2 kg/d) but ranged from 0 to –1 kg/d. Furthermore, the right side of both distribution curves was similar in shape and magnitude. Taken together, these observations suggest that perhaps some cows in the verification data file experienced bouts of being off-feed; this possibility seems more

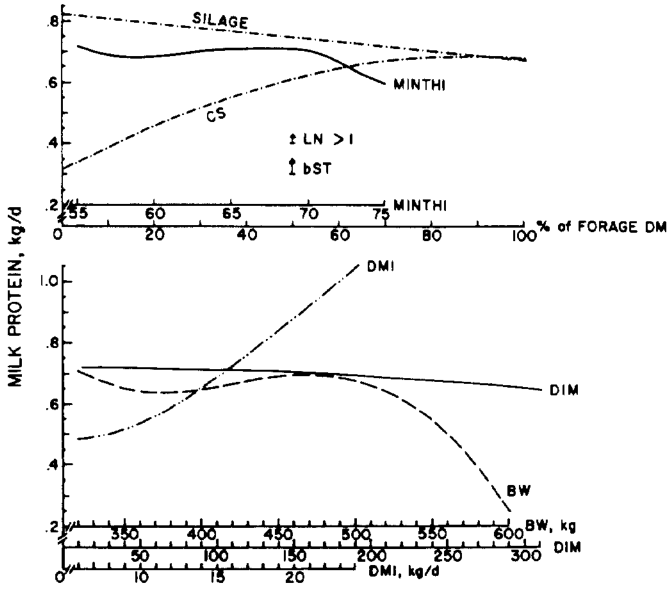

Figure 6. Influence of DMI, BW, DIM, lactation number (LN = 1 vs. ≥2), bST usage, minimum (nighttime) temperature-humidity index (MINTHI) (7), and percentages of forage DM [corn silage (CS) or silage (including CS)] on milk protein yield in Jersey cows; Equation [4]: $R^2 = 0.76$; bias = –7.4%; $P < 0.04$.

likely than the possibility that Equation [2] simply did not predict DMI accurately for the verification data file.

Equation [3] to predict 4% FCM (Table 2) was developed to study the nature of the relationship of FCM to DMI and other predictors of DMI. Nineteen percent of the variation in 4% FCM was not accounted for by this equation. Treatment with bST increased yield of daily 4% FCM by 3.4 kg/d (16%) on average, and cows in parities >1 yielded only 0.3 kg/d more FCM than primiparous cows, other predictors being equal. Figure 5 illustrates that DMI was a major predictor of milk energy yield above approximately 10 kg/d and apparently also accounted for much of the variation in FCM attributed to MINTHI when compared with Equations [1] and [2]. Body weight depressed FCM yield as BW increased from 460 to 560 kg. Brown et al. (2) reported a similar, but much smaller (2.2 vs. 8.0 kg/d), decline in total milk yield of mainly Holstein cows as BW rose from 600 to 800 kg. Dietary fat plus fatty acid concentration exhibited a curvilinear effect on 4% FCM yield, which increased by about 3 kg/d as dietary fat rose from 3 to 6% and then decreased by a similar amount as dietary fat rose further from 6 to 9%. No significant linear relationship occurred (Table 1) between 4% FCM yield and dietary fat content because of the curvilinear nature of the relationship. As forage ADF content of the diet increased from 9 to 17%, yield of 4% FCM declined by 1.75 kg/d. At the same time that total ration ADF, which included forage ADF, increased from 16 to 23% of DM, 4% FCM rose by 4.4 kg/d and then declined 0.8 kg/d as total ADF increased further from 23 to 26%. The combined effects of ADF and forage ADF suggested that milk energy peaked when ration ADF was 21% of DM, which was close to the recommendations of the NRC (11) of 19% at peak lactation and 21% before and after peak lactation. The MINTHI was correlated more closely than was maximum THI (Table 1) with both DMI and 4% FCM, and MINTHI was correlated more closely with DMI than with 4% FCM; DMI accounted for most of the variation in FCM, which might have been an expected result of heat stress (elevated MINTHI).

Figure 6 illustrates the factors used in Equation [4] (Table 2) to predict milk protein yield. Curves for DMI, DIM, and BW were similar to those noted for 4% FCM (Figure 5). Both DMI and BW were associated with much larger changes in milk protein yield than were other predictors over the ranges studied. Daily output dropped 0.11 kg as MINTHI increased from 70 to 75. These MINTHI corresponded approximately with maximum THI of 82 to 90, considered by Armstrong (1) to be in the range for moderate to severe stress. Effects of corn silage and total silage content in forage DM on daily yield of milk protein were similar to those for predicting DMI (Figure 1). Cows in parity category 2 yielded only 4.3% more milk protein per day than did primiparous cows. The use of bST increased milk protein by 7.3% on average, which was less than one-half the corresponding increase (16%) in 4% FCM. The independent variables used in Equation [4] accounted for 76% of the variation in milk protein yields that were between 70 and 127% of predicted yields.

When chemical composition of the ration (e.g., fat, ADF, forage ADF) is known or can be estimated for individual cows prior to ration balancing, as when the TMR system is group fed, then Equation [2] would be useful (Table 2). The addition of ration chemical entitles to the model increased the R^2 from 0.69 to 0.74. The use of milk protein yield eliminated (16) some FCM variables in the prediction of DMI and increased R^2 by 2 or 3 percentage units; milk protein yield was not included in the final DMI equations in Table 2 to simplify their use and because some producers may use NPN-corrected milk protein. Aside from somewhat higher R^2, there is no compelling reason to recommend the use of Equation [2] over the use of Equation [1], but Figure 3 shows the effects of ration composition predictors on DMI.

The range of deviations of predicted DMI above and below observed DMI (Table 2) was examined to see whether outliers had any common characteristics, such as high or low BW, FCM, or the same parity category. Also, confidence in adoption of a prediction equation for DMI to balance the rations of individual cows rests less on mean deviation and more on extreme deviations. For Equation [1] (Table 2), the DMI of cows in the verification data file averaged 98.5% of predicted DMI. However, after the 10% of the observations that were most underpredicted or overpredicted were removed, the observed DMI ranged from 77 to 121% of predicted DMI; the low incidence of these extreme deviations may be examined in Figure 2.

The equations developed for estimation of ad libitum DMI of lactating Jersey cows took into account the variables used by others (8, 14, 15, 18) to predict DMI of Holstein cows, except for BW change (18) and days pregnant (15), and included several variables not used previously: ration ADF, MINTHI, percentages of forage DM constituted by corn silage and total silage, and bST. Because of the scarcity of appropriate and complete data for the Jersey breed, these equations should find widespread application for computer ration balancing in most dairy regions where forages or total mixed diets are fed for ad libitum consumption and where routine measurements are made of milk yield and composition, BW, and ration composition.

Our study tended to confirm the conclusion of Harlan et al. (4) that NDF is not necessarily superior to ADF as a predictor of DMI. We confirmed the work of other researchers (9, 15) that MINTHI rather than daily maximum THI apparently is a useful index for evaluating the effect of heat stress on cow performance; MINTHI always remained in the equation along with FCM despite their correlation ($r = -0.48$). Significant effects of heat stress on DMI, although of shorter duration and of lower severity (highest MINTHI were 70 in Vermont and 75 in Georgia), were apparent in the northern as well as the southern US. These equations might be the first prediction equations for DMI of lactating dairy cows that account for the influence of bST use.

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