Evaluation of Alternative Equations for Prediction of Intake for Holstein Dairy Cows

D. K. ROSELER,[1] D. G. FOX,[2] A. N. PELL,
and L. E. CHASE
Department of Animal Science, Cornell University, Ithaca, NY 14850

ABSTRACT

Six prediction equations for dry matter intake (DMI) were evaluated for accuracy with independent data. The equations were selected based on ease of parameter measurement and practical on-farm use. The equations were assessed for accuracy of predicting individual weekly DMI for primiparous ($n = 105$) and multiparous ($n = 136$) cows; three-fourths of these cows were supplemented with a sustained-release form of bovine somatotropin (bST). Large variations in accuracy were identified across the six prediction equations for effects of parity and bST. Prediction accuracy of all equations for cows in wk 1 to 24 of lactation was better for primiparous cows than for multiparous cows. Precision of prediction equations was poor for cows in wk 8 through 12 of lactation and for cows in >40 wk of lactation. The equation for DMI with the best accuracy measured by a low total lactation mean square prediction error was the modified equation of the National Research Council: DMI (kilograms per day) = $-0.293 + 0.372 \times$ fat-corrected milk (kilograms per day) + $0.0968 \times$ body weight$^{0.75}$ (kilograms). However, the overall mean bias (predicted minus observed) of the prediction of weekly DMI of a single cow was high for all equations, including the modified equation of the National Research Council. For wk 2, 4, 8, 10, and 20 of lactation, the mean bias for the modified equation was +6, +3.4, –1.3, –2.1, and –2.8 kg/d. The accuracy of prediction was lower for cows treated biweekly with bST. High yielding cows and cows treated biweekly with bST had higher milk yields in relation to body weight, and standardized prediction equations for DMI were less accurate.

(**Key words**: feed intake, intake models, prediction equations)

Abbreviation key: **CNCPS** = Cornell Net Carbohydrate and Protein System, **MSPE** = mean square prediction error.

INTRODUCTION

Accurate prediction of DMI is important for the formulation of economical diets and for the diagnosis of potential losses in milk yield. Previous reviews (6, 11) have identified the interactions of cows with environmental, dietary, and management factors to determine daily DMI. Because of the complexity of factors controlling feed consumption, accurate prediction of daily DMI is difficult. The prediction of the weekly mean DMI for a dairy cow could provide a more accurate and practical method for on-farm usage. Thus, the equations selected for evaluation in this study contained easily measured parameters and were evaluated for use in predicting the weekly mean DMI of individual cows.

Prediction equations for DMI have been derived mostly by regression techniques applied to historical databases (6). The developmental databases of previous prediction equations for DMI (5, 11, 13, 20) have not contained high yielding Holstein cows. Similarly, housing systems, dietary ingredients, calving age, and bST supplementation have all altered the relationships among cows and dietary factors, which have traditionally described prediction equations for DMI. Thus, the accuracy of current prediction equations for DMI needs to be evaluated. No systematic evaluation of current prediction equations for DMI has been conducted with dairy cows that have been administered bST.

The purpose of this study was to measure the accuracy of six prediction equations (7, 9, 12, 14, 20) for estimating the weekly DMI of high yielding Holstein dairy cows and to determine whether current prediction equations for DMI with easily measurable parameters adequately predict DMI when cows are supplemented with bST.

Received November 6, 1995.
Accepted August 9, 1996.

[1] Current address: Countrymark Co-op., Inc., Indianapolis, IN 46204.

[2] Reprint requests.

MATERIALS AND METHODS

Prediction Equations for DMI

Six prediction equations for DMI were selected from recent literature based on the criterion that the required variables could be measured with minimal effort on a dairy farm. The six equations are listed in Table 1, and the databases used to develop each equation are described. Four of the equations are multiple regression equations using primarily BW and 4% FCM. The equation developed by Weiss (20) is based on the mechanistic dual intake concept of gut

TABLE 1. Prediction equations for DMI with test data.

Identification and reference	Equation	Developmental database
NRC, modified (12)	DMI (kilograms per day) = $-0.293 + 0.372 \times$ FCM (kilograms per day) $+ 0.0968 \times$ $BW^{0.75}$ (kilograms)	Historical records and empirical adjustments from NRC (12).
CNCPS[1] (7)	DMI (kilograms per day) + [$0.0185 \times$ BW (kilograms) $+ 0.305 \times$ FCM (kilograms)] $\times$ temperature adjustment	None
Rayburn and Fox (14)	if DIM ≤ 84, DMI (kilograms per day) = $0.0117 \times$ BW (kilograms) $+ 0.281 \times$ FCM (kilograms) $+ 0.0749 \times$ DIM; if DIM >84, DMI (kilograms per day) = $0.023 \times$ BW (kilograms) $+ 0.286 \times$ FCM (kilograms) $+ 0.0201 \times$ DIM $- 0.0979 \times$ ration NDF percentage	Period observations (n = 149) from 1284 Holstein cows on data extracted from the literature. Mean milk yield was 27 kg/d; mean intake was 19.8 kg/d.
Kertz et al., single[2] (9)	if DIM ≤ 154, DMI (kilograms per day) = $0.008037 \times$ BW (kilograms) $+ 0.3134 \times$ FCM (kilograms) $+ 0.2286 \times$ DIM $- 0.002176 \times DIM^2 + 0.00000705 \times DIM^3$	Experiments (n = 18) over a 6-yr period from 469 cows. Forage as a percentage of DMI was 37 to 56%. Facilities were evaporatively cooled, and tie-stall barns were utilized.
Kertz et al., multiple (9)	$DMI_1 = 13.08 + 0.1468 \times FCM - 0.003912 \times BW - 1.3 \times LN_1$ $DMI_2 = 12.04 + 0.1951 \times FCM - 0.001136 \times BW - 1.3 \times LN_1$ $DMI_3 = 10.89 + 0.2061 \times FCM + 0.002867 \times BW - 1.3 \times LN_1$ $DMI_4 = 10.19 + 0.2365 \times FCM + 0.004073 \times BW - 1.3 \times LN_1$ $DMI_5 = 9.32 + 0.3031 \times FCM + 0.003478 \times BW - 1.3 \times LN_1$ $DMI_{6-8} = 9.09 + 0.3090 \times FCM + 0.005115 \times BW - 1.3 \times LN_1$ $DMI_{9-13} = 7.43 + 0.3008 \times FCM + 0.010060 \times BW - 1.3 \times LN_1$ $DMI_{14-20} = 6.65 + 0.3428 \times FCM + 0.010553 \times BW - 1.3 \times LN_1$ where DMI = DMI (kilograms per day) at week n, FCM is measured in kilograms per day, BW is measured in kilograms, and LN = lactation number. LN = 1 when LN = 1; otherwise, LN = 0.	Same database as from single equation of Kertz et al. (9).
Weiss (20)	DMI_{gf} (kilograms per day) = $\frac{0.011 \times \text{BW (kilograms)}}{1 - [DE/(4.1 + 0.1 \times EE)]}$ DMI_{er} (kilograms per day) = $0.011 \times$ BW (kilograms) + $\left[\frac{2 \times (0.08 \times BW^{0.75} + 0.74 \times FCM + 5 \times BWC)}{(4.1 + 0.1 \times EE)}\right]$ $C_{LS} = 0.67 + 0.0972 \times [4.04 \times \log(WIM) - 0.095 \times WIM + 0.095]$ where DMI_{gf} = DMI when gut fill is limiting, DE = digestible energy content of the ration (megacalories per kilogram), EE = ether extract concentration of the ration, DMI_{er} = DMI when energy restriction is present, BWC = BW change (kilograms per day), C_{LS} = early lactation adjustment, WIM = weeks in lactation, and log = log base 10.	Based on work from Conrad et al. (4) with high forage diets.

[1] Cornell Net Carbohydrate and Protein System.

[2] Single or multiple equations.

fill and energy requirements developed by Conrad et al. (4) This dual equation predicts DMI independently under each equation; the lower value of either equation is the predicted value. Preliminary evaluation of this dual model by the author (W. P. Weiss, 1990, personal communication) suggested that the gut fill equation was inadequate for the prediction of DMI of high yielding cows fed highly digestible diets. Therefore, the equation was modified to include only the energy restriction equation and the early lactation adjustment factor suggested by Weiss (20).

Evaluation Database

The evaluation database that was utilized to measure the accuracy of the six equations was assembled from four different regions of the US (Arizona, Florida, New York, and Utah). The database contained records of complete lactations for 241 high yielding Holstein dairy cows managed under different environmental, housing (free stalls or tie stalls), and dietary conditions. The database contained 11,755 weekly individual observations of Holstein cows managed under typical farm settings in the US. Daily DMI, milk yield, ambient temperature, and relative humidity were recorded at each location and summarized as weekly means. Milk samples were taken weekly and analyzed for SCC, fat, protein, and lactose. Calving date and day of confirmed pregnancy were used to determine days of gestation.

TABLE 2. Description of the mean and range of cow and environmental variables in the developmental data used to evaluate prediction equations for DMI.

Measurement	n[1]	$\overline{X}$	SD	Range
Maximum DMI, kg/d				
Primiparous, control	26	23.9	3.3	15.5–31.3
Multiparous, control	34	28.8	3.4	20.4–34.0
Primiparous, bST	79	26.3	2.9	20.2–33.8
Multiparous, bST	102	29.7	3.2	22.9–37.8
Mean DMI, all periods	11,755	22.2	4.7	1.0–37.8
Maximum FCM, kg/d				
Primiparous, control	26	28.5	5.6	17.4–37.6
Multiparous, control	34	36.9	6.4	21.6–49.6
Primiparous, bST	79	32.8	5.6	19.0–45.0
Multiparous, bST	102	40.5	6.9	23.6–55.1
Mean FCM, all periods	10,337	26.1	7.8	3.1–55.1
Calving BW, kg per cow				
Primiparous	136	519.1	62.5	365.5–672.2
Multiparous	105	617.5	77.0	446.0–837.2
Mean BW, all periods	11,755	626.6	86.1	365.5–959.4
Body condition score[2]				
At parturition	241	3.0	0.4	2.00–4.00
All periods	11,755	3.1	0.4	1.75–4.75
Maximum DMI, wk[3]				
Primiparous, control	26	24	11.7	7–46
Multiparous, control	34	15	6.2	6–27
Primiparous, bST	79	33	10.8	10–55
Multiparous, bST	102	20	10.7	5–57
Maximum FCM, wk[3]				
Primiparous, control	26	15	10	3–38
Multiparous, control	34	9	6.6	2–33
Primiparous, bST	79	21	10.4	3–49
Multiparous, bST	102	13	7.5	1–41
Ambient temperature[4]				
Maximum, °C/wk	11,533	20.9	. . .	–5.8–39.3
Minimum, °C/wk	11,406	7.7	. . .	–18.0–27.5
Relative humidity, %/wk	11,516	61.9	. . .	12.2–94.6

[1] Number of observations over entire trial period.

[2] Body condition was scored on a five-point scale.

[3] Number of weeks postpartum when the maximum value was identified.

[4] Ambient temperature over the entire 15-mo trial period from the summer of 1987 to the fall of 1988.

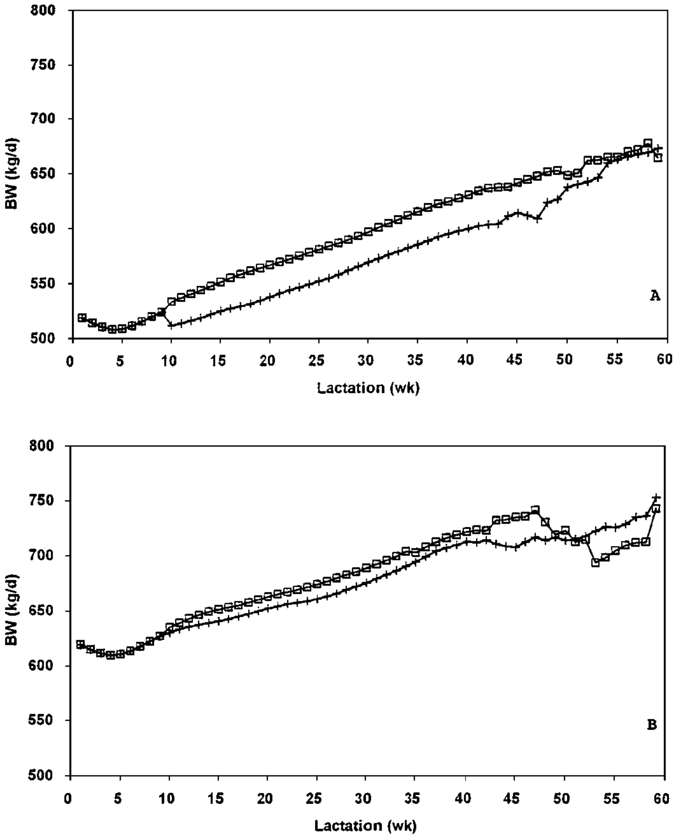

Figure 1. Relationship of mean BW and week of lactation for (panel A) primiparous control cows (□) and primiparous cows treated with bST (+) and (panel B) multiparous control cows (□) and multiparous cows treated with bST (+).

The evaluation database came from a bST dose titration study at four geographical sites (8). All cows in the database were selected prior to bST initiation based on good health and udder conformation and were blocked by parity within the control and each of the three bST treatment groups. The three bST treatments, initiated at 60 d postpartum, consisted of a biweekly sustained-release form of recombinant bST (*n*-methionyl sometribove) at three doses (250, 500, and 750 mg). In this study, control cows and cows receiving bST were separated in order to evaluate the accuracy of the prediction equations. The amount and variation in DMI, milk yield, BW, body condition score, ambient temperature, week of maximum DMI, and week of maximum milk yield across locations and treatments provided a unique database of modern high yielding cows from which to test the accuracy of the current prediction equations for DMI (Table 2).

BW

The BW of each cow was recorded at a common time within each week at all four locations. Individual weekly BW were smoothed using a median smoothing routine (19). Weekly changes in BW were calculated from the smoothed BW using a running mean of three consecutive values. Weekly changes in BW were calculated as $(SBW_{wk+1} - SBW_{wk-1})/2$, where SBW = smooth BW (kilograms per cow) and wk = current week of lactation. The relationships among smoothed BW, FCM, and DMI across lactation by parity and across doses of bST for the test data are shown in Figures 1, 2, and 3. Figure 4 contains a comparison of smoothed and raw BW. Smoothed BW provided a more accurate representation of BW because of the time of weighing relative to DMI, water consumption, and milk removal, which can affect BW measurement. Smooth BW were used when BW were required for the prediction equations used in this study.

TMR and Feeding Practices

The TMR of cows at each experimental location were formulated to meet or to exceed NRC (12) requirements and to contain ingredients common to

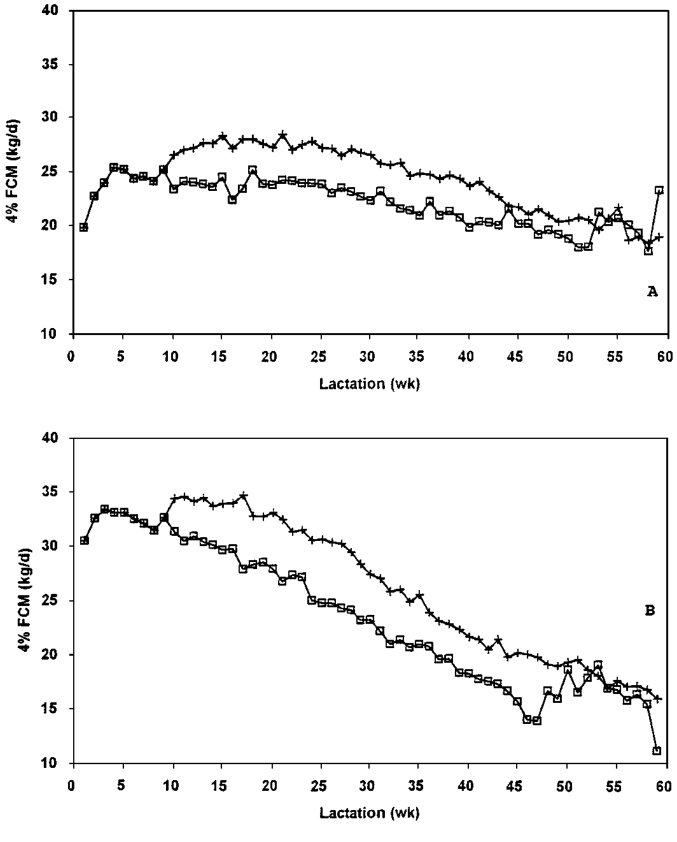

Figure 2. Relationship of 4% FCM and week of lactation for (panel A) primiparous control cows (□) and primiparous cows treated with bST (+) and (panel B) multiparous control cows (□) and multiparous cows treated with bST (+).

that region. All cows were fed a complete TMR to allow approximately 5% orts. Orts and DMI were measured daily. The dietary formulas, ingredient analyses, and nutrient composition of the TMR fed at each of the four locations are presented in Tables 3, 4, 5, and 6, respectively. The criterion used to move cows from one TMR to another within each location was based on days of lactation, milk yield, and body condition. Ingredients and TMR were sampled weekly, composited monthly, and analyzed for CP, ADF, and NDF. Concentrations of ether extract, ash, and lignin were assigned to each TMR ingredient according to Van Soest and Fox (18). Total dietary concentrations of fat, ash, and lignin were calculated as a sum of the percentage of each ingredient in the total DM of the TMR, multiplied by the corresponding nutrient concentrations of the ingredients. Samples of all ingredients and of the TMR at the Utah and Arizona locations were analyzed at Livestock Nutrition Laboratory Services (Columbia, MO). Samples from the Florida and Cornell sites were analyzed at the Northeast DHI Laboratory (Ithaca, NY).

Dry cow nutrition and management, lactation housing, and feeding practices were established according to the management at each location (Table 7). Free-stall housing equipped with Calan gates

TABLE 3. Composition and analyses of the complete TMR fed to cows at Utah.

Composition	Lactation		
	Early	Mid	Late
	(% of ration DM)		
Ingredient			
Alfalfa hay	16.0	20.8	28.5
Hay crop silage	15.5	18.4	16.9
Corn silage	8.6	14.0	18.7
Barley[1]	21.0	16.3	12.1
Beet pulp	11.3	8.8	7.4
Cottonseed, whole	13.7	10.8	8.1
Brewers dried grains	10.9	8.2	6.2
Molasses, liquid	1.2	0.9	0.7
Mineral	1.8	1.8	1.5
Total DM	100.00	100.00	100.00
Analysis			
CP	16.8	16.5	15.5
ADF	27.2	28.2	28.9
NDF	41.5	42.3	43.1
Lignin[2]	7.1	7.2	7.2
Ash[2]	7.8	8.4	8.5
Ether extract[2]	5.3	4.6	4.1
NE$_L$,[3] Mcal/kg of DM	1.67	1.62	1.56

[1] Rolled barley.

[2] Values assigned according to Van Soest and Fox (18) and weighted for total composition of the TMR.

[3] Calculated from ingredient components.

TABLE 4. Composition of TMR and analyses of complete TMR fed to cows at Arizona.

Composition	Lactation		
	Early	Mid	Late
	(% of ration DM)		
Ingredient			
Alfalfa hay	20.0	22.0	34.0
Alfalfa cubes	15.0	17.4	14.0
Concentrate[1]	46.0	42.0	38.0
Cottonseed, whole	15.0	13.0	7.0
Cottonseed, hulls	4.0	6.0	7.0
Total DM	100.0	100.0	100.0
Analysis			
CP	17.2	17.0	16.9
ADF	27.1	28.3	28.7
NDF	39.5	40.8	41.4
Lignin[2]	8.5	8.9	9.1
Ash[2]	7.1	7.1	7.3
Ether extract[2]	5.0	4.6	3.4
NE$_L$,[3] Mcal/kg of DM	1.69	1.68	1.61

[1] Concentrate included 20% rolled barley, 20% rolled corn, 20% malt pellets, 12.5% almond hulls, 7.9% commercial pellet, 6.5% cottonseed meal, 5% wheat midds, 4% liquid molasses, 1.2% urea, and 2.9% minerals.

[2] Values assigned according to Van Soest and Fox (18) and weighted for total composition of the TMR.

[3] Calculated from ingredient components.

TABLE 5. Composition of TMR and analyses of complete TMR fed to cows at Florida.

Composition	Lactation		
	Early (Cool)[1]	Early (Hot)	Late
	(% of ration DM)		
Ingredient			
Alfalfa hay	13.3	13.0	25.0
Corn silage	34.2	33.0	49.2
Corn, cracked	16.0	15.7	6.2
Cottonseed, whole	9.5	10.3	. . .
Distillers grain	13.1	13.7	8.4
Soybean meal[2]	10.8	10.8	9.7
Mineral and vitamin	3.1	3.5	1.5
Total DM	100.0	100.0	100.0
Analysis			
CP	17.6	17.9	15.7
ADF	23.3	23.2	26.1
NDF	37.8	37.7	42.6
Lignin[3]	5.4	5.4	5.9
Ash[3]	7.5	7.9	6.4
Ether extract[3]	5.5	5.7	3.1
NE$_L$,[4] Mcal/kg of DM	1.70	1.70	1.54

[1] Cool = TMR fed from October to April; hot = TMR fed from May to September.

[2] 44% CP Soybean meal.

[3] Values assigned according to Van Soest and Fox (18) and weighted according to total composition of the TMR.

[4] Calculated from ingredient components.

(American Calan, Inc., Northwood, NH) was used at all sites except New York, which used tie-stall housing.

Statistical Evaluation Criteria

The actual (A) mean weekly DMI for each cow and the predicted (P) weekly DMI for each of the six prediction equations (7, 9, 12, 14, 20) were compared using the mean square prediction error (**MSPE**): MSPE = $n^{-1} \Sigma (A - P)^2$, where n = number of pairs of values of actual and predicted DMI being compared. The MSPE can be regarded as the sum of three components (2): MSPE = $(\bar{A} - \bar{P})^2 + S_P{}^2(1 - b)^2 + S_A{}^2(1 - r^2)$, where $S_A{}^2$ and $S_P{}^2$ = variances of the actual and predicted DMI, respectively; $\bar{A}$ and $\bar{P}$ = means of the actual and predicted DMI; b = slope of the regression of A on P; and r = correlation coefficient of A and P. The three components are due to mean bias $\bar{A} - \bar{P}$)], line bias $[S_P{}^2(1 - b)^2]$, and random variation around the regression line $[S_A{}^2(1 - r^2)]$. Line bias is indicative of underlying inadequacies in the structure of the model. The overall mean bias (predicted minus observed) for each equation is displayed in Figures 5, 6, 7, 8, 9, and 10.

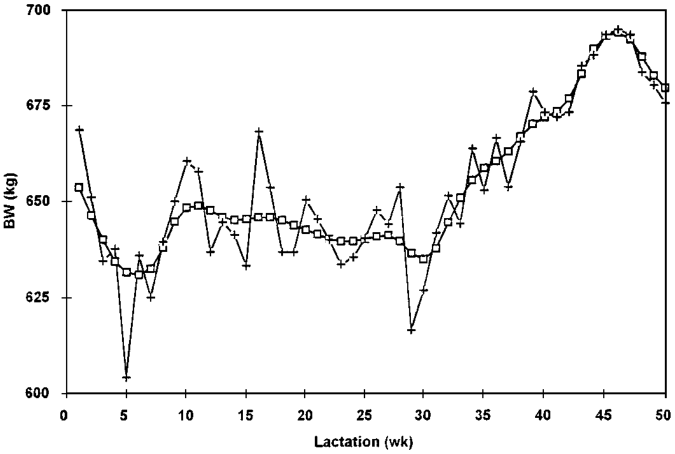

Figure 4. Relationship of observed BW (+) and subsequent BW after smoothing (□) by week of lactation for a single cow. This cow was treated with a biweekly sustained-release dose of 750 mg of bST initiated at wk 9 of lactation.

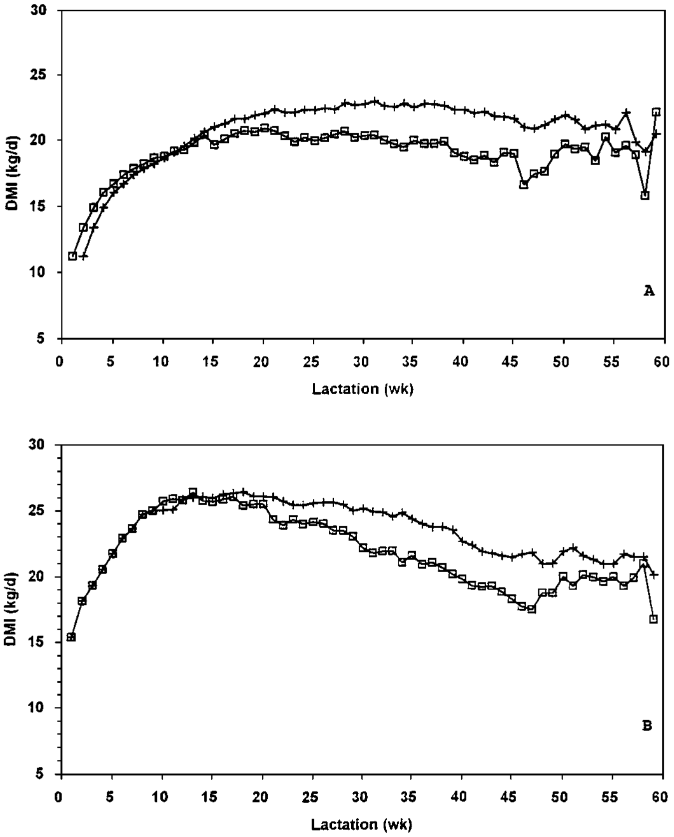

Figure 3. Relationship of DMI and week of lactation for (panel A) primiparous control cows (□) and primiparous cows treated with bST (+) and (panel B) multiparous control cows (□) and multiparous cows treated with bST (+).

Mean proportional bias is calculated as the slope of the regression of the predicted mean weekly DMI and the actual mean weekly DMI with a zero intercept. A regression slope of less than unity indicates an underprediction across the range of the actual values, and a slope greater than unity indicates an overprediction across the range of actual values. Coefficients of multiple determination calculated as 1 minus the error

TABLE 6. Composition of TMR and analyses of complete TMR fed to cows at New York.

	Lactation		
Composition	Early	Mid	Late
	(% of ration DM)		
Ingredient			
Alfalfa hay	9.1	27.0	35.0
Corn silage	49.3	38.0	42.0
Corn grain, ground	20.6	21.5	13.0
Soybean meal[1]	17.3	10.9	8.0
Mineral	3.7	2.6	2.0
Total DM	100.0	100.0	100.0
Analysis			
CP	17.2	16.0	15.3
ADF	19.5	23.4	27.4
NDF	31.3	35.6	40.8
Lignin[2]	2.8	3.8	4.7
Ash[2]	9.5	8.8	8.9
Ether extract[2]	2.7	2.9	2.9
NE_L,[3] Mcal/kg of DM	1.64	1.56	1.44

[1] 49% CP Soybean meal.

[2] Values assigned according to Van Soest and Fox (18) and weighted according to total composition of the TMR.

[3] Calculated from ingredient components.

for sums of squares divided by the total sums of squares from the regression of predicted DMI on actual DMI are presented as a measure of variance accounted for by the respective equation. For the evaluation of biweekly injections of bST, the contrast of weekly versus biweekly values for MSPE was nonsignificant ($P < 0.10$), thus indicating that the time of the injection cycle (biweekly) of the bST did not alter the magnitude of the error associated with predicting DMI. Similarly, dosage of bST was nonsignificant ($P < 0.10$) on the MSPE; thus, the MSPE is presented as an aggregate of all doses of bST. Unequal sample sizes did not alter ($P < 0.10$) the magnitude of the differences in the MSPE. For ease of presentation and summary, the DMI data were divided into lactation periods. Period 1 includes wk 1 through 9 of lactation, period 2 includes wk 10 through 24 of lactation, period 3 includes wk 25 through 36 of lactation, period 4 includes wk 37 through 48 of lactation, and period 5 includes wk 38 through 60 of lactation.

RESULTS

MSPE and Effects of Parity

Wide variation existed in the accuracy of the six prediction equations for DMI as measured by MSPE. The lowest MSPE, 4.7 kg^2/d, occurred during lactation period 2 with the quadratic single equation of Kertz et al. (9) for cows in early lactation (Table 8). The multiple equations of Kertz et al. (9) for cows in early lactation was the least accurate; MSPE was 265.2 kg^2/d.

Lower values for MSPE were more evident for primiparous cows than for multiparous cows during lactation periods 1 and 2. Primiparous cows had less variability in BW and milk yield than did multiparous cows in early lactation (Figures 1 and 2), which might provide for a more consistent and stable relationship with DMI. A lower MSPE for primiparous cows has been observed in previous research (13). Primiparous cows may be more representative of the mean BW and milk yield of cows used to develop these regression equations for DMI.

TABLE 7. Description of dairy facilities and feeding management practices of evaluation databases.

	Utah	Arizona	Florida	New York
Housing	Two pens (36 cows per pen) in enclosed barn with free stalls equipped with Calan gates (American Calan, Inc., Northwood, NH)	Six outdoor pens (~12 cows per pen) equipped with Calan gates and Korral Kool Coolers (Korral Kool, Mesa, AZ), which were used when the temperature was >29.4°C.	Two shade structures equipped with Calan gates and adjacent field lots.	Individual tie stalls in an enclosed, open-air ventilated barn.
Cows, no.				
Primiparous	31	16	35	23
Multiparous	39	41	33	23
Dry cow management	Two groups. Far off dry cows fed a 12% CP ration with 1.41 Mcal of NE_L/kg. Close up TMR fed for 2 to 3 wk. TMR composed of early lactation TMR at 50% of total intake and grass hay in winter for ad libitum intake or summer pasture for ad libitum intake.	Two groups. Close up cows fed a TMR for 3 to 4 wk (DM analysis, 17.7% CP and 1.45 Mcal of NE_L/kg). The ration was composed of alfalfa hay fed for ad libitum intake with 3.4 kg of a 14% cow concentrate, 2.7 kg of alfalfa cubes, 0.7 kg of whole cottonseed, and 0.7 kg of cottonseed hulls.	Two groups. Close up cows fed a TMR for 2 to 3 wk (DM analysis, 15% CP and 1.55 Mcal of NE_L/kg). The ration DM was composed of 42% corn silage, 31% alfalfa hay, 12% corn distillers, 9% ground corn, 5% soybean meal (48%), and 1% mineral and vitamin mix.	Two groups. Close up cows fed a TMR for 2 to 3 wk (DM analysis, 15% CP and 1.48 Mcal of NE_L/kg). The ration DM was composed of 5 kg of legume grass hay with the remaining DM composed of 60% corn silage, 20% grass silage, 10% ground corn, 8% soybean meal (48%), and 2% mineral and vitamin mix.
Feeding schedule, h				
a.m.	0800	0400	0730	1000
p.m.	1600	1300	1300	
Orts measured	0700	0100	0630	0900
Feeding method	TMR, alfalfa hay separate.	TMR, alfalfa hay separate.	TMR with alfalfa hay.	TMR.

TABLE 8. Ranking of equations[1] for DMI in order of ascending mean square prediction error (MSPE) by period of lactation for treated[2] and control primiparous and multiparous cows.

Primiparous				Multiparous			
Control		Treated		Control		Treated	
Equation	MSPE	Equation	MSPE	Equation	MSPE	Equation	MSPE
Period 1[3]							
	(kg²/d)		(kg²/d)		(kg²/d)		(kg²/d)
Kertz et al., single[4]	6.4	...	...	Kertz et al., single	12.1	...	...
Weiss,[5] restricted	7.3	...	...	CNCPS	13.9	...	...
CNCPS	8.5	...	...	NRC, modified	15.6	...	...
Rayburn and Fox	8.8	...	...	Weiss, restricted	16.1	...	...
NRC, modified	13.9	...	...	Rayburn and Fox	20.6	...	...
Kertz et al., multiple	26.6	...	...	Weiss	64.9	...	...
Weiss	28.3	...	...	Kertz, multiple	71.5	...	...
Period 2[6]							
Kertz et al., single	4.7	NRC, modified	5.9	NRC, modified	12.9	NRC, modified	8.9
NRC, modified	5.2	Weiss, restricted	7.9	Kertz et al., single	16.0	Kertz et al., single	10.9
Weiss, restricted	8.0	Rayburn and Fox	9.3	Weiss, restricted	19.4	Weiss, restricted	15.2
Rayburn and Fox	9.8	CNCPS	10.9	Rayburn and Fox	20.8	Rayburn and Fox	15.3
CNCPS	11.2	Kertz et al., single	16.0	CNCPS	25.3	CNCPS	18.3
Weiss	39.0	Weiss	45.3	Weiss	75.1	Weiss	82.2
Kertz et al., multiple	122.2	Kertz et al., multiple	125.7	Kertz et al., multiple	265.2	Kertz et al., multiple	220.2
Period 3[7,8]							
NRC, modified	7.4	Rayburn and Fox	7.9	NRC, modified	7.9	Rayburn and Fox	8.5
Rayburn and Fox	8.2	NRC, modified	8.6	Rayburn and Fox	8.0	NRC, modified	10.9
Weiss, restricted	10.0	Weiss, restricted	12.4	Weiss, restricted	10.5	Weiss, restricted	15.8
CNCPS	16.1	CNCPS	20.0	CNCPS	15.4	CNCPS	22.9
Weiss	34.7	Weiss	49.0	Weiss	32.9	Weiss	61.5
Period 4[9]							
NRC, modified	9.3	NRC, modified	10.8	NRC, modified	5.3	NRC, modified	11.1
Weiss, restricted	9.9	Rayburn and Fox	11.2	Weiss, restricted	6.5	Rayburn and Fox	12.6
CNCPS	17.1	Weiss, restricted	14.5	CNCPS	9.4	Weiss, restricted	13.5
Rayburn and Fox	17.9	CNCPS	27.1	Weiss	11.3	CNCPS	24.9
Weiss	22.3	Weiss	36.5	Rayburn and Fox	21.5	Weiss	34.2
Period 5[10]							
NRC, modified	6.6	NRC, modified	13.8	NRC, modified	6.3	NRC, modified	15.3
Weiss, restricted	7.0	Weiss, restricted	14.6	Weiss, restricted	7.0	Weiss, restricted	8.2
CNCPS	9.2	Rayburn and Fox	22.3	CNCPS	13.1	Rayburn and Fox	26.1
Weiss	13.8	CNCPS	25.2	Weiss	13.9	CNCPS	27.6
Rayburn and Fox	32.3	Weiss	28.5	Rayburn and Fox	30.1	Weiss	29.9

[1] References for equations: Kertz et al. (9), Weiss (20), Cornell Net Carbohydrate and Protein System (CNCPS) (7), Rayburn and Fox (14), and NRC (12).

[2] Treatments consisted of a sustained-released form of bST at 250, 500, or 750 mg biweekly.

[3] Period 1 includes wk 1 to 9 of lactation. No bST was administered during period 1.

[4] Kertz et al. (9) equations are for single or multiple equations.

[5] Weiss (20) equations with or without (restricted) the adjustment factor.

[6] Period 2 includes wk 10 to 24 of lactation.

[7] Period 3 includes wk 25 to 36 of lactation.

[8] The equations of Kertz et al. (9) were designed to predict DMI through wk 20 of lactation, and, therefore, were excluded from periods 3, 4, and 5.

[9] Period 4 includes wk 37 to 48 of lactation.

[10] Period 5 includes wk 49 to 60 of lactation.

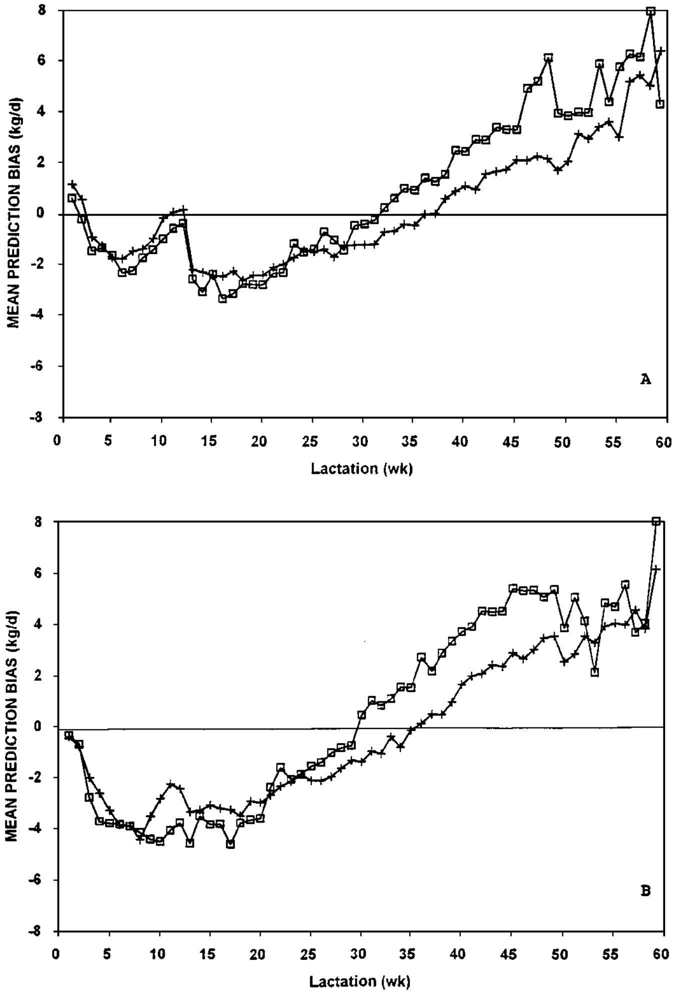

Figure 5. Relationship of DMI mean prediction bias (kilograms per day) (predicted minus observed) by week of lactation from the equation of Rayburn and Fox (14) for (panel A) primiparous control cows (□) and primiparous cows treated with bST (+) and (panel B) multiparous control cows (□) and multiparous cows treated with bST (+).

The MSPE was similar for both parity groups for lactation periods 3 through 5 (Table 8).

MSPE and Effects of bST

Overall, the accuracy of intake prediction was lower for cows treated with bST than for control cows in most periods, as measured by the magnitude of MSPE (Table 8). The MSPE within equations for control cows and for cows treated with bST were similar in lactation period 2. Period 2 included the immediate postpeak cows for which the relationship between milk yield and BW was similar for cows in control and treatment groups (Figures 1 and 2). The magnitude of the difference in the MSPE between control cows and those treated with bST increased with each progressive lactation period (Table 8). The lower accuracy of the prediction equation for DMI of cows treated with bST might be the result of elevated and cyclic milk yield responses and not the result of bST directly. The increase in MSPE with each progressive lactation period was partly due to an increase in the line (slope) bias (Tables 9 and 10). High line bias indicates an underlying inadequacy in the structure of the prediction model (15), and the line bias that was calculated for the modified NRC (12) equation (Tables 9 and 10) showed trends that were indicative of and common to all six equations. High line bias was indicated in the early and late lactation periods. However, the primiparous cows

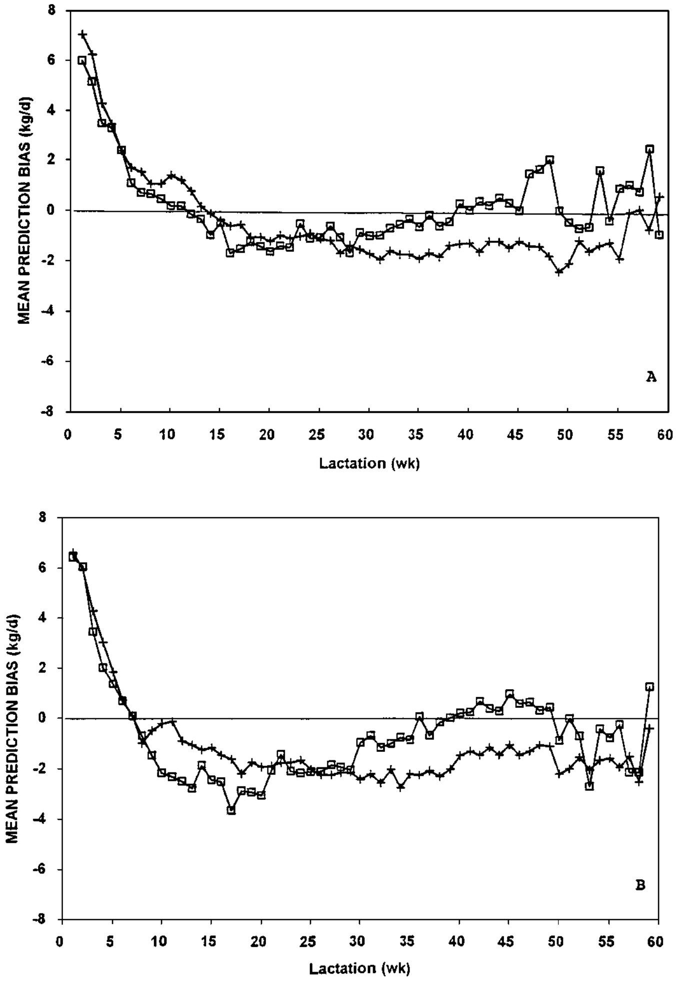

Figure 6. Relationship of DMI mean prediction bias (kilograms per day) (predicted minus observed) by week of lactation from the NRC (12) modified equation for (panel A) primiparous control cows (□) and primiparous cows treated with bST (+) and (panel B) multiparous control cows (□) and multiparous cows treated with bST (+).

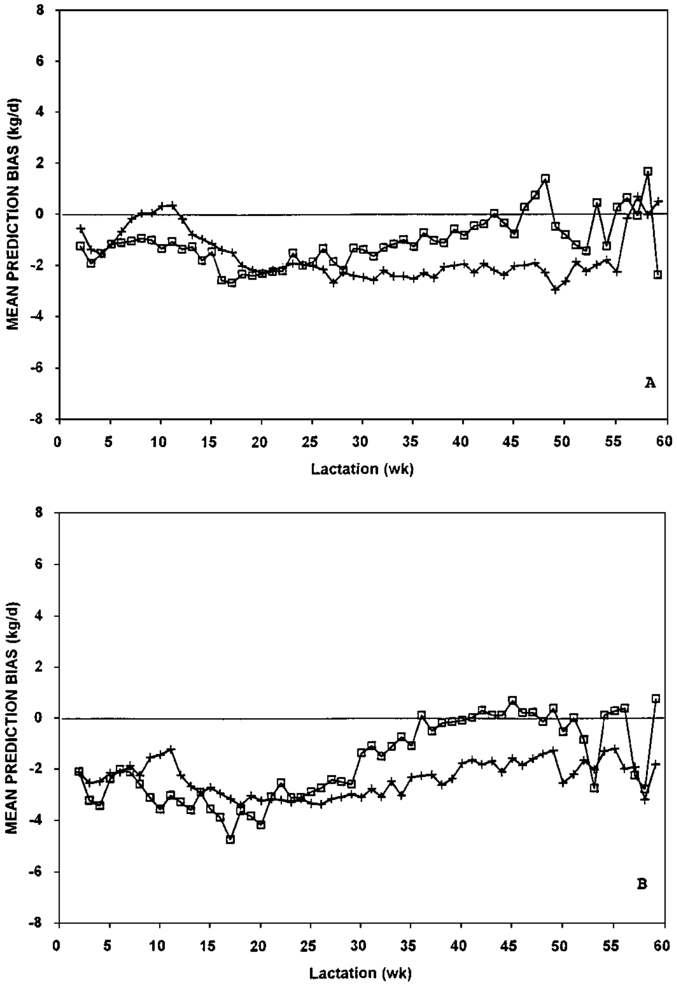

Figure 7. Relationship of DMI mean prediction bias (kilograms per day) (predicted minus observed) by week of lactation from the Weiss (20) equation for (panel A) primiparous control cows (□) and primiparous cows treated with bST (+) and (panel B) multiparous control cows (□) and multiparous cows treated with bST (+).

treated with bST did not have elevated line bias in late lactation, which was characteristic of the untreated primiparous cows (Table 9). The DMI of cows treated with bST was higher than that of control cows in late lactation because of elevated milk yield (Figure 3).

Equations for DMI

The mean prediction bias (predicted minus observed) of the six prediction equations for DMI was different across lactations. The mean prediction bias of each equation is graphically displayed in Figures 5, 6, 7, 8, 9, and 10. The modified NRC (12) equation and the equation of the Cornell Net Carbohydrate and Protein System (**CNCPS**) (7) overpredicted DMI of cows in early lactation, and the equation of Rayburn and Fox (14) and the multiple equation of Kertz et al. (9) underpredicted DMI postcalving (Figures 5, 6, 8, and 10). The single equation of Kertz et al. (9) and the equation of Weiss (20) performed best in the prediction of DMI for cows in early lactation (Figures 7 and 9). The CNCPS (7) equation, the modified NRC (12) equation, and the Weiss (20) equation underpredicted DMI for cows in late lactation. The equation of Rayburn and Fox (14) consistently had a lower MSPE for cows treated with bST than for control cows across all locations (Figure 5). Their equation was developed with period observations of Holstein cows, but systematically overpredicted DMI of cows in late lactation, regardless of

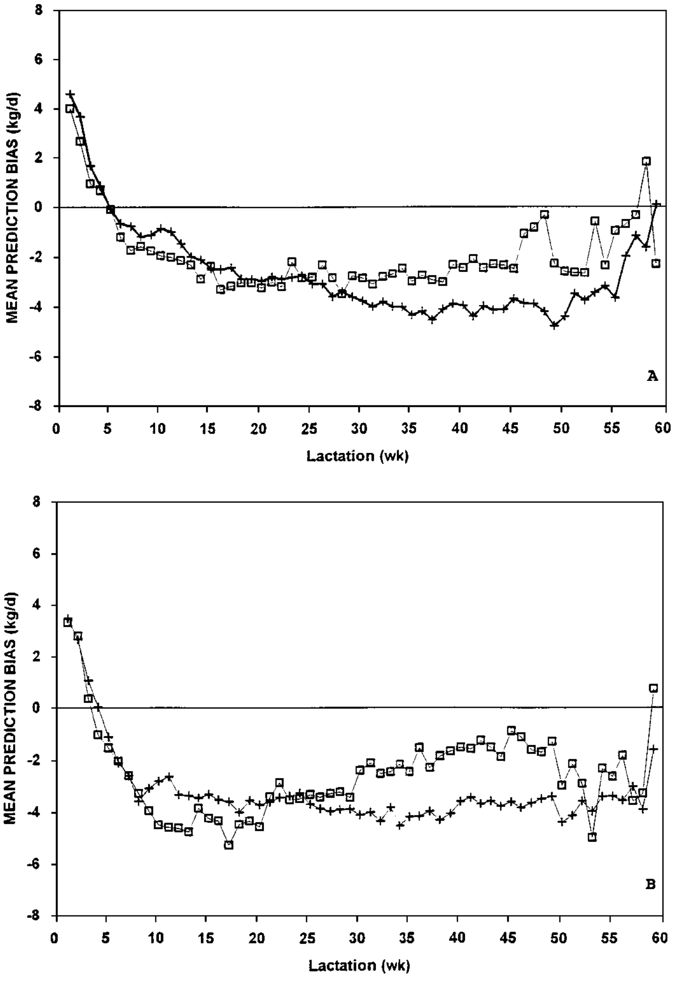

Figure 8. Relationship of DMI mean prediction bias (kilograms per day) (predicted minus observed) by week of lactation from the Cornell Net Carbohydrate and Protein System (7) equation for (panel A) primiparous control cows (□) and primiparous cows treated with bST (+) and (panel B) multiparous control cows (□) and multiparous cows treated with bST (+).

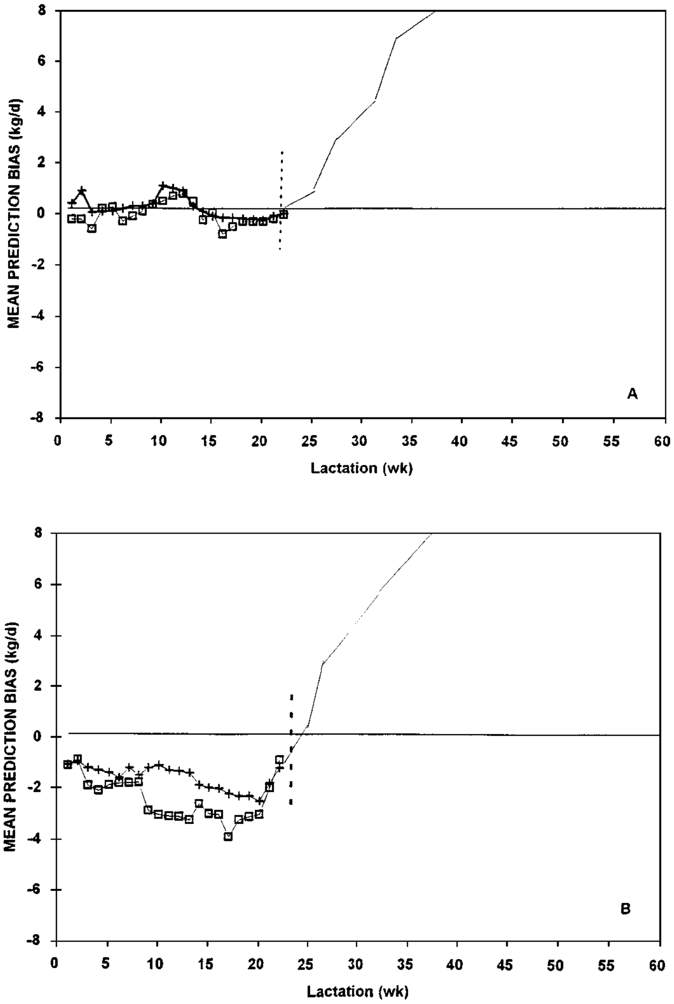

Figure 9. Relationship of DMI mean prediction bias (kilograms per day) (predicted minus observed) by week of lactation from the Kertz et al. (9) single DMI equation for (panel A) primiparous control cows (□) and primiparous cows treated with bST (+) and (panel B) multiparous control cows (□) and multiparous cows treated with bST (+). Extrapolated values are plotted to the right of the vertical line.

parity (Figure 5). The equation of Rayburn and Fox (14) overpredicted DMI of cows in late lactation because the coefficient for days of lactation was only developed from cows ≤258 d of lactation. Diets for cows in late lactation formulated from an erroneously high predicted intake can result in a greater loss of body condition score, lower milk yield, or both.

The modified equation of the NRC (12) generally provided the lowest MSPE in lactation periods 2 through 5 for control cows and for cows treated with bST. The linear coefficients of the modified equation greatly overpredicted DMI during wk 2 through 10 of lactation (Tables 9 and 10). The modified equation of the NRC (12) accounted for 26% to 79% (Tables 9 and 10) of the variation in weekly DMI. The R^2 of the modified equation of the NRC was the highest of all six of the equations for the prediction of DMI. The weekly R^2 were high when the only factors accounted for in the equation were milk yield and BW. Lower R^2 were evident for cows treated with bST, indicating the need for refined parameters for models when bST is used.

DISCUSSION

The regression prediction equations for DMI that were tested in this study accounted for approximately 50% of the variation in prediction of the weekly DMI

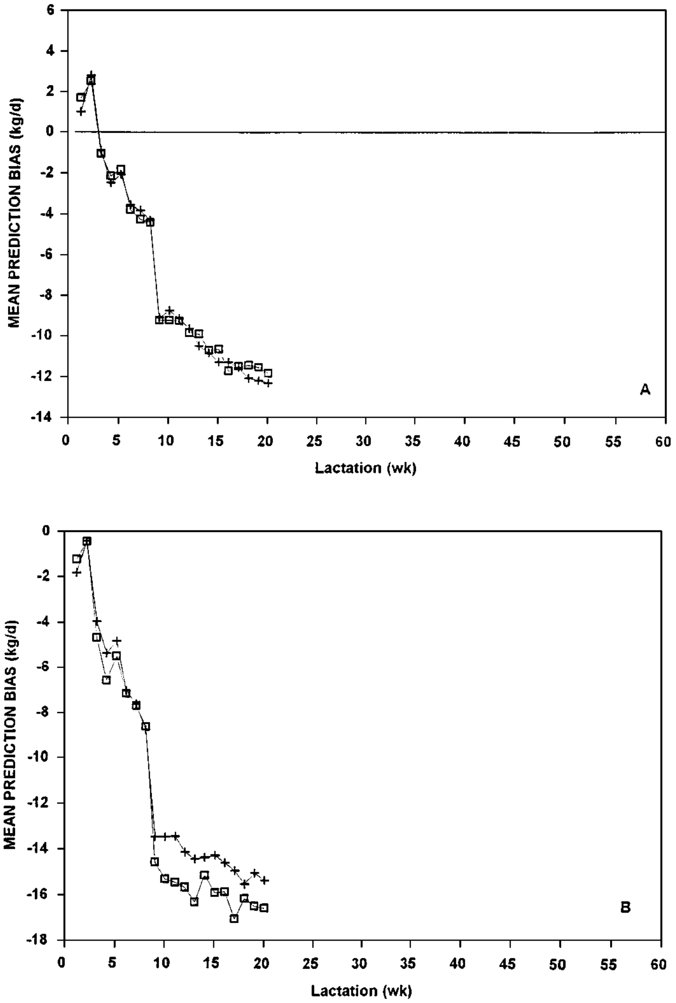

Figure 10. Relationship of DMI mean prediction bias (kilograms per day) (predicted minus observed) by week of lactation from the Kertz et al. (9) multiple DMI equation for (panel A) primiparous control cows (□) and primiparous cows treated with bST (+) and (panel B) multiparous control cows (□) and multiparous cows treated with bST (+). The multiple equation of Kertz et al. (9) is only valid for the first 20 wk of lactation.

TABLE 9. Precision of the NRC (12) modified equation for predicting individual weekly DMI of primiparous control cows and those treated with bST.

		Feed intake		Test statistic	
Lactation	Cows	Actual	Predicted	R^2	Line bias[1]
(wk)	(no.)	(kg/d)			
2	74	13.2	18.4	0.52	1.0
4	90	16.1	19.6	0.53	6.8[2]
6	102	17.5	19.1	0.26	3.5[2]
8	105	18.2	19.1	0.36	6.5[2]
10	26	18.8	18.7	0.41	1.0
20	26	20.9	19.3	0.79	<1.0
30	26	20.4	19.3	0.56	2.6
40	26	18.8	18.7	0.64	6.2[2]
50	10	19.7	18.6	0.52	9.0[2]
58	6	15.8	18.4	0.50	34.0[2]
		bST treatment			
10	79	19.0	20.2	0.36	5.3[2]
20	79	22.4	21.1	0.45	4.6[2]
30	79	23.0	21.3	0.44	<1.0
40	79	22.0	20.6	0.38	<1.0
50	43	21.5	19.7	0.44	2.2
58	18	20.5	19.4	0.35	<1.0

[1] Expressed as a percentage of total mean square prediction error.

[2] Periods of elevated line bias, indicative of underlying inadequacies of model structure.

of a single high yielding Holstein dairy cow. Accuracy of prediction of DMI, as measured by MSPE, was lower for cows treated with a sustained-release form of bST. The modified equation of the NRC (12) provided the best overall prediction, as measured by MSPE, during wk 10 through 60 of lactation; however, DMI of cows in early lactation was severely overpredicted by this equation. Adjustment factors for DMI of cows in early lactation that were utilized by the Weiss (20) equation and the single equation of Kertz et al. (9) improved prediction of DMI. However, the early and late lactation periods are areas in which improved accuracy of DMI prediction is needed.

Equations for DMI

The prediction of weekly DMI of individual cows across a wide range of management and environmental conditions explained approximately half of the variation in DMI ($R^2 = 0.5$). The equation developed by Vadiveloo and Holmes (17) for predicting an individual weekly DMI from BW, week of lactation, milk yield, and level of concentrate yielded an R^2 of 0.72 with a test data file. The R^2 was improved by predicting population means in contrast to individual weekly means (5, 16). Curran et al. (5) concluded that, for farm application, the prediction of individual daily DMI was imprecise, but the DMI of groups of 30 similar cows could be predicted satisfactorily. The precision of DMI prediction of a group depended on the homogeneity of the individuals in the group.

The ability to predict individual weekly DMI accurately would be adequate for ration formulation given the common practice of grouping cows according to week of lactation. As this study revealed, current prediction equations could, at best, estimate individual weekly DMI ±2.1 kg/d (MSPE = 4.7), or approximately 8 to 10% of mean DMI. Group intake could be predicted to within ±7 to 8% of the DMI (17). Improved prediction precision will come from a more quantitative understanding of factors that control eating. More descriptive databases of cows managed under a diversity of dietary and environmental conditions, as used in this study, combined with enhanced statistical analysis, could provide for the development of more robust prediction equations.

Empirical regression equations that are developed from narrow data have limited application (9), as evidenced by the multiple equation of Kertz et al. (9) used in this study. Similarly, the CNCPS (7) equation and the modified NRC (12) equation were inadequate for predicting DMI of cows in early lactation, but the single equation of Kertz et al. (9) performed well for cows in early lactation. The early lactation factor of the Weiss (20) equation (Table 1) improved prediction, but a negative bias was still evident. Performance of the Rayburn and Fox (14) equation for cows in late lactation was poor because the equation was not developed with cows >258 d of lactation. The

TABLE 10. Precision of the NRC (12) modified equation for predicting individual weekly DMI of multiparous control cows and those treated with bST.

Lactation	Cows	Feed intake		Test statistic	
		Actual	Predicted	R^2	Line bias[1]
(wk)	(no.)	(kg/d)			
2	110	18.0	24.0	0.34	1.5
4	135	20.5	23.9	0.38	1.2
6	136	22.9	23.6	0.32	2.9
8	136	24.8	23.5	0.35	5.4[2]
10	35	25.7	23.6	0.33	<1.0
20	35	25.5	22.7	0.52	2.4
30	35	22.1	21.3	0.72	4.1[2]
40	31	19.7	20.0	0.64	2.5
50	7	20.0	20.0	0.61	18.0[2]
58	3	20.9	18.8	0.42	20.0[2]
	bST treatment				
10	101	25.0	24.7	0.41	2.1
20	101	26.0	24.5	0.40	2.8
30	101	25.1	22.7	0.65	<1.0
40	97	22.5	21.1	0.64	4.1[2]
50	41	21.8	20.3	0.38	25.2[2]
58	18	20.5	19.4	0.35	<1.0

[1] Expressed as a percentage of total mean square prediction error.

[2] Periods of elevated line bias, indicative of underlying inadequacies of model structure.

equation of Rayburn and Fox (14) includes ration NDF to account for the limiting effect of diet fill in late lactation (10). The effect of fill might be important because of the relatively low digestibility of diets fed in late lactation. Fill also might be affected by reduced gut capacity from body fat and conceptus growth. Other prediction equations have not been developed for cows >40 wk of lactation. Improved performance of prediction equations for DMI of cows >40 wk of lactation might be enhanced by accounting for gestation and effects of BW gain.

Supplementation of bST

Elevation in DMI as a result of bST treatment was moderated by dosage (8), frequency of administration (3), farm management (1), and stage of lactation. The shape of the lactation curve and the relationship of milk yield to metabolic BW was altered with somatotropin treatment (1). Current prediction equations for DMI, when applied to data for cows treated with bST, account for less variation and have less prediction accuracy than when applied to data for control cows. However, predicted DMI might also be less accurate for cows that have not been treated with bST but have elevated milk yield in late lactation. Therefore, the low accuracy of prediction equations for DMI is the effect of elevated milk yield in relation to BW and not the effect of bST directly. The mean bias was inconsistent for data of cows treated with bST across the six equations evaluated in this study, and a standard adjustment in DMI cannot be used to improve prediction of DMI of cows treated with bST.

CONCLUSIONS

The evaluation of six prediction equations for DMI revealed large differences in the accuracy of prediction as measured by MSPE and mean bias. The accuracy of prediction of DMI was better for primiparous than for multiparous cows. An inconsistent weekly mean bias, measured as predicted minus actual intake, was evident across all equations. The bias was lower for control cows than for cows treated with bST. The adjustment of the equation for early lactation by Weiss (20) and the single equation of Kertz et al. (9) improved the prediction of DMI for cows in early lactation. The accuracy of the prediction of DMI was lower for cows treated with bST than for control cows because of elevated milk yield. Improved prediction equations for DMI are possible through the use of more descriptive databases, which include descriptions of feed, cow, management, and environmental conditions.

ACKNOWLEDGMENTS

Data was provided by Monsanto, Inc. (St. Louis, MO) through the effort of G. Hartnell and R. Hintz. The investigators at each of the respective universities that provided approval for data acquisition were D. E. Bauman, H. H. Head, J. T. Huber, and R. C. Lamb.

REFERENCES

1 Bauman, D. E. 1992. Bovine somatotropin: review of an emerging animal technology. J. Dairy Sci. 75:3432.

2 Bibby, J., and H. Toutenburg. 1977. Prediction and Improved Estimation in Linear Models. John Wiley & Sons, London, England.

3 Chilliard, Y. 1989. Long-Term Effects of Recombinant Bovine Somatotropin (rBST) on Dairy Cow Performances: A Review. Use of Somatotropin in Livestock Production. K. Sejrsen, M. Vestergaard, and A. Neimann-Sorensen, ed. Elsevier Appl. Sci., New York, NY.

4 Conrad, H. R., A. D. Pratt, and J. W. Hibbs. 1964. Regulation of feed intake in dairy cows. 1. Change in importance of physical and physiological factors with increasing digestibility. J. Dairy Sci. 47:54.

5 Curran, M. K., R. H. Wimble, and W. Holmes. 1970. Prediction of the voluntary intake of food by dairy cows. Anim. Prod. 12: 195.

6 Forbes, J. M. 1986. The Voluntary Food Intake of Farm Animals. Butterworths and Co., Boston, MA.

7 Fox, D. G., C. J. Sniffen, J. D. O'Connor, J. B. Russell, and P. J. Van Soest. 1992. A net carbohydrate and protein system for evaluating cattle diets: III. Cattle requirements and diet adequacy. J. Anim. Sci. 70:3578.

8 Hartnell, G. F., S. E. Franson, D. E. Bauman, H. H. Head, J. T. Huber, R. C. Lamb, K. S. Madsen, W. J. Cole, and R. L. Hintz. 1991. Evaluation of sometribove in a prolonged-release system in lactating dairy cows—production responses. J. Dairy Sci. 74: 2645.

9 Kertz, A. F., L. F. Reutzel, and G. M. Thomson. 1991. Dry matter intake from parturition to midlactation. J. Dairy Sci. 74: 2290.

10 Mertens, D. R. 1987. Predicting intake and digestibility using mathematical models of ruminal function. J. Anim. Sci. 64: 1548.

11 National Research Council. 1987. Predicting Feed Intake of Food-Producing Animals. Natl. Acad. Sci., Washington, DC.

12 National Research Council. 1989. Nutrient Requirements of Dairy Cattle. 6th rev. ed. Natl. Acad. Sci., Washington, DC.

13 Neal, H.D.C., C. Thomas, and J. M. Cobby. 1984. Comparison of equations for predicting voluntary intake by dairy cows. J. Agric. Sci. 103:1.

14 Rayburn, E. B., and D. G. Fox. 1993. Variation in neutral detergent fiber intake of Holstein cows. J. Dairy Sci. 76:544.

15 Rook, A. J., M. S. Dhanoa, and M. Gill. 1990. Prediction of the voluntary intake of grass silages by beef cattle. 3. Precision of alternative prediction models. Anim. Prod. 50:455.

16 Torabi, M. T., R. C. Lamb, and J. L. Walter. 1978. Prediction of feed intake and feed utilization efficiency from measures of production and physical characteristics of dairy cows. J. Dairy Sci. 61(Suppl.1):94.(Abstr.)

17 Vadiveloo, J., and W. Holmes. 1979. The prediction of the voluntary feed intake of dairy cows. J. Agric. Sci. 93:553.

18 Van Soest, P. J., and D. G. Fox. 1992. Discounts for net energy and protein—fifth revision. Page 40 *in* Proc. Cornell Nutr. Conf. Feed Manuf., Rochester, NY. Cornell Univ., Ithaca, NY.

19 Velleman, P. F., and D. C. Hoaglin. 1983. Data conversion. Page 159 *in* Applications, Basics, and Computing of Exploratory Data Analysis. Duxbury Press, Boston, MA.

20 Weiss, W. P. 1991. Estimating dry matter intake. Page 9 *in* Proc. Ohio Dairy Nutr. Conf. Ohio State Univ. Ext., Wooster.