Dry Matter Intake in Dairy Heifers.
1. Factors Affecting Intake of Heifers Under Intensive Management[1]

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ABSTRACT

Effects of body weight, body weight gain, ration acid detergent fiber, neutral detergent fiber, bulk density, and ambient temperature on intake of dry matter and digestible energy were examined using 118 Holstein heifers weighing 100 to 400 kg. Animals grouped according to body weight (100, 200, 300 kg) were fed total mixed rations (corn silage, ground hay, high moisture corn, soybean meal) once daily for 28 d. Rations were balanced to mean body weight according to National Research Council recommendations for protein, vitamins, and minerals and to 85, 95, 105, and 115% of recommended total digestible nutrients. Second order polynomial regression of ration fiber content and density explained 20 and 21% of variation in dry matter intake and 46 and 45% of digestible energy intake. Dry matter intake increased linearly with increasing body weight and gain. Dry matter intake correlated −.42, −.42, and .39 with acid detergent fiber, neutral detergent fiber, and bulk density when neutral detergent fiber was greater than 42% of dry matter and .03, −.03, and −.02 when less than 42%. Predictions of dry matter intake should include body weight, gain, and polynomial terms of ration fiber or ration energy to account for changing metabolic systems controlling intake.

INTRODUCTION

Accurate prediction of dry matter (DM) consumption requires that significant factors be included in predictive models. Factors of practical importance that influence nutrient intake in ruminants include body weight (4, 8, 14, 15, 16), change in body weight (1, 4, 14, 15), ration energy concentration (8, 9, 16, 19), ration bulk and energy density (2, 5, 17, 18, 20), and environmental temperature (6, 22).

Multiple regression models including one or more of these and other independent variables predict intake in lactating dairy cows with a high degree of precision (6, 7, 27). No similar research is available with dairy heifers. Published predictions of dry matter intake (DMI) in dairy heifers are based on body weight plus gain (21) using data obtained from heifers not fed for ad libitum consumption and at less than optimum rates of gain (21).

Systems for rearing replacement heifers in confinement housing and feeding total mixed rations (TMR) for ad libitum intake have become more popular in the Southeastern US. There is an increasing need to define factors affecting intake and to develop accurate predictions of DMI in heifers under these intensive management conditions. The objective of this study was to determine factors affecting DMI of heifers weighing 100 to 400 kg housed in confinement housing and fed TMR for ad libitum consumption.

MATERIALS AND METHODS

One hundred eighteen Holstein heifers were assigned to one of 12 treatments in two trials as in Table 1. Sixty-four heifers used in trial 1 were reassigned to treatment during trial 2, resulting in 182 heifer records in the final data set.

Preliminary Period

Prior to assignment to treatment, heifers were placed into three groups according to

Received April 21, 1986.
[1] Partially supported by a grant from the Virginia State Dairymen's Association.
[2] Nutrena Feed Division, Cargill, Inc., Minneapolis, MN.
[3] Reprint requests.

body weight (100 to 199 kg, 200 to 299 kg, 300 to 400 kg) and fed a TMR once daily for ad libitum consumption. Rations contained corn silage, ground orchardgrass hay,[4] soybean meal, ground shell corn, and minerals formulated to at least 100% of 1978 National Research Council (NRC) recommendations (21) for each body weight. At each feeding, a basal ration formulated for heifers weighing 300 kg was fed to all heifers; soybean meal, corn, and minerals were added to 100 and 200-kg weight group rations at the bunk. Animals remained in groups for 42 days until assignment to treatment or reassignment to a heavier group. Heifers not assigned to treatment and reaching 400 kg left the study.

Experimental Period

To begin each period, four groups of six to eight heifers each were selected randomly from preliminary groups and assigned to treatment and moved to the experimental facility for a 14-d acclimation period prior to data collection. Three periods of four treatments per period were used per trial.

Experimental facility consisted of four pens (3.6 m × 9.1 m) counterslope design open to the south. Pens were cleaned weekly and bedded with sawdust. Computerized TMR feeder was located on the south side of each pen and was available at all times except during cleaning pens and weighing animals. Accuracy of computerized feeders was tested at beginning of each trial. Water and salt were available at all times.

Following acclimation, individual feed intake[5] was measured daily for 28 d. Ambient temperature was measured every 2 h and reported for each 24-h period. Experimental TMR were sampled daily and stored at 4°C prior to compositing weekly and analyzing portions for bulk density (g/ml, as fed) as in (5), crude protein (CP),[6] acid detergent fiber (ADF),[6] and neutral detergent fiber (NDF)[7] as in (11). Daily (Trial 1) or pooled weekly (Trial 2) samples of TMR were analyzed in duplicate for DM (convection oven, 100°C). Feed ingredients were sampled daily, stored at 4°C, composited into weekly samples, and portions analyzed for DM, CP, and ADF as described. The TDN concentrations of ingredients and TMR were estimated from ADF[6] (TDN = 89.8 −.768 × ADF). Digestible energy (DE) concentrations of TMR were estimated using the formula 1 kg TDN = 4.409 Mcal DE (21).

Body weights were recorded once weekly and interpolated to a daily basis by second order polynomial regression of day of experiment on weekly body weight. Daily gains were calculated using estimated daily body weight. Daily gain predicted to be less than −1.0 or greater than 2.5 kg/d were deleted from the data set. Following intake measurement, heifers returned to the preliminary facility and were held for at least 42 d prior to assignment to a subsequent group to minimize carryover effects of ration energy concentration.

Statistical analysis of data was conducted by regression as outlined (23, 24), assuming all variables to be continuous. Data set was completed by including all variables from each trial on a daily basis. First, second, and third order polynomial regression using independent variables ration fiber, density, daily gain, and temperature and dependent variable DMI (g/kg body weight$^{.75}$) and digestible energy intake (DEI, kcal/kg body weight$^{.75}$) were evaluated

TABLE 1. Classification of experimental treatments and number of heifers[1] per treatment.

% NRC[2]	Treatment code for heifers 100 kg BW[3]	200 kg BW	300 kg BW
85	1 (14)	5 (15)	9 (16)
95	2 (16)	6 (16)	10 (14)
105	3 (14)	7 (16)	11 (16)
115	4 (15)	8 (15)	12 (15)

[1] Number of heifers per treatment in trials 1 and 2 in parentheses.

[2] Percent of National Research Council (NRC) recommendation for ration total digestible nutrients.

[3] BW = Body weight.

[4] Orchardgrass hay was ground in a tub grinder to an average length of 7 cm.

[5] Pinpointer 4000B, UIS Inc., Cookeville, TN.

[6] Virginia Tech forage testing lab. Blacksburg, VA.

[7] New York Dairy Herd Improvement Cooperative forage testing lab, Ithaca, NY.

by improvement in r^2. Body weight was evaluated in a similar fashion with DMI (kg/d) as dependent variable.

RESULTS AND DISCUSSION

Chemical composition of ingredients used in preliminary and experimental periods is in Table 2. All ingredients were of average quality and similar those of NRC (21). Animals were healthy throughout the trial. One animal was removed after treatment for infectious conjunctivitis.

Basal ration fed during preliminary period averaged (DM basis) 50.5% DM, 9.6% CP, 29.1% ADF, and 67% TDN during Trial 1 and 50.7% DM, 9.2% CP, 28.1% ADF, and 68.2% TDN during Trial 2. Nutrient concentrations were consistent with published requirements (21) except CP was slightly lower. Ingredient composition of experimental rations pooled for both trials varied as energy in ration increased (Table 3); this was required to meet NRC recommendations for protein, vitamins, and minerals. As dietary energy increased, amount of hay in rations decreased and high moisture corn increased except in rations fed to heifers weighing 200 kg and fed for 115% NRC recommendation. More hay was included in this ration than originally formulated – therefore, energy is unchanged from 105% treatment. Heifers in 200 and 300-kg groups were fed 100% orchardgrass hay to meet 85% energy recommendation.

Dry matter intake, ration fiber, TDN, bulk, animal parameters, and temperature pooled for both trials (Table 4) suggest a range of all variables except ambient temperature sufficiently wide to be predictive of practical situations.

Temperature extremes encountered in this study are not indicative of those in northern portions of the US. It is probable that ambient temperature did not leave the thermoneutral zone for extended periods; thus, temperature did not affect intake markedly. Intake did not decrease above approximately 20 to 25°C as predicted (22). It is possible that when ambient temperature was greater than 25°C, heifers consumed feed during cooler night hours when heat stress was not a factor. Dulphy (10) reported that during hot weather 14 to 35% of grazing occurs at night in cattle.

TABLE 2. Chemical composition of feed ingredients used in preliminary and experimental rations.

	Corn silage		Ground orchard-grass hay		High moisture corn		Soybean meal	
	(% of dry matter)							
	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
Dry matter[1]	41.6	.9	87.1	.5	75.4	.6	87.6	.3
Crude protein[1]	9.0	.4	10.3	.2	10.6	.1	47.9	.6
Acid detergent fiber[1]	27.5	.7	41.7	.9	6.4	.4	12.6	.5
Total digestible nutrients[1]	67.2	.3	53.7	1.0	84.9	.3	80.1	.4
Macrominerals[2]								
Calcium	.36	.02	.44	.13	.02	.01	.74	.19
Phosphorus	.31	0	.22	.02	.30	.03	.61	.01
Magnesium	.23	.01	.28	.08	.21	.06	.32	.05
Potassium	1.29	.16	1.51	.08	.27	.10	2.12	.01
Sodium	.02	.01	.05	.04	.01	0	.01	.01
Sulfur[3]	.15	...	.25	...	0	...	.45	...

[1] Mean of 24 observations.

[2] Mean of 2 observations.

[3] One observation.

TABLE 3. Percent[1] corn silage (CS), ground orchardgrass hay (HAY), soybean meal (SBM), high moisture corn (HMC), and minerals (MIN) in ration dry matter.

Trt[2]	CS	HAY	SBM	HMC	MIN[3]
1	32.7	43.3	8.3	15.1	.4
2	46.7	24.8	8.1	19.7	.6
3	28.2	13.2	7.0	50.7	.7
4	27.0	0	8.3	63.3	1.2
5	0	100.0	0	0	0
6	51.9	34.8	3.9	8.8	.5
7	42.1	27.8	4.8	25.0	.4
8	40.8	35.8	2.7	20.5	.6
9	0	100.0	0	0	0
10	38.2	55.7	.8	5.0	.3
11	62.1	21.3	2.3	14.2	.1
12	64.5	6.6	1.9	26.6	.4

[1] Average of trials 1 and 2.

[2] See Table 1 for treatment (Trt) codes.

[3] Includes minerals and salt.

Dry matter intake averaged 6.1 kg/d, ranging from 0 to 16.8 kg/d. Minimum and maximum predicted DMI for heifers from 100 to 400 kg are 2.8 and 8.6 kg/d (21). Concentrations of ADF and NDF in ration were greater than those reported to result in maximum DMI (8, 18), although minimum fiber in rations (9.4% ADF, 24.1% NDF) should allow DMI to be regulated by energy requirement of the animal (8, 18). Treatments 5 and 9, containing 100% hay, resulted in greatest fiber. Consumption of DM in heifers fed all hay rations is restricted by size of the animal (9).

Intake of ration DM and independent variables for all treatments are in Table 5. Dry matter consumption for each weight group tended to increase with increasing energy to 105% of TDN recommendation, then decrease slightly (Table 5). Increased proportion of concentrate in rations fed to heifers generally results in increased intake when rations are offered for ad libitum consumption (13, 25) until energy requirement of the animal is reached. Increased concentrate in the ration above this point results in decreased DMI and relatively constant DE consumption. Daily gain increased an average of .2 kg/d with each incremental increase in ration energy for all weight groups (Table 5). Weight gain has been shown to increase with increasing concentrate in the ration (12, 13, 14, 15) until intake is maximum. With further increases in concentrate feeding, gain remains constant (12) or declines slightly (13).

Ration ADF and NDF tended to decrease with increasing ration energy, reflecting the relationship between fiber and energy content of feeds. Bulk density increased with increasing ration energy, except in TMR fed heifers weighing 200 kg, which contained .08, .16, .14, and .16 g/ml as fed (Table 5).

TABLE 4. Mean, standard error (SE), minimum and maximum dry matter intake (DMI), ration acid detergent fiber (ADF), neutral detergent fiber (NDF), total digestible nutrients (TDN), bulk density (BULK), body weight (BW), daily gain (GAIN), and ambient temperature (AMBT) for all treatments.

	n	Mean	SE	Min	Max
DMI[1]	4972	6.1	.03	0	16.8
ADF[2]	96	30.0	.8	9.4	45.4
NDF[2]	96	51.6	1.2	24.1	72.4
TDN[2]	96	66.1	.8	49.6	82.6
BULK[3]	90	.16	.01	.06	.33
BW[4]	5096	247.2	.9	117.2	392.5
GAIN[4]	4846	.9	.01	−1.0	2.5
AMBT[5]	5032	12.5	.1	−11.3	25.6

[1] Kilograms per day.

[2] Percent of DM.

[3] Grams per milliliter as fed.

[4] Kilograms. Predicted by regression from weekly weights.

[5] Degrees.

TABLE 5. Mean plus standard error (SE) of dry matter intake (DMI), body weight (BW), daily gain (GAIN) ration acid detergent fiber (ADF), neutral detergent fiber (NDF), total digestible nutrients (TDN), bulk density (BULK), and ambient temperature (AMBT) for all treatments (Trt).

Trt	DMI[1]		BW[1]		GAIN[2]		ADF[3]		NDF[3]		TDN[3]		BULK[4]		AMBT[5]	
	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
1	4.6	.07	177	1.6	.6	.02	34.8	.8	56.0	2.1	63.1	.6	.12	.01	13.5	1.2
2	4.7	.04	174	1.0	.8	.01	28.5	.9	45.2	2.4	68.0	.7	.18	.01	13.2	1.3
3	5.3	.07	175	1.3	1.2	.03	18.4	1.0	40.8	1.9	75.6	.8	.23	.01	9.5	1.4
4	5.1	.04	183	1.0	1.4	.02	14.1	.9	30.5	1.6	79.1	.7	.30	.01	13.2	.9
5	3.7	.07	228	1.3	.5	.03	40.4	1.0	67.5	.8	54.9	1.1	.08	.01	13.2	.9
6	6.2	.05	240	1.0	.9	.04	32.7	1.3	57.0	.9	64.7	1.0	.16	.01	10.9	1.6
7	6.9	.06	255	1.5	1.0	.02	30.6	1.1	48.2	3.0	66.4	.8	.14	.01	14.8	1.0
8	6.8	.06	253	1.1	1.1	.02	29.6	1.0	50.5	2.3	67.1	.8	.16	.01	13.5	1.2
9	5.6	.06	307	1.1	.5	.03	41.0	1.3	68.4	1.0	54.3	1.5	.07	.01	14.5	1.1
10	7.5	.09	300	.9	.7	.02	36.5	.8	58.7	2.4	61.8	.6	.11	.01	13.5	1.2
11	8.2	.06	337	1.4	1.0	.03	28.4	.7	50.2	1.6	68.0	.6	.19	.01	10.9	1.6
12	8.0	.07	326	1.1	1.2	.02	24.9	.6	46.3	1.3	70.7	.4	.24	.01	9.5	1.4

[1] Kilograms per day, n = 377 to 448.

[2] Kilograms, n = 392 to 448.

[3] Percent of dry matter, n = 8.

[4] Grams per milliliter as fed, n = 6 to 8.

[5] Degrees, n = 54 to 56.

Polynomial regression indicated that second order polynomial regression best represents effects of ration ADF, NDF, and bulk density on DMI and DEI (Table 6). When quadratic effects were included r^2 of regression increased, whereas only slight increases in r^2 were obtained when cubic terms were included in models (Table 6). Body weight and daily gain increased linearly with increasing DMI and DEI. Quadratic and cubic terms improved precision of models only slightly. Ration ADF, NDF, and bulk density account for approximately twice the variation in data when DE is a dependent variable, suggesting that DEI and ration fiber are more related than DMI and ration fiber.

Second order polynomial regression of ration ADF, NDF, and bulk density on DMI and DEI are in Figures 1, 2, and 3, respectively. Data were pooled by treatment and week within trial to remove daily and individual animal variation. Dry matter intake ranged from approximately 75 to 110 g/kg body weight$^{.75}$. Digestible energy intake ranged from approximately 150 to 350 kcal/kg body weight$^{.75}$, which was similar to recommended dietary DE for growing ruminants (3). Maximum DMI and DEI were reached when ADF in ration DM reached approximately 21 and 16%, respectively (Figure 1). Jahn et al. (12) and Kang and Liebholz (13) reported maximum intake in heifers at 20 and 23% ADF in ration DM, respectively. Both DMI and DEI decrease as ADF increases above point of maximal intake, and physical factors related to animal size begin to restrict intake. It is of interest that DM intake curve plateaued before DEI curve. Bull (5) reported that depression of digestibility above maintenance of intake resulted in maximal DEI occurring before maximal DMI. Estimation of DE from TDN may have resulted in slight error in nature of DE curve.

Relationships between DMI and NDF and DEI and NDF (Figure 2) were similar to those of ADF. Maximum intake of DM occurred between 40 and 44% NDF, which was slightly higher than Mertens (18), who reported that optimum NDF in ration DM for maximum DMI in lactating dairy cows ranged from 32 to 40%.

TABLE 6. First, second, and third order polynomial regression of ration fiber and density, body weight and gain, and ambient temperature on dry matter and digestible energy intake.

Variable			Order of regression (r^2)[1]		
Dependent	Independent	n	1	2	3
DEI[2]	ADF[3]	4972	.44	.48	.48
DMI	ADF	4972	.13	.20	.20
DEI	NDF	4972	.36	.42	.43
DMI	NDF	4972	.13	.20	.21
DEI	BULK	4636	.37	.45	.47
DMI	BULK	4636	.12	.21	.24
DEI	GAIN	4735	.13	.14	.15
DMI	GAIN	4735	.07	.08	.08
DEI[4]	BW	4972	.28	.29	.30
DMI	BW	4972	.43	.43	.43
DEI	AMBT	4908	.01	.04	.04
DMI	AMBT	4908	.01	.03	.04

[1] r^2 of first (1), second (2), and third (3) order polynomial regression.

[2] DEI = Digestible energy intake (kcal/kg body weight$^{.75}$), DMI = dry matter intake (g/kg body weight$^{.75}$).

[3] ADF = Acid detergent fiber (% of dry matter), NDF = neutral detergent fiber (% of dry matter), BULK = bulk density (g/ml as fed), GAIN = body weight gain (kg/d), BW = body weight (kg), AMBT = ambient temperature (°C).

[4] DEI = Digestible energy intake (kcal/d), DMI = dry matter intake (kg/d).

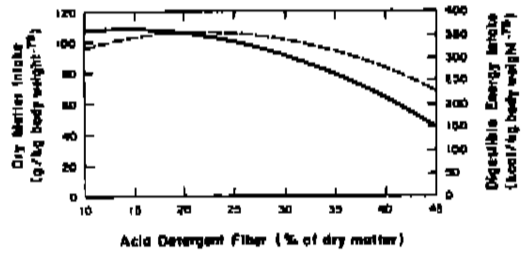

Figure 1. Second order polynomial regression of acid detergent fiber on dry matter intake (- - -; n = 96, r^2 = .44, $S_{y.x}$ = 11.1) and digestible energy intake (——; n = 96, r^2 = .76, $S_{y.x}$ = 31.6) in heifers weighing 100 to 400 kg.

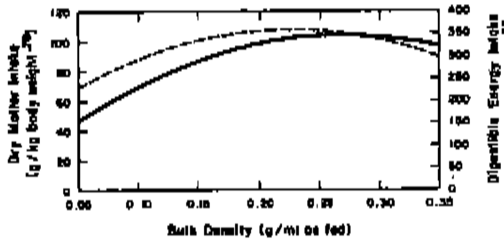

Figure 3. Second order polynomial regression of bulk density on dry matter intake (- - -; n = 96, r^2 = .46, $S_{y.x}$ = 10.95) and digestible energy intake (——; n = 89, r^2 = .69, $S_{y.x}$ = 35.0) in heifers weighing 100 to 400 kg.

Cattle with requirement for more energy will alter point of maximal feed intake to regulate more accurately energy balance (5). Maximum DEI occurred between 34 and 36% but changed little between 25 and 40% NDF (Figure 2).

Both DMI and DEI increased with increased bulk density up to .25 and .26 g/ml as fed, then decreased as bulk continued to increase (Figure 3). Bulk density resulted in prediction of DMI equivalent (as estimated by r^2) to ADF (Table 6). Below approximately .25 g/ml intake appears to be limited by physical factors.

Second order polynomial regression of NDF and DMI (Figure 2) produced r^2 similar to ADF (Figure 1) and bulk density (Figure 3). Because NDF is reported to be highly correlated to intake of forages (18, 26), it was of interest to determine whether NDF was more highly correlated with DMI at higher NDF than lower NDF. Correlations between DMI, ADF, and NDF in ration DM and bulk density when NDF in ration DM was greater than 42% (point of maximum DMI) or less than 42% are in Table 7. Correlations between NDF and DMI at NDF greater and less than 42% were −.42 and −.03, respectively, suggesting that NDF is more important in regulation of voluntary intake when rations contain more NDF. Coefficients between ADF and DMI were similar to NDF when NDF was above and below 42%.

Bulk density was also highly correlated with DMI when NDF was greater than 42% of ration DM (Table 7). When NDF was less than 42% of

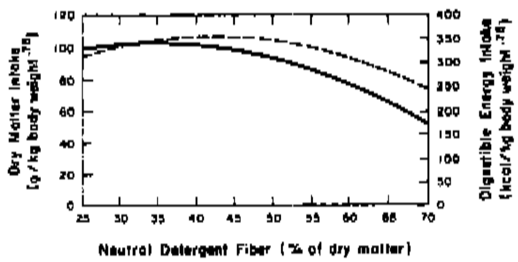

Figure 2. Second order polynomial regression of neutral detergent fiber on dry matter intake (- - -; n = 96, r^2 = .46, $S_{y.x}$ = 10.9) and digestible energy intake (——; n = 96, r^2 = .67, $S_{y.x}$ = 36.5) in heifers weighing 100 to 400 kg.

TABLE 7. Correlation coefficients[1] of intake of dry matter and acid detergent fiber, neutral detergent fiber, and bulk density when NDF in ration dry matter is greater or less than 42%.

Correlation[2]	NDF in ration	
	Greater	Less
DMI:NDF	−.42	−.03*
DMI:ADF	−.42	−.03*
DMI:BULK	.39	−.02*
NDF:ADF	.81	.24
NDF:BULK	−.82	−.52

[1] All coefficients significant ($P<.001$).

[2] Number of observations: greater = 4148, less = 824. DMI = Intake of dry matter (g/kg body weight$^{.75}$), NDF = neutral detergent fiber (% of ration DM), ADF = acid detergent fiber (% of ration DM), BULK = bulk density (g/ml as fed).

*$P>.05$.

ration DM, correlation of bulk density, ADF, and NDF with DMI were nonsignificant ($P > .05$). Correlations between NDF and ADF were .81 and .24 when NDF was greater and less than 42% of ration DM, respectively. This suggests that ratio of NDF to ADF in ration DM changed with varying types of feed ingredients used in this trial. Correlation between NDF and bulk density was similar to that of NDF and ADF.

Addition of ration fiber terms to body weight and daily gain should increase accuracy and precision of equations predicting DMI in dairy heifers. Selection of ADF, NDF, or TDN depends upon information available. Effects of ambient temperature were statistically significant but may not be of practical importance in temperate climates.

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