Prediction of Available Energy in Dairy Cow Rations from Dietary Fiber

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ABSTRACT

Two published equations and four derived equations that predict dietary energy from dietary crude or acid detergent fiber were evaluated for accuracy. The equations estimated total digestible nutrients, digestible energy, metabolizable energy or net energy lactation of diets of cows completing 480 lactations in which mean dietary crude fiber varied among seven dietary groups from 174 to 225 g crude fiber per kilogram of dry matter consumed. Intakes of available dietary energy were compared against feeding standard requirements. Mean quotients obtained by dividing energy intakes from equations by energy requirements (concurrence values) varied from 1.00 to 1.05 among equations. Concurrence values decreased as dietary fiber increased.

Available dietary energy content expressed in any common energy term was accurately predicted from dietary fiber for full-fed milking Holsteins through use of equations presented in the text.

INTRODUCTION

Knowledge of available energy content of rations is needed to feed dairy cows properly (1). Four energy units—TDN (total digestible nutrients), DE (digestible energy), ME (metabolizable energy) and NE_l (net energy lactation)—are used to describe the available energy of feedstuffs or rations (1, 14, 17). Equations are used to calculate available energy content from ration components or to convert one energy unit to another (3-5, 8, 12-19). The usefulness of equations to predict available energy contents of dairy cattle rations depends on their accuracy. CF (crude fiber) and ADF (acid detergent fiber) of DM (dry matter) consumed by cows were highly negatively correlated with milk production (2). Among published equations using CF to estimate the TDN content of feedstuff DM are:

Equation I:

TDN (g/kg DM) = 902.5 − 1.175 g CF/kg DM

Equation II:

TDN (g/kg DM) = 787 − .802 g CF/kg DM

Equation I was derived from data obtained from 14 feeding trials using milking cows (8). Equation II was derived by regressing TDN contents of alfalfa hays (determined with sheep in metabolism trials) on CF contents of those hays (12, 13). These equations have not been tested extensively enough to ascertain their reliability in predicting TDN contents of rations fed to high-producing cows. However, preliminary evaluations indicate both equations should reliably predict TDN contents of ration DM (2, 8).

Use of ADF to predict dietary energy offers advantages over using CF because ADF is a more specific fiber fraction and is more easily determined (5, 20).

Objectives were: 1) to derive equations to predict dietary energy from dietary ADF, 2) to evaluate accuracy of two published and four derived equations in estimating energy content of dietary DM from ration CF or ADF of diets for full-fed, high-producing cows.

METHODS

Derivation of Equations

Equations to predict dietary TDN, DE, ME and NE_l contents from ADF were derived in a manner similar to those in (8) and from the same feeding trials used in (8). Ration ingredients, dietary ADF, intake and production data from 170 lactations of Holstein cows distributed among 14 rations are in Table 1. Data from each cow were compiled by 14-day periods for the first 6 months of each lactation. The DMI (DM intake) and ADF of consumed DM were determined for each cow in each period; ADF was determined by method in (20). Means for DMI, dietary ADF, body weight, body weight change, and production of 4.0% FCM (fat-corrected milk) were derived for cows fed each of the 14 rations. Mean daily cow requirements by ration group for TDN, DE, ME and NE_l were calculated for maintenance, weight change, and milk from constants listed in (17). These 14 sets of data are in Table 1. Each energy requirement in Table 1 was divided by the related DMI to obtain energy concentrations of consumed DM for each of the 14 diets for the four energy units used. Each of the four sets of energy concentrations and dietary ADF values were used in regression analysis to derive equations to predict TDN, DE, ME and NE_l of consumed DM from ADF of consumed DM (Table 2).

Table 1. Ration ingredients, mean of daily DMI (dry matter intake), FCM (4.0% fat corrected milk) produced, ADF (acid detergent fiber) content of DM (dry matter) consumed, requirements of TDN (total digestible nutrients), DE (digestible energy), ME (metabolizable energy), NE_l (net energy lactation) of 14 cow groups (ration).

Ration[2]	DMI	FCM	ADF	Energy required[1]			
				TDN	DE	ME	NE_l
	kg/da	kg/da	% of DM	kg/day	Mcal per day		
Alfalfa[3]	15.9	14.1	30.5	8.23	36.3	30.9	18.7
Alfalfa[4]	13.8	10.1	35.0	6.56	29.0	24.9	14.9
Alfalfa[3]	17.7	13.5	38.0	8.04	35.4	30.5	18.3
Alf-CS[5]	15.4	14.8	35.2	8.63	38.1	32.7	19.6
Alfalfa[4]	11.1	5.9	45.8	4.92	21.7	18.6	11.2
Alf-CS[6]	12.6	10.4	39.8	6.74	29.7	25.5	15.3
Alfalfa[3]	17.9	14.5	39.8	8.44	37.2	32.0	19.2
Alf-CS[5]	15.7	16.1	35.5	8.80	38.8	33.4	20.0
Alfalfa[4]	13.6	8.4	44.7	5.86	25.8	22.2	13.3
Alf-CS[6]	12.8	11.2	37.9	6.80	30.8	25.8	15.5
Alf-CS[5]	14.4	18.2	29.2	8.90	42.9	36.9	22.2
CS[7]	14.0	17.8	19.8	9.86	43.5	37.4	22.4
Alf-CS-C[8]	17.9	19.6	27.0	10.92	48.2	41.4	24.8
CS-C[9]	15.0	18.7	17.1	10.26	45.3	38.9	23.3

[1]Requirements for maintenance, milk produced and weight change calculated from (17).
[2]Based on 13 14-day periods of lactation and an average of 13 cows per ration.
[3]Hay cut in early bloom.
[4]Hay cut in late bloom.
[5]Hay cut in early bloom with corn silage.
[6]Hay cut in late bloom with corn silage.
[7]Corn silage fortified with corn and urea.
[8]Hay cut in early bloom, corn silage, corn and urea.
[9]Corn silage, corn and urea.

Table 2. Equations used to estimate available dietary energy from dietary CF (crude fiber) or ADF (acid detergent fiber) on a dry matter (DM) basis.

Equation number		Equation	R^2	Ref.
I[1]	TDN (g/kg DM)	= 902.5—1.175 g CF/kg DM	.89	8
II	TDN (g/kg DM)	= 787 —.802 g CF/kg DM	.76	12, 13
III[1]	TDN (g/kg DM)	= 859.6—.9339 g ADF/kg DM	.83	
IV[1]	DE (Mcal/kg DM)	= 3.86 —.00427 g ADF/kg DM	.79	
V[1]	ME (Mcal/kg DM)	= 3.313—.00366 g ADF/kg DM	.79	
VI[1]	NE_l (Mcal/kg DM)	= 1.985—.00218 g ADF/kg DM	.79	

[1]Number of observations equals 14; an average of 13 cows per ration observed for 13 14-day periods of lactation.

Evaluation of Equations

Data from two herds of Holstein cows that were not used to derive equations were used to test equations in Table 2 for accuracy. Both herds had been used to evaluate effects of dietary energy on milk production (6, 7). Cows in herd 1 completed 232 lactations and were divided into four groups, in which dietary fiber for total lactations averaged 221, 203, 189 and 174 g CF/kg DM consumed. Two qualities of alfalfa hay were supplemented with corn-based concentrates to form the four dietary groups. In herd 2, 248 lactations were completed among diets containing 255, 236, and 205 g CF/kg DM consumed. Cows in herd 2 generally consumed equal quantities of alfalfa haylage and corn silage. Amounts of concentrates fed were based on three concentrate-to-milk ratios to form three dietary groups. For each lactation period, the following information was compiled for the seven dietary groups of the two herds: DM intake, CF content of consumed DM, body weight, body weight change, milk production, and fat percent of milk. ADF content of consumed DM in herds 1 and 2 was predicted from dietary CF: ADF (g/kg DM) = 31.7 + 1.04 g CF/kg DM. This equation was derived from the relation of CF and ADF in dietary DM from base data (8). The two forms of fiber were highly correlated (r = .98).

Equations were tested for accuracy to predict dietary energy content as follows: each equation was used to calculate the mean energy content of ration DM from dietary fiber content for the seven dietary groups. These energy contents were multiplied by the related DM intakes to obtain "equation energy intakes". Dietary energy requirements for maintenance, milk produced, and weight change were calculated from factors in (8, 16, 17). It was assumed that these energy requirement sums derived from feeding standards and termed "standard intakes", were the best possible estimates of dietary energy requirement (intake) available against which to test energy intakes derived from use of these equations. Energy consumed and dietary requirements are in Table 3. Equation energy intakes were divided by standard intakes (requirements). The resulting quotients, termed concurrence values, were measures of the accuracy of the equations used. A concurrence value of 1.0 indicated equation energy intake equaled standard energy requirement and therefore accurately assessed the energy of dietary DM. Deviation of concurrence from 1.0 reflects the degree of inaccuracy of an equation to predict the energy content of a diet; values below 1.0 indicate underestimations, those above 1.0 overestimations.

Table 3. Mean daily consumption of dietary energy[1] and energy required for maintenance, milk produced and body weight change for complete lactation by cows fed different mean concentrations of crude fiber in two herds.

Item	Herd 1				Herd 2		
Mean dietary crude fiber, g/kg DM	221	203	189	174	255	236	205
Energy consumed daily							
Equation I, kg TDN[2]	9.52	10.09	10.74	11.45	10.73	11.38	12.20
Equation II, kg TDN	9.03	9.48	10.03	10.61	10.36	10.88	11.46
Equation III, kg TDN	9.10	9.62	10.22	10.84	10.31	10.94	11.61
Equation IV, Mcal DE[3]	40.80	43.20	45.80	48.70	46.30	49.10	52.10
Equation V, Mcal ME[4]	34.80	36.80	39.20	41.50	39.50	41.90	44.50
Equation VI, Mcal NE_l[5]	20.90	22.00	23.50	24.90	23.70	25.10	26.70
Energy required daily							
NRC-71[6], TDN, kg	9.36	9.77	10.01	10.62	10.76	11.25	11.65
NRC-78[7], TDN, kg	9.23	9.59	9.85	10.40	10.58	11.09	11.40
NRC-78, DE, Mcal	40.70	42.30	43.40	45.90	46.70	48.90	50.30
NRC-78, ME, Mcal	35.00	36.60	37.40	39.50	40.20	42.10	43.30
NRC-78, NE_l, Mcal	21.00	21.90	22.40	23.60	24.00	25.20	25.90

[1]Product of dry matter intake and predicted energy content of consumed feed.
[2]Total digestible nutrients.
[3]Digestible energy.
[4]Metabolizable energy.
[5]Net energy lactation.
[6]Nutrient Requirements of Dairy Cattle. 1971. (8, 16).
[7]Nutrient Requirements of Dairy Cattle. 1978. (17).

Mean concurrence values over total lactations for the seven dietary groups represented in herds 1 and 2 were calculated using the six equations in Table 2. Requirements were derived through use of factors in (17). These 42 concurrence values shown in Table 4 were subjected to analysis of variance that considered equations and diets as sources of variance. The remaining variance constituted error variance.

Analyses of variance of TDN intakes using Equations I and II (equation intakes) and standard TDN requirement intake were used to explore effects of lactation period on the relationship between equation intakes and requirement (Table 5). Selection of equations was arbitrary; all would have shown similar relationships. Because Equation I was derived to meet energy requirements outlined in (8, 16) those requirements were used in these analyses of variance. Dietary group mean TDN intakes for all lactation periods were analyzed. Means from herds 1 and 2 were based on averages of 58 and 83 observations per period. Data from each herd were analyzed separately. Variables considered in the analysis using herd 1 were the three methods by which TDN intake was calculated, dietary CF content, period of lactation, and interactions. Intakes of TDN derived from only Equation I and the standard requirement were included in analysis of variance of herd 2 data.

Table 4. Mean lactational concurrence values[1] as effected by equation and dietary fiber when 1978 feeding standard was used to calculate requirements.

Dietary ADF	Equations used[2]					
	I	II	III	IV	V	VI
g/kg DM						
			Herd 1			
262	1.03	.98	1.01	1.00	.99	1.00
243	1.05	.99	1.01	1.02	1.01	1.00
228	1.09	1.02	1.06	1.06	1.05	1.05
213	1.10	1.02	1.07	1.06	1.05	1.06
			Herd 2			
300	1.01	.98	.99	.99	.98	.99
277	1.03	.98	1.00	1.00	1.00	1.00
245	1.07	1.01	1.03	1.04	1.03	1.03

[1]Concurrence value = dietary energy consumed/dietary energy requirement.
[2]See Table 2 for equations.

Table 5. Analysis of variance of dietary means of TDN (total digestible nutrients) intake as affected by method used to calculate intake, ration CF (crude fiber) and period of lactation.

Source of variance	Herd 1[1]			Herd 2[2]		
	df[3]	SS[4]	P[5]	df	SS	P
Method of measurement (M)[6]	2	22.11	<.01	1	.00	
Ration CF (C)	3	88.68	<.01	2	14.31	<.01
M X C	6	3.27	<.01	2	1.07	<.01
Period of lactation (P)[7]	21	497.60	<.01	9	9.50	<.01
M X P	42	14.02	<.01	9	2.30	<.01
C X P	63	5.77	<.01	18	2.25	<.05
Error (M x C x P)	126	4.06		18	.87	

[1]Mean values contained 58 observations per period of lactation.
[2]Mean values contained 83 observations per period of lactation.
[3]Degrees of freedom.
[4]Corrected sums of squares.
[5]Probability.
[6]Involved use of equations to predict dietary TDN content from dietary CF and multiplying those values with dry matter intakes. The standard intake against which other intakes were compared was TDN required for maintenance, milk produced and body weight changes (8, 14).
[7]Herd 1 used 14-day periods; Herd 2 used 30-day periods.

RESULTS AND DISCUSSION

Evaluating Equations

Approximately 80% of variance in dietary energy concentrations was explained by variation in dietary CF or ADF among the 14 rations (Table 2).

Details of the relationships between estimated dietary TDN intake derived from Equations I and II and requirements (8, 16) throughout lactation are depicted in Figures 1 and 2 for herds 1 and 2. Lactation periods affected TDN intake ($\underline{P}<.01$, Table 5, Figures 1 and 2). As mean dietary CF increased among groups within herds, TDN intake decreased (Table 3). These two effects are normal and were shown previously (2, 6-8, 18). Period of lactation interacted with method of predicting TDN intake ($\underline{P}<.01$, Table 5). As lactation advanced, differences among TDN intake estimates varied according to method used to measure TDN intake (Figures 1 and 2). This relationship will be covered in greater detail when concurrence values are discussed. The interaction of method of predicting TDN intake and CF level affected TDN intake ($\underline{P}<.01$, Table 5). As mean ration CF for complete lactations decreased, TDN intake within herds increased at different rates for the equation intakes relative to intakes from standards (Table 3).

Concurrence values (energy intake/energy required). With Equation I, mean concurrence values for the seven dietary groups ranged from 1.00 to 1.08 (mean of 1.037) when the older feeding standard (8,16) was used and ranged from 1.01 to 1.10 (mean of 1.054) when a newer feeding standard (17) was used (Table 4). These differences in concurrence values based on selection of feeding standard were caused by differences between feeding standards. TDN requirements calculated from the 1978 feeding standard (17) were about 2% below those from the 1971 standard (8, 16). Use of Equation II resulted in similar differences between concurrence values when different sets of factors were used to calculate TDN requirements. Concurrence values generated through use of (17) were affected by the equation used ($\underline{P}<.001$, Table 4). Mean concurrence values using Equation I exceeded those from Equation II (1.05 vs 1.00; $\underline{P}<.001$). Mean concurrence values were 1.02 for the remaining equations. Concurrence values from every equation increased ($\underline{P}<.001$) as dietary fiber decreased (Table 4). However, the range of values was small. Equation II was the most accurate in predicting TDN contents of the seven rations fed to cows in herds 1 and 2. Equation II resulted in estimates of TDN intake that deviated less than 3.0% from dietary requirements (17) for any one of the seven dietary groups (Table 4). Equations III through VI predicted energy intakes within 7% of requirements in every case.

Coffey et al. (3) indicated that estimates of energy intakes for total lactations exceeded requirements calculated from (17) by 6 to 8%. All concurrence values for total lactations in this study were closer to 1.0 than in (3). We concluded that all equations effectively predicted mean energy contents of rations for milking cows based on requirements from (8, 16) or (17). In the case of equations using ADF to predict energy content, the question arises whether these equations were adequately tested when it was necessary to predict ADF from CF in herds 1 and 2. However, even though the testing procedure for Equations III, IV, V and VI was not ideal, results are not likely to be misleading. It is clear that these equations need further testing in trials in which dietary ADF was analyzed.

At this point, accuracy of the equations for predicting ration DM energy contents for periods within lactations was not known. Figure 3 depicts mean concurrence values by lactation periods derived from the use of Equations I and II with (8, 16) for diets fed to cows in herd 1. Concurrence values for lactation periods for herd 1 using other equations also were determined. It was clear that concurrence between energy intake and energy requirement varied among periods of lactation. There were factors other than dietary fiber that affected concurrence values among lactation periods. Equations I, III, IV, V and VI were derived from mean data of cows that were full-fed (8). After lactations were initiated, feed intake increased for several weeks even though dietary fiber also increased (6, 7). It was noted (4, 12, 14) that as feed intake increased, digestibility decreased. In herds 1 and 2 digestibility may have decreased because of a compounding effect of an increase in dietary fiber and DMI as lactation progressed. That could explain concurrence values that increased to the time of maximum DMI. However, Ehle found no decrease in DM digestibility of several diets as lactation advanced even though dietary intake increased (9). Gastrointestinal fill increased with these diets as lactation advanced (11). These latter two observations suggest that concurrence values among lactation periods in herds 1 and 2 were not affected by changes in digestibility as lactation advances except for change in dietary fiber content.

Concurrence values that deviated from lactation means among lactation periods probably were caused by errors in predicting energy requirements among lactation periods from (17). Energy requirements were based on energy needs for milk production, maintenance and an adjustment to that energy need depending on whether the cow lost, maintained or gained weight. There was one factor for weight lost and another for gain, neither of which probably reflected accurately the energy involved. Determining the cause of variance in concurrence values among lactation periods is beyond the scope of this paper but the need for further research is clearly indicated. If the causes of deviations from lactational mean concurrence values among lactation periods could be explained, more confidence in the use of the equations presented would follow.

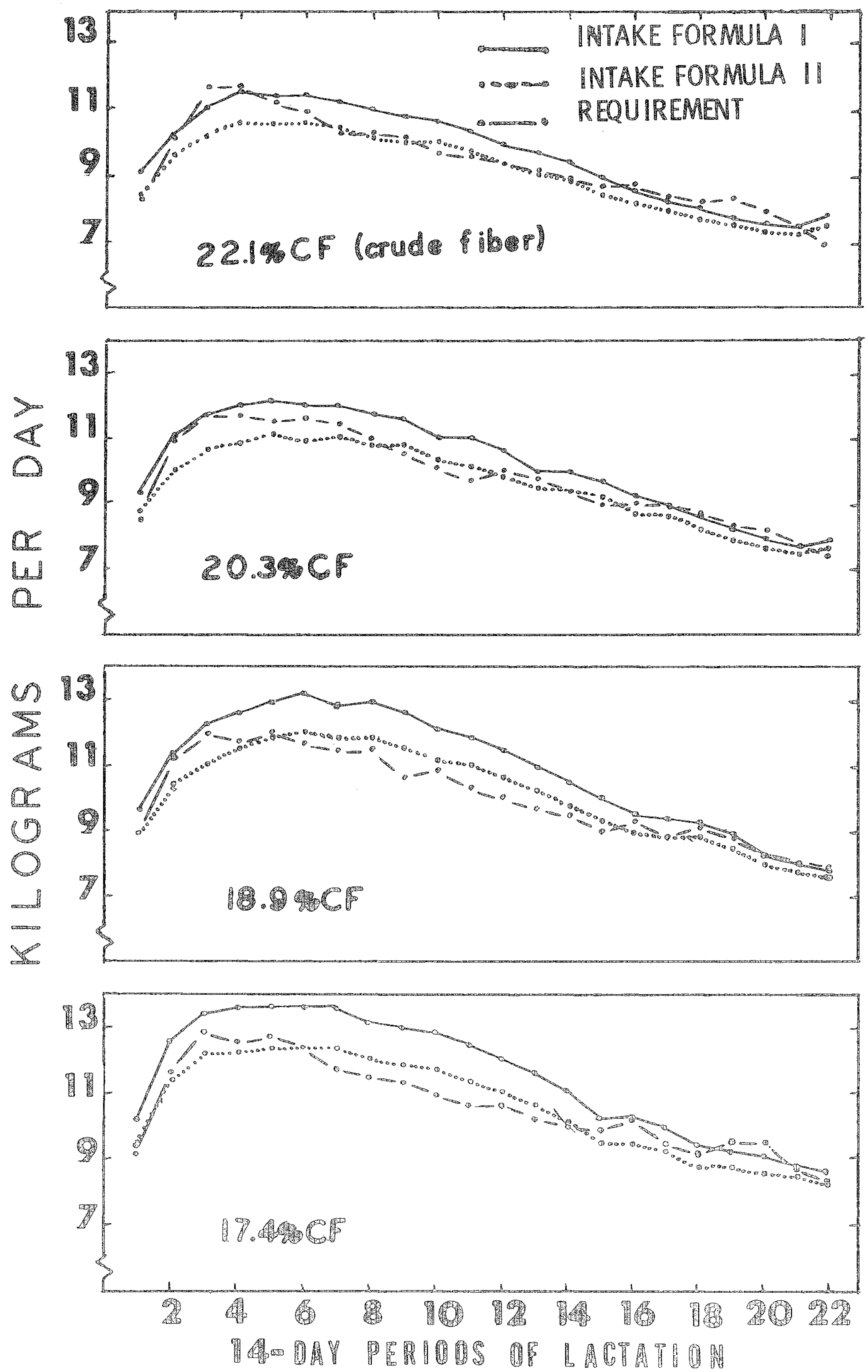

Figure 1. Intake of TDN (total digestible nutrients) derived from Equation I (——), Equation II (······) and TDN requirements (·———·), of cows in Herd 1 by period of lactation for cows fed four diets with mean CF (crude fiber) contents of 221, 203, 189 and 174 g CF/kg dietary dry matter (22.1, 20.3, 18.9 and 17.4% CF).

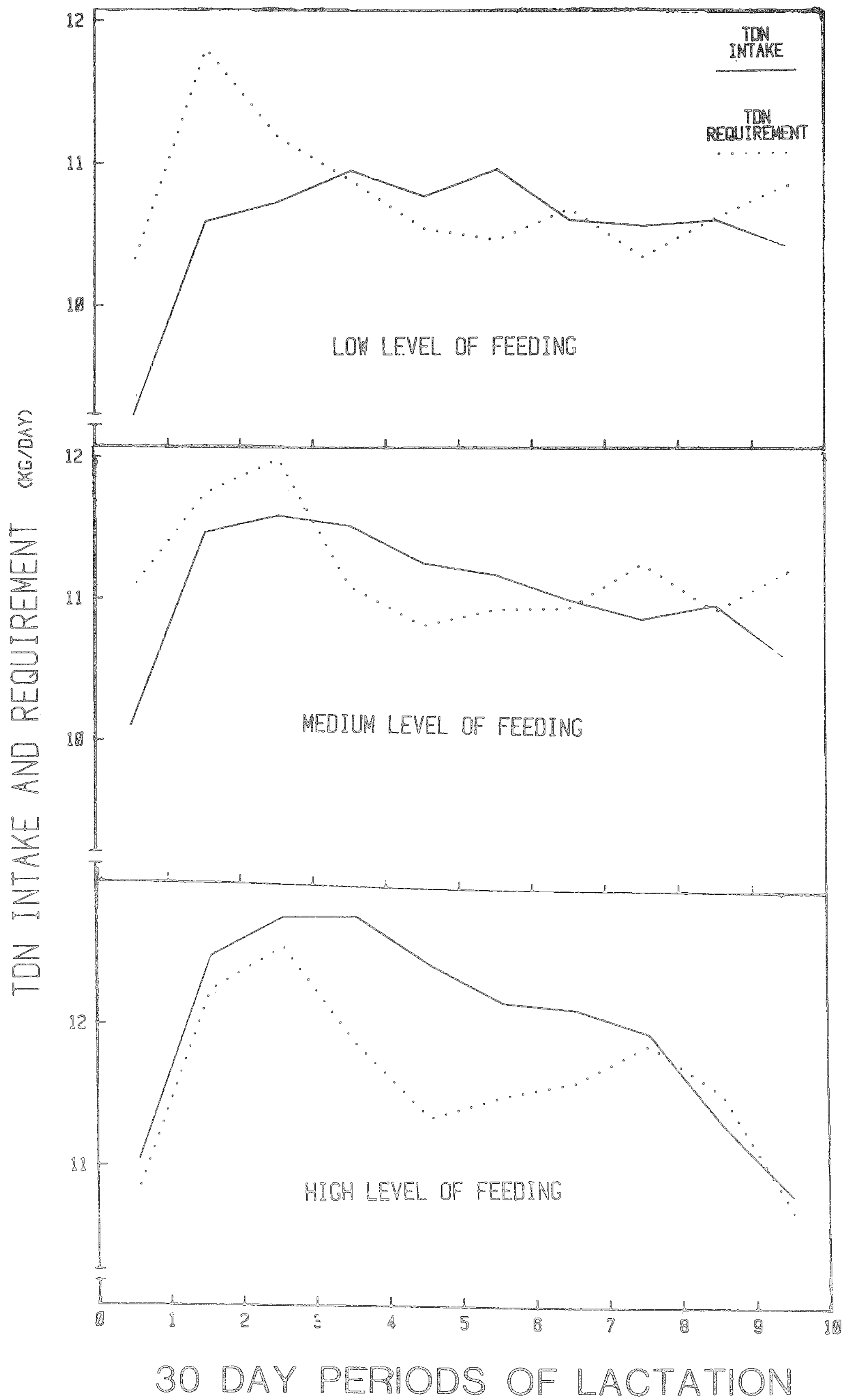

Figure 2. Intake of TDN (total digestible nutrients) derived from Equation I (———) and TDN requirements (······) of cows in Herd 2 by period of lactation for cows fed a low level of feeding (255 g CF (crude fiber)/kg dietary DM (dry matter), a medium level of feeding (236 g CF/kg DM) and a high level of feeding (205 g CF/kg DM).

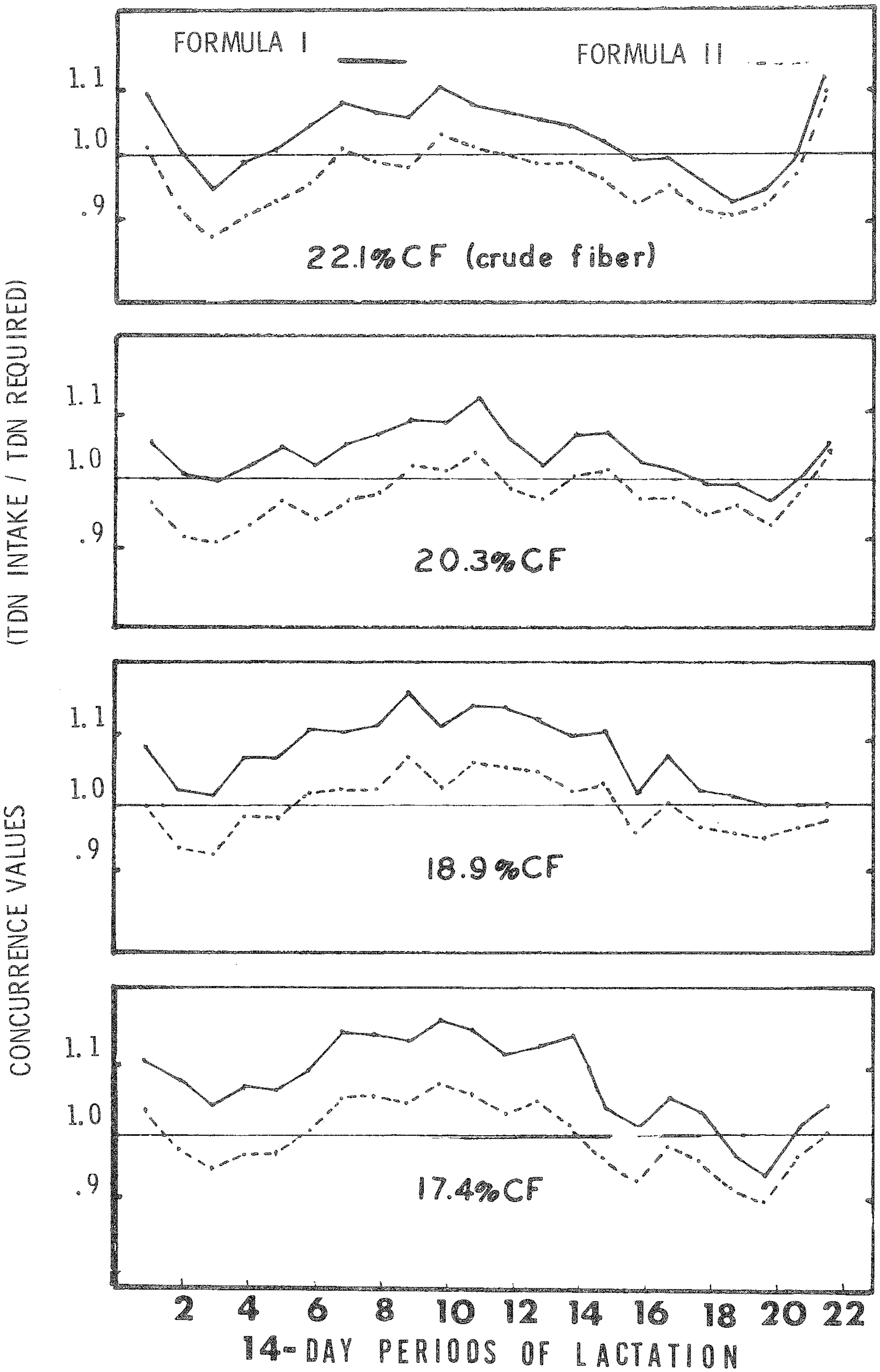

Figure 3. Concurrence of TDN (total digestible nutrients) intake by use of Formulas I and II with TDN required of cows in Herd 1 by periods of lactation and rations that differed in mean crude fiber contents.

CONCLUSIONS

The derivation and testing of equations to predict the available energy content of rations for high-producing dairy cattle was encouraging. All equations using CF or ADF predicted the available energy contents of the seven rations within 10.0% of what would balance energy need for complete lactations; the mean concurrence value was 1.02 and ranged from 1.0 for Equation II to 1.05 for Equation I. Equation II predicted TDN contents that were in all cases within 2.0% of requirements among the seven test groups. The concurrence between intake of dietary energy and its requirement from the 1978 feeding standard deviated considerably more from 1.0 among lactation periods than lactation means for all equations. Causes of this variance are not known. The equations presented are relatively simple, compared to others (4), and have been tested extensively with data from milking cows.

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