Application of Neutral Detergent Fiber in Modeling Feed Intake, Lactation Response, and Body Weight Changes in Dairy Cattle

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ABSTRACT

A computer simulation model was developed using theoretical equations to predict DM intake in dairy cattle when the NDF and energy content of the diet and the energy requirements of the animal were known. An adjustment factor for NDF quality was determined to account for differences in intake with legume-based and grass-based diets when formulated at equal NDF content. Mathematical functions were developed from actual data to describe body reserve tissue mobilization and deposition and used to refine the determination of energy requirements and energy balance of the animal.

Actual data on milk production and BW changes of Holstein cows under three feeding systems (individual concentrate, one- and two-group total mixed rations) were used to evaluate the model. There was good agreement between observed and predicted production responses, except for the one group total mixed ration, where daily milk yield was over-predicted during early lactation. Further calculations showed that the amount of available CP was too low to support the high milk production that the model predicted in early lactation with the one-group feeding system. This problem was corrected by incorporating a protein restriction on milk production using NRC guidelines.

INTRODUCTION

Mathematical modeling and computer simulation have been successfully used to conduct systems research and to provide management decision support. A prerequisite for the effective use of this approach in management is the availability of a simple but accurate mathematical description of the system's response to various inputs.

Published data have shown a strong relationship between DM intake and production responses, but it has been difficult to establish cause and effect (21, 28). Over the past three decades much research has been focused on the prediction of DM intake, and more recently, Mertens (13) developed a feed intake model based on the concepts presented by Conrad (6). Theoretical equations were used in this model to describe both physical and physiological mechanisms of intake regulation. The model represents a significant improvement over previous methods of predicting DM intake. Its major advantages are: 1) it is based on sound theoretical principles of feed intake regulation; 2) the inputs can be obtained from forage analyses and DHI records; and 3) it is relatively simple computationally.

The model of Mertens (13) also has some limitations that restrict its accuracy. First, because it uses strictly NDF to quantify the fill effect of the diet, it fails to reflect differences in DM intake between legume and grass-based diets formulated at equal NDF content. The second limitation is the simplistic method by which the energy available from body tissue mobilization is determined and accounted for in the total energy balance of the animal. Finally, by assuming a constant gut capacity, the model predicts more or less constant DM intakes over the entire lactation.

The first objective of this study was to improve the accuracy of Mertens' method of predicting DM intake and, subsequently, energy intake by 1) incorporating a correction factor for NDF quality into the prediction model, 2) refining the method of calculating energy requirements, especially with respect to body tissue mobilization and deposition, and 3)

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allowing gut capacity to vary over the lactation. The second objective was to develop a mathematical model to predict the production responses in dairy cattle in terms of milk yield and BW changes based on the predicted energy intake. It is proposed that this model would accurately predict the performance of individual cows or of groups of similar cows when fed various rations with different feeding strategies, and the model would greatly enhance our ability to conduct nutritional management research.

MATERIALS AND METHODS

The model proposed by Mertens (13) is illustrated in Figure 1. The curves a to b and b to c represent physical and physiological intake regulation described by Equations [i] and [ii], respectively. Mertens proposed that NDF be used to represent the fill effect of the diet and that gut capacity be expressed in terms of NDF intake capacity (NDFIC) in Equation [i].

Equations [i] and [ii] may be solved independently and the smaller of the two predicted intakes may be used as the predictor of DM intake. However, there is a unique solution at the point where the two equations intersect. This solution is obtained by setting the equations equal to each other, as in Equation [iii], and solving for DM intake. Equation [iii] may be rewritten as:

$$\text{Intake} = \frac{\text{NDF intake capacity}}{(\text{A})\text{FNDF} + (1 - \text{A})\text{CNDF}} = \frac{\text{Net energy requirements}}{(\text{A})\text{FNE}_l + (1 - \text{A})\text{CNE}_l} \quad [1]$$

where A is the fraction of forage DM in the total ration, FNDF and CNDF are the fractions of NDF in the forage and concentrate, and FNE_l and CNE_l are the energy densities of the forage and concentrate.

Mertens used a value of 1.1% of live BW as an estimate of NDFIC. The NDF and net energy content of the forage and concentrate may be obtained from tabulated values or feed analyses. The net energy requirement of the animal is the sum of energy requirements for maintenance, milk production, pregnancy, and growth. A solution for A is first obtained; then either of the two equations may be used to solve for DM intake. This model represented the starting point in this study, and the refinements that were incorporated are discussed herein.

Neutral Detergent Fiber Quality

The model described in Figure 1 assumes that all sources of NDF will have the same effect on intake, but experimental data (12) have shown higher intakes of legume-based than grass-based rations, even when rations are formulated at equal NDF content. Van Soest et al. (26) suggested that the higher intake of legume than grass-based diets is due to the faster rate of fermentation and greater buffering capacity of legume cell walls. Fiber sources with low cation exchange capacity (CEC) tend to have a low buffering capacity, long lag times, and slow rates of fermentation.

McBurney et al. (10) found significant negative relationships between CEC and the ratio of hemicellulose plus cellulose to lignin, and Mertens (12) observed decreased intakes with three forage-based rations as the ratio of hemicellulose plus cellulose to lignin increased (Figure 2).

McBurney et al. (11) stated that the role of the fiber matrix in buffering the rumen is primarily a function of the buffering capacity

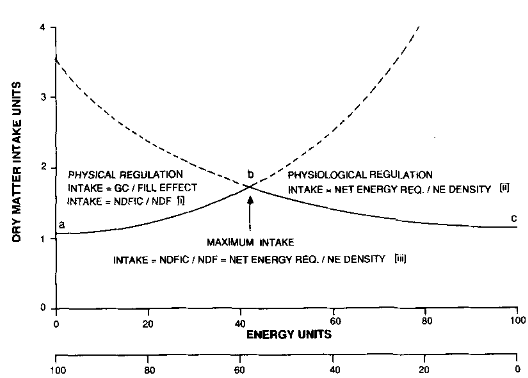

Figure 1. Mertens's dry matter intake model, adapted from Conrad (6). Line a to b represents intake limited by the fill effect of the diet; line b to c represents intake limited by energy demand of the animal. Dashed lines represent unattained intake, predicted by extrapolating the theoretical Equations [i] and [ii].

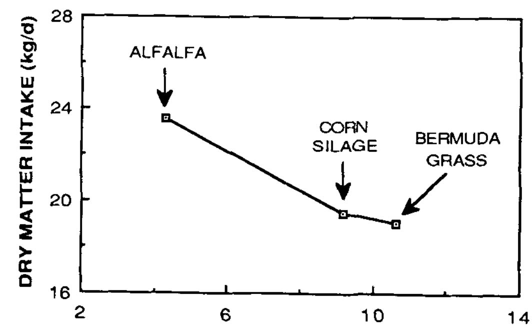

Figure 2. Observed intakes of three rations based on alfalfa, corn silage, and bermuda grass, all formulated at 36% NDF content. Data from Mertens (12).

of the matrix and the quantity of cell wall ingested. Therefore, any adjustment factor for NDF quality should take into account the fraction of forage in the total diet (A), the fraction of NDF in the forage (FNDF) and the ratio of structural carbohydrate to lignin. Initially we tried an additive adjustment factor (NDFADJ), which would increase or decrease the NDF fraction in the ration depending on the forage source, and which was based on the reciprocal of the hemicellulose plus cellulose to lignin ratio (RATIO):

$$NDFADJ = A * FNDF * RATIO \qquad [2]$$

For any specific forage, FNDF and RATIO are constant and NDFADJ is a linear function of the forage fraction (A) in the ration. Using compositional data from Van Soest et al. (26) for most of the common grass and legume species and values for A ranging from 0 to 1, calculated NDFADJ ranged from .0 to .14. The NDF in the ration was adjusted by the deviation of the NDFADJ value from the midpoint of its range. Thus:

$$ANDF = NDF + (.07 - NDFADJ) \qquad [3]$$

where ANDF is the adjusted NDF fraction in the ration.

Predicted intakes based on ANDF, using Equations [2] and [3] were higher for alfalfa and lower for corn silage and bermuda grass rations compared with data from Mertens (12). This was interpreted to indicate that the importance of the buffering capacity of the forage is inversely related to the forage to concentrate ratio and, therefore, a curvilinear adjustment factor may be more appropriate. The best fit to data of Mertens (12) was obtained with the following equation:

$$NDFADJ = A * FNDF * RATIO * 1.33^{-A} \qquad [4]$$

Calculated values for NDFADJ using Equation [4] ranged from .0 to .10, and the following equation was used to adjust for NDF quality:

$$ANDF = NDF + (.05 - NDFADJ) \qquad [5]$$

Values for NDFADJ with different forage fractions for a typical corn silage forage (55% NDF and 6% lignin) using Equations [2] and [4] are shown in Figure 3. In Table 1 predicted intakes without adjustment and with adjustment for NDF quality using Equations [4] and [5] are compared to observed intakes from Mertens (12). Without adjustment, the predicted intakes are identical for all three rations and different from observed, but with adjustment, the predicted intakes are similar to observed. Consequently, Equation [1] was modified by including Equations [4] and [5] to adjust for NDF quality. With this modification the solution for A had to be obtained by iteration, using a starting value for A from the original form of Equation [1].

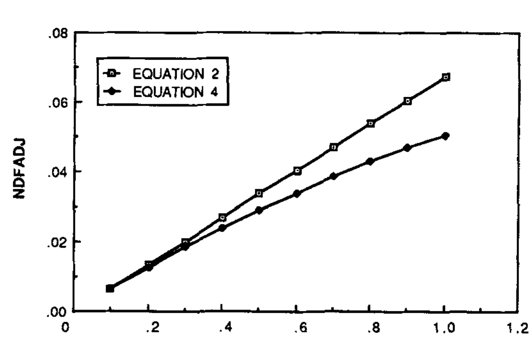

Figure 3. Values for NDF adjustment factor (NDFADJ) using Equations [2] and [4] with a typical corn silage forage (55% NDF and 6% lignin).

TABLE 1. Observed[1] and predicted intakes of alfalfa, corn silage, and bermuda grass-based rations at equal NDF (36%) content.

Forage	Dry matter intake		
	Observed	Predicted	
		A[2]	B[3]
	(kg/d)		
Alfalfa	23.58	21.67	23.49
Corn silage	19.50	21.67	20.60
Bermuda grass	19.05	21.67	19.80

[1] Observed data from Mertens (12).

[2] Without adjustment for NDF quality.

[3] With adjustment for NDF quality.

Body Reserve Tissue Mobilization

The mobilization of body reserve tissue is an important biological process, that is positively correlated with milk production responses during early lactation and total lactation milk yield (24). In addition, changes in body tissue reserves and fat also affect feed intake both physically and physiologically (2, 22). Studies on BW changes during early lactation (9, 24) indicate that body reserves may be mobilized during the first 6 to 12 wk postpartum and that the length of this period depends on the genetic ability of the cow for milk production (4, 23). The rate of mobilization tends to increase very sharply to a miximum at about 14 d postpartum (24) and approximately two-thirds of total body tissue mobilized is lost during the first 4 wk of lactation (9, 24). Based on these findings, the mobilization of body reserve tissue was defined using the following three constraints: 1) tissue mobilization ends on d 70 postpartum; 2) it is maximum on d 14 postpartum; and 3) 66% of total mobilization takes place in the first 4 wk postpartum. The following equation was developed to describe the potential amount of body reserves that the animal was capable of mobilizing on day t ($INCM_t$):

$$INCM_t = (.23 * t^{.74} * e^{-.048t}) - |5 - t|/351 \quad [6]$$

The values for $INCM_t$ from d 1 to 70 of lactation are illustrated in Figure 4. These values may be interpreted as the amount of body tissue from a reserve pool of a certain size that is mobilized on day t of lactation. The size of this hypothetical reserve pool is the area under the curve in Figure 4. Values of $INCM_t$ were converted to fractions of total and were used to describe a fixed rate of tissue mobilization from a variable pool size. This pool of reserve tissues represented the potential amount of reserves the cow was capable of mobilizing.

Moe (14) showed that 33% of the milk energy output during the first 28 d of lactation was obtained from body reserve tissues for cows producing an average of 907 kg of FCM during this period. Using this information, the potential fraction of energy coming from body reserves during the first 28 d of lactation (RSEN28) was calculated as:

$$RSEN28 = .33 * FCM28/907 \quad [7]$$

where FCM28 is kilograms of FCM produced in the first 28 d of lactation. The term FCM28/907 is used as a scaling factor so that if FCM28 is larger than 907, then RSEN28 would be greater than 33%. RSEN28 is then used to calculate the potential amount of body reserves (RESPO) that the cow is capable of mobilizing during the first 70 d postpartum.

$$RESPO = (RSEN28 * FCM28 * .74 * 1.5)/ENRES \quad [8]$$

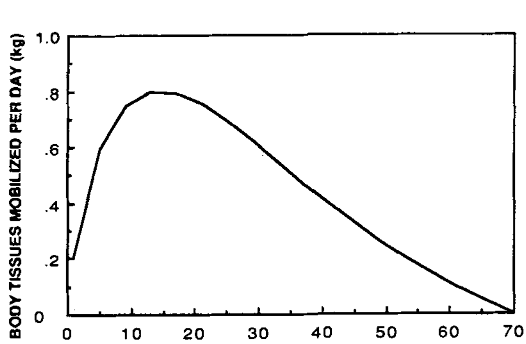

Figure 4. Values for the potential amount of body tissue reserves mobilized per day, for an animal mobilizing 30.81 kg of reserve tissues, from d 1 to 70 of lactation.

where .74 is the energy value in megacalories NE_l per kilogram 4% FCM, the factor 1.5 accounts for the fact that only 66% of total potential reserves is mobilized during the first 28 d of lactation, and ENRES is the energy value of body reserves in Mcal NE_l/kg. This equation would account for very high producers having a much greater potential to mobilize body reserves than low producers, due to the scaling factor FCM28/907 used in calculating RSEN28, and the fact that FCM28 is positively correlated with total lactation production. However, RESPO could be in error for cows that deviate in BW from the BW of the cows in Moe's (14) study.

Body Tissue Deposition

The efficiency with which dietary energy is utilized for body tissue deposition is much higher during lactation than during the dry period (15). Therefore, it was assumed that the cow had the ability to replenish body reserves, which were mobilized during early lactation, before drying off. Whether or not this is actually achieved would depend primarily on the energy intake relative to protein intake and milk yield in mid lactation and late lactation.

No information was found on the rate at which body reserves are replenished after mobilization is over, but actual data from Trimberger et al. (24) suggests a rate that increases as lactation progresses. The following function was developed to predict the rates of body tissue deposition after the initial period of mobilization was over, assuming a balanced protein nutrition:

$$INCD_t = .23 * (376 - t)^{.8} * e^{-.012(376 - t)} \qquad [9]$$

where $INCD_t$ is the amount of body tissue from a predetermined amount, which is deposited on day t of lactation, and 376 − t restricts the process to the period from d 71 to 305 of lactation. The values of $INCD_t$ were converted to fractions of total tissue deposition, and the total amount of body tissues mobilized was multiplied by these fractions to obtain the potential amount of tissue reserves which the cow was capable of depositing on any day from d 71 to d 305 of lactation.

The amount of energy needed to deposit body tissue reserves on day t of lactation was calculated and added to the energy requirements of the cow. This added energy represented a potential for body tissue deposition, which may not be achieved if energy intake is lower than energy requirements. This may happen with high NDF diets and the total body reserves mobilized during early lactation may not be replenished by d 305.

The equations used to model body tissue deposition were based on the assumption that all tissue actually mobilized in early lactation is fully replenished by d 305 of the lactation. If full replenishment of body tissue was not achieved by this time, then it was assumed that the cow was capable of replenishing the remainder at a constant rate, equal to rate on day 305, each lactation day above 305 or during the dry period with an efficiency of utilization of energy for body tissue deposition of .595 (15).

In the model of Mertens (13), body reserve tissue was mobilized prior to the determination of energy intake and the amount of energy available from the mobilized tissue was subtracted from the energy requirements. In this study, the daily energy balance was calculated after calculating the energy requirements and predicting energy intake. Body reserve tissues were mobilized or deposited, depending on whether the energy balance was negative or positive. This scheme (Figure 5) was proposed by Monteiro (18) and is supported by data from Chigaru and Topps (4) and Trigg and Topps (23). When mobilization occurred, the energy from the mobilized tissues was added to the energy intake, and this total available energy was partitioned to maintenance and production.

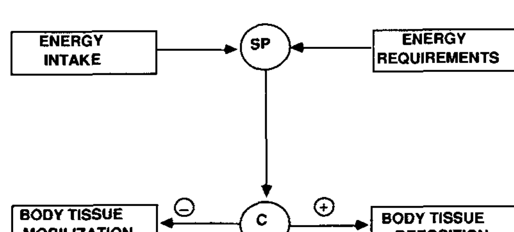

Figure 5. Schematic diagram of body tissue reserve changes in relation to energy intake and energy requirements. Adapted from Monteiro (18). SP = Summation point, C = controller.

Energy Requirements

Total energy requirements on day t were calculated by summing the requirements for maintenance, milk production, pregnancy, growth, and body tissue deposition. Maintenance requirements of 80 and 73 kcal/kg $BW^{.75}$ were used for lactating and dry cows, respectively (17, 19).

The potential milk yield by day of lactation was described by Wood's equation (29) with parameters estimated by Congleton and Everett (5). The energy value in megacalories NE_l of the potential milk yield was calculated by converting the actual milk to 4% FCM and multiplying it by .74.

The requirements for pregnancy in terms of megacalories NE_l per day of gestation were calculated with the following equation from Moe and Tyrrell (16):

$$ME_{pt} = .576 * e^{.0174t} \quad [10]$$

where ME_{pt} is the metabolizable energy in megacalories required on day t of gestation. These energy values were converted to NE_l values dividing by 1.55 (15).

Potential average daily gain was predicted using the first derivative of the Bertalanaffy growth function, which was:

$$dW_t/dt = 3\ k\ W_t\ (u_t^{-.33} - 1) \quad [11]$$

where W_t is body weight on day t, u_t is the proportion of mature weight attained by day t ($u_t = W_t/A$, where A is mature weight), and k is a rate constant, which determines the spread of the curve along the time axis. Values for k of .0026, .0024, and .0022 were used for mature weights of 600, 650, and 700 kg, respectively (1).

Sensitivity Analysis

Sensitivity analysis was used to derive relationships in several areas of the model in which the authors were not aware of directly applicable published results. This approach was applied to: 1) the determination of gut capacity; 2) the calculation of DM intake when physical and physiological intakes were not the same, and 3) the determination of priority factors for partitioning energy intake between milk production and growth and body tissue reserve deposition.

Gut Capacity

Tulloh and Hughes (25) showed that rumen volume in lactating cows was 32 to 40% larger than in dry cows. Martin and Ehle (9), using deuterium dilution, found that mean gastrointestinal fill was 30% greater at 5 mo postpartum than at 1 mo prepartum. Therefore, gut capacity was allowed to vary between .8% and 1.2% of live BW. The values for gut capacity as a percent of BW, which resulted in intake curves similar to data from Trimberger et al. (24), were calculated and are given in Figure 6.

Dry Matter Intake

Most empirical equations used to predict DM intake give increased predicted intakes with increased milk production. Part of this increased intake is probably due to the fact that high producing cows are fed more concentrates, but it is also possible that the physical limit on intake is not a fixed and absolute value. It seems that the physical limit is elastic, and it increases as the deficit in meeting metabolic needs becomes greater (7). Therefore, the physical intake was increased by 10% of the difference between the physical and physiological intake if the latter was greater.

According to the physiological theory of intake regulation, animals regulate intake in relation to their energy needs, but evidence to support this control mechanism has not been conclusive (8). It seems that, especially with

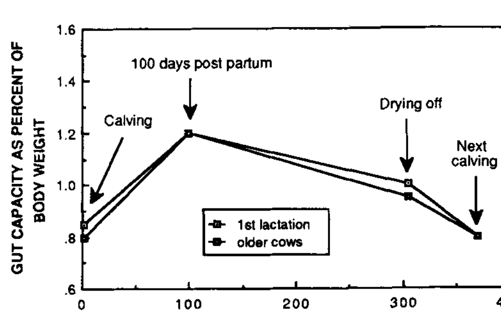

Figure 6. Gut capacity as a percent of body weight for first lactation and older cows.

high concentrate diets, energy intake exceeds energy requirements (20). This was accounted for in the model by decreasing the physical intake by 60% of the difference between the physical and physiological intake, whenever the former was greater.

Priority for Growth and Body Tissue Reserve Deposition

Energy intake in the model was partitioned to maintenance, pregnancy, milk production, growth, and body tissue reserve deposition. When energy intake was insufficient through physical limitations to meet the energy requirements after d 70 postpartum, a priority factor was used to decrease milk production and the extra energy was diverted to growth and body tissue reserve deposition. This method is supported by Waldo (27) who suggested that production is decreased and the physical limit is driven up by an energy deficit. The priority factor, PRIOR, for first lactation cows was calculated as:

$$\text{PRIOR} = (1/(\text{LACLEN} - 70)) * (\text{DIM} - 70) \qquad [12]$$

where LACLEN is the length of the present lactation and DIM is days in milk. This factor ranged from almost 0 on d 71 postpartum to 1 at drying off. For older cows, PRIOR was multiplied by .25.

These calculations were done for each cow in the model on each day of the production cycle and from the energy intake the various production parameters such as milk production, body weight change and body tissue deposition were determined. The model is written in Fortran and runs with the GASP IV simulation language. A flow chart of the model is given in Appendix 1.

RESULTS AND DISCUSSION

Because of the strong relationship between production and DM intake (21, 28), a satisfactory validation of the model in production responses would also indirectly confirm the accuracy with which the model predicted DM intake. Predicted results from the model were compared with experimental data from Cassel et al. (3) on daily milk yield and BW changes in Holstein cows. These data were collected over 44 wk of lactation from both first lactation and older cows on different feeding systems. The feeding systems were: 1) individual concentrate feeding; 2) one-group total mixed ration; and 3) two-group total mixed ration. There were 7, 6, and 18 first lactation cows and 16, 11, and 17

TABLE 2. Observed and predicted lactation milk yields and body weights for first lactation cows under different feeding systems.

Item	Total 44-wk milk	Body weight		Tissue reserves	
		Start	End	Start	End
	(kg)				
Individual concentrate feeding					
Observed[1]	7240	473	583		
Estimated	7293	473	584	47	73
One-group total mixed ration					
Observed[1]	6378	472	597		
Estimated	6333	472	571	47	71
Two-group total mixed ration					
Observed[1]	6683	476	583		
Estimated	6684	476	590	48	83
Three-group total mixed ration[2]					
Estimated	6974	476	589	48	83

[1] Observed data from Cassel et al. (3); no estimates of tissue reserves were given in this data.

[2] Observed data for the three-group feeding system were not available.

older cows, respectively, on these feeding systems.

The first step in the validation process was to evaluate the response in total lactation yield and BW changes. For the three feeding systems considered, there was little difference between the observed and predicted lactation yields for first lactation (Table 2) and for older cows (Table 3). Predicted BW changes for first lactation (Table 2) and for older cows (Table 3) with the three feeding systems were also close to the observed values. The model was also used to predict lactation yields and BW changes for a three group total mixed ration. The results given in Tables 2 and 3 show that lactation yields with this feeding system are much closer to the individual concentrate feeding system than the one- and two-group total mixed ration.

Predicted body tissue reserve changes are also given in Tables 2 and 3 for first lactation and older cows. For the older cows, the ending tissue reserves with one-, two-, and three-group total mixed ration were much higher than for cows on the individual concentrate feeding system, probably because the rations were too high in energy for the amount of milk produced by these cows. These results demonstrate that the model accurately predicts the lactation yield and BW change for a wide range of feeding systems.

The second step in validating the model was to evaluate responses in daily milk production. Observed and predicted daily milk production with the individual concentrate and the two group total mixed ration feeding systems for first lactation and older cows are illustrated in Figures 7 and 8. Overall there was a close agreement between the predicted and observed daily milk yields, although for first lactation cows with the two-group total mixed ration, daily milk yields tended to be a little higher and lower, before and after the ration changed on d 188 in the lactation. On the other hand, with the one-group total mixed ration the model predicted much higher daily milk yields than observed during early lactation for both first lactation (Figure 9a) and older cows (Figure 9b).

Response in milk yield predicted with the model up to this point was entirely a function of energy intake and energy availability from body tissue reserves. Calculations showed that the one-group total mixed ration was the only feeding system among those evaluated in which the available CP was too low to support the high milk production predicted by the model

TABLE 3. Observed and predicted lactation milk yields and body weights for second and greater lactation cows under different feeding systems.

Item	Total 44-wk milk	Body weight		Tissue reserves	
		Start	End	Start	End
	(kg)				
Individual concentrate feeding					
Observed[1]	7545	560	640		
Estimated	7536	560	633	71	89
One-group total mixed ration					
Observed[1]	7024	606	670		
Estimated	7047	606	689	87	129
Two-group total mixed ration					
Observed[1]	7324	579	640		
Estimated	7322	579	654	76	104
Three-group total mixed ration[2]					
Estimated	7486	579	658	76	109

[1] Observed data from Cassel et al. (3); no estimates of tissue reserves were given in this data.

[2] Observed data for the three-group feeding system were not available.

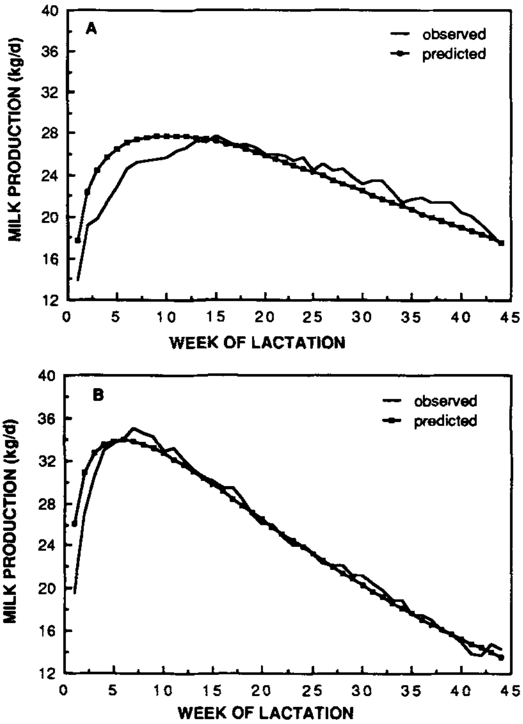

Figure 7. Observed and predicted daily milk yields with individual concentrate feeding: A) first lactation cows; B) second lactation and older cows.

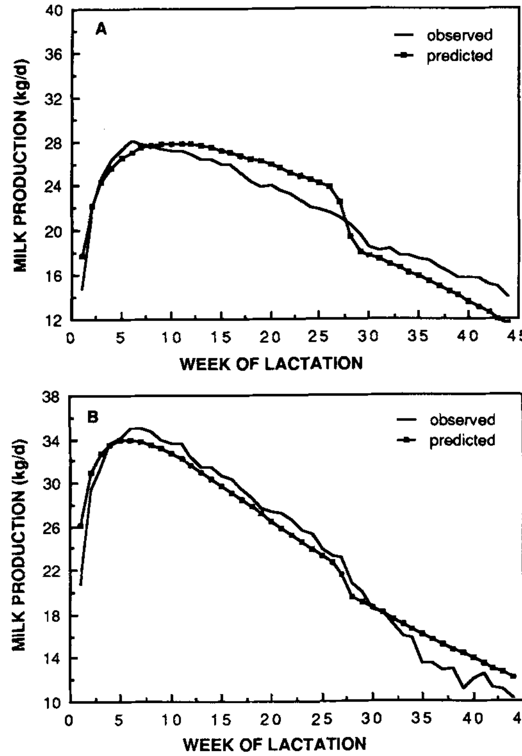

Figure 8. Observed and predicted daily milk yields with two-group total mixed ration: A) first lactation cows; B) second lactation and older cows.

during early lactation, (Figure 9). Therefore, the model was refined to restrict milk production during early lactation to the amount of available CP after maintenance requirements, according to NRC (19) guidelines. This restriction resulted in lower peak milk yields and more persistent lactations for both first lactation (Figure 10a) and older cows (Figure 10b), and there was a closer agreement with the observed daily milk yields.

The model was tested with rations based on alfalfa (45% NDF), corn silage (55% NDF), and bermuda grass (65% NDF) with an individual concentrate feeding system. The results of the simulation runs are given in Table 4. Total lactation milk yield was about 1500 and 500 kg lower with the bermuda grass and corn silage-based rations, respectively, and the amount of body tissues that were mobilized were much higher with these two types of rations than with the alfalfa-based ration. Dry matter intake peaked much earlier and at a higher intake, and postcalving BW was regained earlier in the lactation with the alfalfa-based ration versus the rations that were based on corn silage or bermuda grass. These results are in line with those obtained in the field with similar types of rations, and they illustrate the robustness of the model in predicting responses with various forage-based rations and feeding strategies.

CONCLUSIONS

The actual mechanisms that control feed intake in ruminant animals and the importance of different intake control mechanisms in animals with different physical characteristics and in different physiological states are still not clearly understood. Interactions between the chemical and physical properties of the feeds and animal characteristics are also important in determining the type of intake control mechanism that is operative.

The feed intake model developed in this study, using the model of Mertens (13) with the

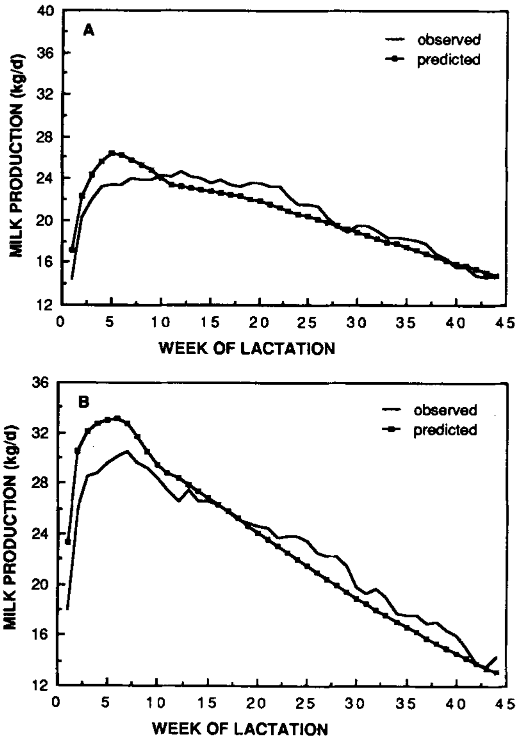

Figure 9. Observed and predicted daily milk yields with one group total mixed ration: A) first lactation cows. B) second lactation and older cows.

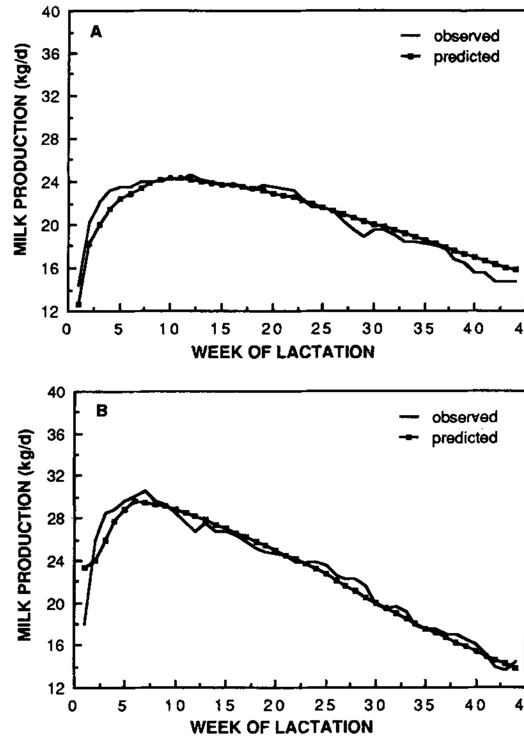

Figure 10. Observed and predicted daily milk yields with one group total mixed ration. Milk yield was restricted during early lactation to the amount of available crude protein: A) first lactation cows; B) second lactation and older cows.

refinement for NDF quality, improved the prediction of DM intake for different forage-based rations. Also, with the inclusion of other refinements for body tissue mobilization, gut capacity, and especially CP availability, the model accurately predicted animal performance with different types of feeding systems.

The evidence examined suggests that certain characteristics of the forage cell wall component have an effect on feed intake. The operative mechanism in this case seems to be a relationship between these forage cell wall characteristics and rates of fermentation and passage. This mechanism was handled in the model by using a correction factor for NDF quality, which was based on the hemicellulose plus cellulose to lignin ratio. As more empirical data become available, the quantitative relatioinships can be expressed more precisely. There is also a need for other forage characteristics that are important in determining rate of passage, especially particle size, to be considered in the intake model.

In developing the feed intake model sensitivity analysis was used in the absence of published data to derive some parameters. The most important of these parameters were rates

TABLE 4. Results of simulation runs with different forage-based rations.[1]

Item	Alfalfa	Corn silage	Bermuda grass
NDF, %	45	55	65
Lactation yield, kg FCM	9370	8898	7878
Body reserves mobilized, kg	55	96	100
Week of peak DM intake	11	14	15
Peak DM intake, kg	24.3	21.4	19.5
Week postcalving BW regained	28	33	34

[1] These results were obtained with an individual concentrate feeding system.

of body tissue mobilization and deposition, gut capacity, and NDF quality. Lack of information suggests a need for empirical research in these areas. The question of protein reserves also needs to be researched, since CP availability is important in determining daily milk yield during early lactation. Finally, the model may be further refined by including dietary protein fractions and protein reserve pool and keeping an inventory on this pool for each animal.

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APPENDIX

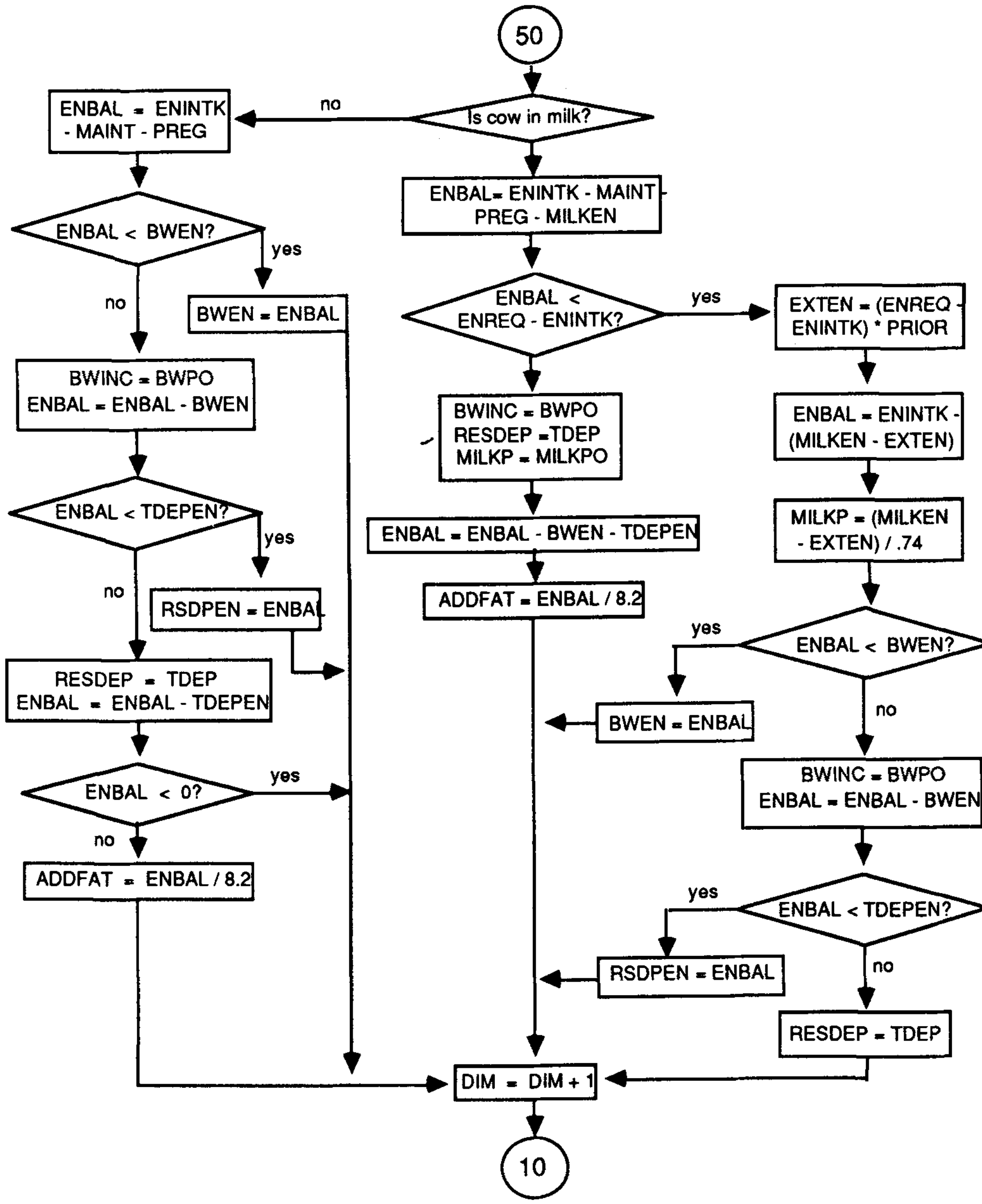

Figure A1. Flow chart of the dry matter intake model. DIM = Days in milk, FNDF = forage NDF, CNDF = concentrate NDF, FNEL = forage NE_l, CNEL = concentrate NE_l, FLIG = forage lignin, RSENPO = potential energy from body tissue reserves, PEAKD = day of peak milk production, BWPO = potential average daily gain, MILKPO = potential daily milk production, MILKP = actual daily milk production, ENREQ = energy requirements, GUTCAP = gut capacity, A = forage fraction in total ration, DMINTK = dry matter intake, ENINTK = energy intake, RESMOB = actual amount of body reserves mobilized/d, BWINC = actual daily gain in body weight from growth, ADDFAT = actual amount of fat deposited, EXSEN = excess energy intake above requirements, RESPOT = daily potential energy available from body reserves, ENDEF = energy deficit, ENBAL = energy balance, MAINT = maintenance requirement for energy, PREG = pregnancy requirement for energy, BWEN = energy in body weight gain, MILKEN = milk energy, RESDEP = actual body tissue reserves deposited, TDEP = potential body reserves to be deposited, and EXTEN = extra energy for growth and body tissue deposition.