Short Communication: Further Validation of the Fat Sub-Model in the Cornell-Penn-Miner Dairy Model

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ABSTRACT

Recently, a fat sub-model was introduced into the Cornell-Penn-Miner Dairy model (CPM-Dairy; Moate et al., 2004). The principal aim of the work reported here was to validate this fat sub-model in terms of its accuracy in predicting the apparent absorption (intake – feces) of total long-chain fatty acids (LCFA) in lactating dairy cows. The fat sub-model in CPM-Dairy was used to predict the amounts (g/d) of total LCFA apparently absorbed from 63 diets described in 14 published experiments. These predicted amounts (PLCFA) were regressed against the amounts reported to be apparently absorbed (RLCFA). The regression equation was:

$$\text{PLCFA} = -24.8 \pm 25.2 + 1.011 \times 0.029 \times \text{RLCFA}; \\ R^2 = 0.95, \text{RMSE} = 55.2 \text{ g/d}.$$

The results show that for a diverse range of diets, the fat model in CPM-Dairy can accurately predict apparent absorption of dietary total LCFA.

Key words: fat model, apparent absorption, validation

The fat sub-model in the Cornell-Penn-Miner Dairy model (**CPM-Dairy**) is unique among models of fat digestion in dairy cows in that it can predict: 1) the intake (g/d) of 10 long-chain fatty acids (**LCFA**) from dietary feeds; 2) the amount (g/d) of each LCFA produced within the rumen as a result of lipolysis; 3) the biohydrogenation within the rumen of lipolyzed unsaturated LCFA; 4) the de novo synthesis within the rumen of LCFA; 5) the passage to the duodenum of lipolyzed and unlipolyzed LCFA; and 6) the intestinal absorption of both unlipolyzed and lipolyzed LCFA (Moate et al., 2004). The fat model was developed almost entirely with data from published experiments involving lactating dairy cows in which daily dietary intakes, duodenal flows, and fecal outputs of individual LCFA were reported. Unfortunately for validation purposes, this left a dearth

of suitable data from experiments with lactating dairy cows. Therefore, as described previously, the initial validation of the model involved 7 experiments with non-lactating cattle (mostly young growing steers) and only 1 experiment with lactating dairy cows (Moate et al., 2004). The initial validation involved 36 experimental diets from 8 published papers. That validation exercise compared the reported and predicted flows (g/cow per d) of 10 individual LCFA (lauric, myristic, palmitic, palmitoleic, stearic, oleic, vaccenic, octadecadienoic, octadecatrienoic, and “other” LCFA) to the duodenum and also compared the reported and predicted amounts of these same 10 LCFA that were truly absorbed in the intestines (duodenal – fecal). Despite the fact that the fat sub-model in CPM-Dairy had been developed entirely with data from lactating dairy cows, the sub-model was able to accurately predict the duodenal flows and intestinal absorptions of the majority of the individual LCFA and there was close concordance between the reported and predicted amounts of total LCFA truly absorbed from the intestines (Moate et al., 2004). Despite this validation of the model in nonlactating cattle, a major aim of CPM-Dairy is to accurately predict the absorption of nutrients from the intestines of dairy cows to enable accurate prediction of the lactation response to a particular diet. The principal aim of the work reported here was to validate the fat sub-model in terms of its accuracy of predicting the apparent absorption (intake – feces) of total LCFA in lactating dairy cows.

Sources used for data in the current investigation were experiments that measured the apparent absorption of total LCFA in multiparous, lactating Holstein cows. The inclusion criteria used were: 1) experiments had to involve lactating dairy cows; 2) the published reports of the experiments contained the information required by CPM-Dairy for making predictions on apparent absorption of total LCFA; and 3) the reported information on each experiment had to be internally consistent. With respect to criterion 2, the necessary information included total LCFA intake (g/d), fecal output of total LCFA (g/d), dietary concentrations of CP and NDF and cow details. With respect to criterion 3, there could be no major inconsistencies within a paper. For example, when the relevant data were reported,

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the reported total intake of LCFA had to be equal to the sum of the reported quantities of DM of the individual feeds by the corresponding reported LCFA concentration in each individual feed. Of the experiments that, *prima facie*, seemed to be applicable to this validation but were excluded, the most common reason was inadequate description of dietary inputs. Three cases were excluded due to serious inconsistencies (>200 g/d) in reported experimental data.

There were 2 types of experiments: abomasal infusion experiments and feeding experiments. The various dietary treatments in both the abomasal infusion and feeding experiments covered a diverse range of fat supplements. There were 3 abomasal infusion experiments, all conducted at the University of Illinois and involving 15 treatment groups in total (Drackley et al., 1992; Christensen et al., 1994; Bremmer et al., 1998). The abomasal infusion experiments involved a control group of cows being fed a standard TMR based on corn silage, alfalfa hay or silage, corn grain, and a protein supplement, usually soybean meal. Additional treatments consisted of different quantities and types of fat supplement being continually infused into the abomasum of the cows. The fat supplements were infused by means of infusion lines that had been passed through the rumen cannula, the rumen, the sulcus omasi, and anchored in the abomasum with a rubber flange. For the abomasal infusion experiments, the mean $\pm$ standard deviation, minimum, and maximum in the total intakes (g/d, including infusate) of total LCFA were: $1,005 \pm 164$, 637, and 1,256, respectively.

The data for the feeding experiments came from 11 experiments (Jenkins and Jenny, 1989; Schauff et al., 1992; Schauff and Clark, 1992; Wu et al., 1993; Elliott et al., 1996; Pantoja et al., 1996; Chan et al., 1997; Pires et al., 1997; Ruppert et al., 2003; Avila et al., 2000; Weiss and Wyatt, 2004) conducted in 5 laboratories from across the United States (Arizona, California, Illinois, Ohio, and South Carolina). The feeding experiments, like the abomasal infusion experiments, generally involved a control group of cows being fed a standard TMR based on corn silage, alfalfa hay or silage, corn grain, and a protein supplement, usually soybean meal. Additional treatments in these experiments usually involved supplementing the cows' diets with different quantities and types of fat supplements. Tallow was used in 9 diets, whole cottonseeds in 8 diets, prilled LCFA in 5 diets, hydrogenated esterified fat in 7 diets, and calcium salts of LCFA in 5 diets. There were 50 diets in the 11 experiments, but 2 diets from 1 experiment were excluded from this investigation because there were substantial discrepancies (282 and 248 g) between the reported daily intake of total LCFA and the calculated daily intake of total LCFA (based on the

reported intakes of dietary feeds and reported concentrations of total LCFA in dietary feeds). For the 48 diets in the feeding experiments, the mean $\pm$ standard deviation, minimum, and maximum total intakes (g/d) of total LCFA were: $1,189 \pm 391$, 552, and 1,828, respectively. Additional experimental details on the abomasal infusion and feeding experiments are given in each publication.

Version 3.0 of CPM-Dairy was used to make predictions on the apparent absorption of total LCFA from each of the individual diets from the abomasal infusion and feeding experiments. The usual procedure was as follows. When modeling diets from a single experiment, the control diet was first entered into a CPM-Dairy session. First, all the feeds in the control diet were selected from the CPM-Dairy feed dictionary and their amounts (kg of DM) were entered into the session. These amounts were calculated from the reported total DMI for the control diet and from the reported concentration of feed ingredients in the control diet. Next, the CPM-Dairy feed report was checked to compare the CPM-Dairy estimated dietary concentrations of CP and NDF with the reported concentrations for these nutrients. If discrepancies were evident, alternative feeds, usually a different alfalfa hay or corn silage, were selected from the feed dictionary so that the estimated and reported dietary concentrations of CP and NDF were similar. The next step involved matching the reported intake of total LCFA with the CPM-Dairy predicted intake of total LCFA. If total intake of LCFA was not explicitly reported in a particular experiment, then it was estimated as the product of the reported DMI (kg) and the concentration (g/kg) of total LCFA in the DM. By adjusting the concentration of ether extract of the forage ingredients in the ration, the predicted intake of total LCFA was made to match the reported intake of total LCFA. The ether extract of the forage ingredients was adjusted because, in our experience, forages generally have greater coefficients of variation in concentrations of ether extract (and total LCFA) than do "high-fat" feeds. In most experiments, detailed fatty acid profiles for individual feed ingredients were not reported. However, in some experiments, fatty acid profiles were reported for some of the major dietary feeds, usually the fat supplement, and sometimes the major forage ingredient; these profiles were edited into the ration when applicable. In some experiments, the fatty acid profiles of the total mixed rations were reported. When this was the case, the fatty acid profiles of the forages were edited so that, as far as possible, the predicted fatty acid profile of the total diet matched the reported fatty acid profile of the total diet.

Once the CPM-Dairy session for the control diet matched the reported control diet in terms of total in-

take of LCFA, profile of LCFA, and concentrations of CP and NDF, the next step was to enter the 14 cow details required by the CPM-Dairy program. Although the cow details are required for running of CPM-Dairy program, cow details other than current BW have no impact on the calculations related to the fat model. The cow details are: lactation number, current age (mo), first calving age (mo), calving interval (mo), current BW (kg), mature BW (kg), calf BW (kg), days pregnant, BCS, live-weight change, milk production (L/d), milk fat percentage, DIM, and milk protein percentage. Many of these details were reported in each publication. When days pregnant was not reported, but DIM was, days pregnant was assumed to be DIM minus 70 when DIM was greater than 70, and zero when DIM was less than or equal to 70. When individual publications failed to report the current BW for cows in a particular experimental treatment (cow BW was not reported in any of the infusion experiments), a value of 600 kg was employed. Once the control diet had been completely entered and saved as a CPM-Dairy session, the control diet session was used as a template for the remaining diets in that particular experiment. Quantities of all dietary ingredients including the specific fat supplement were entered into the session. For most diets, there were small discrepancies between the reported and predicted intakes of total LCFA. In these cases, small adjustments were made (in the ration dictionary) to "total LCFA as a percentage of ether extract" so that the predicted total intake of LCFA matched the reported total intake of LCFA.

In all diets, for all feeds other than the infused fat supplements, the dictionary default values in CPM-Dairy were used for lipolysis rates and efficiencies of intestinal absorption of LCFA (Moate et al., 2004). For the abomasal infusion experiments, a lipolysis rate of 0.01%/h was employed for all supplements of infused LCFA. This maneuver resulted in approximately 99.8% of the infused fat supplement not being subjected to the calculations concerned with ruminal lipolysis and biohydrogenation. Because the abomasal infusion experiments involved infusates of free (nonesterified) LCFA, the intestinal absorption coefficients for the rumen bypass fractions of these infusate LCFA were edited to equate to those of rumen free LCFA (Moate et al., 2004).

The amounts of total LCFA apparently absorbed were regressed against the reported amounts of total LCFA apparently absorbed (Figure 1). The Y intercept was -24.8 ± 25.19 , which was not significantly different from zero ($P = 0.33$). The slope of the regression was 1.011 ± 0.029 , which was not significantly different from 1 ($P = 0.71$). The R^2 for this regression was 0.95 and the root mean square error was 55.2 g/d. Concordance

Figure 1. Concordance between reported and predicted amounts of dietary total long-chain fatty acids (LCFA) apparently absorbed in lactating dairy cows. Squares represent data from 48 diets in 11 feeding experiments in which different types and quantities of fat supplements were fed. Circles represent data from 15 diets in 3 experiments in which different types and quantities of LCFA were infused into the abomasums. The continuous line is the line of identity. The dashed line is the regression line (predicted regressed against reported) with y intercept = -24.8 ± 25.2 and slope 1.011 ± 0.029 , with root mean square error = 55.2 g/d and $R^2 = 0.95$.

analyses (Lin, 1989) of the predicted and measured amounts of total LCFA apparently absorbed from the different dietary treatments in both the infusion and feeding experiments were also carried out. For the diets from the infusion experiments, Lin's concordance correlation coefficient was 0.923 ± 0.040 and Pearson's r value was 0.940. For the diets from the feeding experiments, the corresponding values were 0.975 ± 0.007 and 0.977. Pearson's regression analysis assumes that the reported values of total LCFA apparently absorbed were measured without error. However, it is probable that the reported values may include sampling and analytical errors associated with measuring LCFA in the feeds and feces. Indeed, considering that the average intake of LCFA in the feeding experiments was 1,190 g/d and the average output of LCFA in feces was 355 g/d, an average error of less than 5% in measuring intake and fecal outputs of LCFA could easily account for the majority of the observed discrepancies between the amounts of LCFA reported and predicted to be apparently absorbed. Other factors unrelated to the model could have caused some of the discrepancies between the reported and model predictions of the amounts of LCFA absorbed. Many of the published reports of experiments lacked detailed chemical descriptions of experimental diets and of the major feeds in the diets and pertinent animal details. Thus, inaccurate replication

Figure 2. Assessment of prediction bias. Squares represent data from the feeding experiments and circles represent data from the infusion experiments. The mean bias, 15.8 g/d, is not significant. The constant bias, 64 g/d, and the linear bias, -0.060 , although both significant statistically ($P < 0.05$), together result in a positive bias of 41.7 g/d at the minimum predicted value of 369.8 g/d, and a negative bias of 16.1 g/d at the maximum predicted value of 1,339.8 g/d. These biases are less than the root mean square error, 53.3 g/d, and translate to an error of 11% at the minimum predicted value and 1.2% at the maximum predicted value.

of the experimental diets could have caused some of these discrepancies.

An analysis of residuals (reported – predicted total LCFA apparently absorbed) was carried out to assess the extent of prediction bias (St. Pierre, 2003). As shown in Figure 2, the mean bias was only 15.8 g/d; this was not significant. The constant bias, 64 g/d, and the linear bias, -0.060 , although both significant statistically ($P < 0.05$), together resulted in a positive bias of 41.7 g/d at the minimum predicted value of 369.8 g/d, and a negative bias of 16.1 g/d at the maximum predicted value of 1,339.8 g/d. These values are less than the root mean square error, 53.3 g/d, and translate to a positive error of 11% at the minimum predicted value and negative error of 1.2% at the maximum predicted value. With the small data set analyzed here, we cannot explain the

reasons for the small systematic bias in prediction. As further data become available, this bias may disappear or we may adjust the model appropriately to remove the bias. Despite this small systematic bias, as can be seen from Figure 1 and shown by the concordance analyses, the model generally predicts the apparent absorption of total LCFA very well.

To determine if the fat model had any systematic prediction errors related to type of fat supplement, we collated the data and predictions of apparent digestibilities of diet total LCFA for diets containing 5 commonly fed types of fat supplements (Table 1). Using paired *t*-tests, only in diets containing whole cottonseed was the predicted digestibility of total LCFA significantly ($P < 0.01$) different from the measured digestibility of LCFA, but the mean difference was only 2.8 digestibility units. Sampling difficulties of TMR diets containing whole cottonseed may account for this difference. Furthermore, the data on diets containing whole cottonseed came from just 2 experiments, and it is possible that this difference will disappear as more experimental data become available. Thus, for diets containing these major types of fat supplements, the fat sub-model does not contain any substantial systematic biases.

The fact that the fat sub-model accurately predicts the apparent absorption of total LCFA infused into the abomasum of cows indicates that appropriate intestinal absorption coefficients are employed in the model. The fact that the model also accurately predicts the apparent absorption of total LCFA in the feeding experiments is evidence that the model must also correctly describe ruminal processes such as lipolysis, biohydrogenation, and de novo synthesis of LCFA that can influence apparent absorption of total LCFA. Based on the current validation data set and the analyses presented here, we conclude that the fat sub-model in CPM-Dairy accurately predicts the apparent absorption of dietary total LCFA in lactating dairy cows. It is our intention that, as new publications report the effects of specific feeds

Table 1. Comparison of reported and predicted digestibilities (mean $\pm$ SD) of dietary total long-chain fatty acids for diets containing 5 different types of fat supplements

Diet type	References	n ¹	Diet fatty acid digestibility	
			Reported	Predicted
Tallow	Avila et al., 2000; Pantoja et al., 1996; Ruppert et al., 2003; Schauff and Clark, 1992; Wu et al., 1993	9	70.2 $\pm$ 7.18	71.0 $\pm$ 1.40
Hydrogenated esterified fat	Jenkins and Jenny, 1989; Pantoja et al., 1996; Weiss and Wyatt, 2004	7	57.0 $\pm$ 5.72	57.4 $\pm$ 6.29
Whole cottonseeds	Chan et al., 1997; Pires et al., 1997	8	74.7 $\pm$ 1.92	71.9 $\pm$ 0.44*
Prilled fatty acids	Chan et al., 1997; Elliott et al., 1996	5	71.0 $\pm$ 3.39	72.2 $\pm$ 0.53
Calcium salts of palm fatty acids	Jenkins and Jenny, 1989; Schauff et al., 1992; Weiss and Wyatt, 2004; Wu et al., 1993	5	77.6 $\pm$ 2.82	75.8 $\pm$ 1.18

¹n = Number of diets.

* $P < 0.01$.

on the ruminal transformations of LCFA and intestinal digestion of LCFA, the fat sub-model will continue to be refined to reflect the latest scientific findings.

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