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Comparison of feed intake models for dairy cows

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Introduction

Feed intake in dairy cattle. Feed intake in dairy cows has a large effect on performance, in terms of milk production and body condition. The complex interaction between feed and feed intake in ruminants has therefore been investigated for decades (Ingvartsen, 1994). The production of large quantities of milk in high yielding dairy cows requires vast amounts of energy (Allen, 2000) and is sensitive to the profile of absorbed nutrients, resulting in an interest for modeling feed intake.

Why model feed intake? Feed intake, especially forage intake, accounts for most of the variation in productivity of dairy cows (Mertens, 2007). Dry matter intake (DMI)-systems are necessary to optimize the dietary proportion of concentrate feeds to achieve a well-balanced and cost efficient diet (Ingvartsen, 1994; Zom et al., 2012). Over the years, feed intake models have become more advanced, moving from the simple model supposed by National Research Council (NRC; NRC, 2001), which only includes animal factors, towards more advanced models like the Nordic feed evaluation system (NorFor; Volden, 2011) and the total dry matter intake index (TDMI; Huhtanen et al., 2011), which include both dietary and animal factors. The latest feed intake model by Zom and co-workers ('Zom model'; Zom et al. 2012) focuses on additive feed characteristics of individual feeds and does not include milk yield as an animal factors.

Comparing feed intake models. Evaluation of feed intake models on independent datasets reveals not only the accuracy and robustness of the existing models but can lead to an extended understanding of model parameters effect on prediction performance, which can be used in development of new and improved models.

Short description of the feed intake models compared. The feed intake model proposed by NRC (2001) is the simplest model of the four evaluated here. This model includes only fat corrected milk yield (FCM), body weight (BW), and week of lactation (WL), but not dietary characteristics. In NorFor (Volden et al., 2011) the intake capacity (IC) expresses how much a cow can eat and is estimated from similar inputs as in NRC, i.e. days in milk (DIM), energy corrected milk yield (ECM), and BW, however the model depends also on parity and breed. Each feedstuff is given a fill value (FV), and both IC and FV are expressed in arbitrary units. Concentrates are given a constant FV, whereas FV's for forages are calculated from organic matter digestibility (OMD) and neutral detergent fibre (NDF) content. Adjustments of FV's are made depending on content of sugar and starch in the total ration and the quality of forage. The TDMI index (Huhtanen et al., 2011) is a sum of silage dry matter index (SDMI) and concentrate dry matter index (CDMI). SDMI is calculated based on digestible organic matter concentration (D-value) found by NIR-analysis, the concentration of total acid (TA), dry matter (DM), and NDF, together with the proportion of regrowth, legume, and whole-crop silage (a, b, and c, respectively). CDMI is calculated based on allocated concentrate DM, supplementary concentrate crude protein (CCPI) (CP > 170 g/kg DM), and content of NDF (CNDF) and fat (Cfat) in concentrate. The prediction of DMI is calculated based on standardized ECM (sECM), BW, DIM, and the TDMI index of the ration. The prediction of DMI by the ‘Zom model’ is similar in approach to both NorFor and TDMI but does not include daily milk yield and BW as input in the estimation of feed intake capacity (FIC). FIC is calculated based on parity, DIM, and days in gestation. All feeds are assigned a satiety value (SV) resulting in a weighted SV for the ration. Depending on the type of forage SVs are calculated from contents of DM, CP, crude fiber (CF), and OMD.

Objective. The objective of this study was to compare the ability of different feed intake models to predict DMI in dairy cows fed total mixed rations (TMR).

Material and methods

Data used for evaluation. The evaluation of the four models was conducted on Danish intake data from eight different references described by Volden et al. (2011b), consisting of ten experiments with a total of 85 treatment means from lactating dairy cows of varying breed, parity (primi- and multiparous), and lactation stage (Table 1). Housing was registered as either tied up or loose housing.

Table 1 Experiments and breeds together with DMI, DIM and ECM expressed as mean ± SD.

Data		Breeds			Feed intake (kg DM/day)		DIM		ECM (kg/day)	
References	Experiments	Danish Holstein	Jersey	Danish Red	Mean	SD	Min	max	mean	SD
8	10	52	16	17	20.2	±2.6	25	275	31.1	±6.0

Feed and feeding practice. The ten experiments was conducted between 1999 and 2009 and included 11 different grass/clover-grass silages, eight maize silages, two whole-crop silages, and five alfalfa silages. All rations were fed as TMRs. Table 2 describes the variation in forage share, OMD, NDF, CP, sugar plus starch, and chewing time index (CI) as mean ± SD of the data.

Table 2 Nutritional value of the TMRs used to evaluate intake models.

	Forage share (% of DM)		OMD (%)		NDF (g/kg DM)		CP (g/kg DM)		Sugar + starch (g/kg DM)		CI (min/kg DM)	
	Mean	SD	Mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
TMR	59	7.8	74.5	2.3	341	18	159	17	206	36	35	4

Modifications of equations used for prediction of DMI.

<u>NorFor:</u> The NorFor equations used in this evaluation has minor modifications compared to the equations published by Volden et al. (2011a). In the equation: FV_SubR (eq. 10.7; Volden et al., 2011a) the constants 0.1 and 0.05 are used to control the output for optimization purpose and were removed for the purpose of prediction. In equation: FV_MR (eq. 10.8; Volden et al., 2011a) the IC/8 variable was excluded in a newer unpublished revision of this equation (Nielsen, 2013; pers. com.).

<u>TDMI:</u> In the TDMI-model by Huhtanen et al. (2011) several of the variables were estimated or substituted by similar variables given by NorFor feed analysis. In the SDMI the D-value was substituted with OMD, calculated from in vitro organic matter solubility analysed by the Tilly and

Terry method (Tilley and Terry, 1963). The parameters a, b, and c (Huhtanen et al., 2011) were estimated based on the information given in the data. In the CDMI-index, CCPI was calculated as the amount of CP (kg/d) given above the level of 170 g CP/kg DM. CEPD was set to 0.7 for all TMR's (Huhtanen, 2013, pers. com.).

'Zom model': In the 'Zom model' most of the input variables were available in the Danish data material. However, CF values were estimated based on a regression performed on feedstuff data supplied by Zom et at. (2012). CF (g/kg DM) in grass-, legume-, and whole crop silage was predicted from: -14.769 + 5.549*NDF (g/kg DM), and for concentrate: -9.972 + 0.454* NDF (g/kg DM). Maximum and minimum values of forage SV (Zom et al., 2012) were used as limitations for the calculation of SV for the given feedstuffs. FIC values for Jersey were corrected to 80% of ordinary FIC (Zom, 2013; pers. com).

Statistical criteria of testing the accuracy. The accuracy of prediction by the feed intake models is evaluated by Mean Square Prediction Error (MSPE) as statistical criteria: The MSPE is calculated as follows:

$$MSPE = \sum (A - P)^2/n$$

where A is the actual DMI, P is the predicted DMI and n is the number of pairs of A and P being compared. According to Bibby and Toutenberg (1977) the MSPE can be considered as the sum of three components: mean bias $(\bar{A} - \bar{P})^2$, which indicates the difference between the actual and predicted mean of DMI and is seen as the deviation of the intercept from 0, line bias $(S_P^2(1-b)^2)$, which indicates how much of the error is due to the fitted line and is seen as the deviation of the slope from zero, and random variation around the regression line (error of disturbance) of A on P$(S_A^2(1-r^2))$. Accordingly, MSPE is calculated as follows:

$$MSPE = (\bar{A} - \bar{P})^2 + S_P^2(1-b)^2 + S_A^2(1-r^2)$$

where $\bar{A}$ is mean of the actual DMI, $\bar{P}$ is mean of the predicted DMI, S_A^2 is the variation of actual DMI, S_P^2 is the variation of predicted DMI, b is the slope of the regression of A on P with intercept zero, and r is the correlation coefficient of A and P (Bibby and Toutenberg, 1977).

Results and discussion

Observed and predicted DMI from the four intake models are presented as means in Table 3, together with the statistical criteria.

Table 3 Accuracy of four feed intake models predicting DMI in dairy cows fed TMR's.

	DMI kg/day		Evaluation criteria					
Model[1]	Mean predicted	Mean observed	RMSPE (kg DM/day)	RMSPE (%)	MSPE	Mean bias	Line bias	Error of variation
NorFor	20.0	20.2	1.5	7.3	2.2	0.03 (1%)	0.91 (42%)	1.24 (57%)
NRC	21.7	20.2	1.8	9.1	3.4	2.08 (62%)	0.16 (5%)	1.12 (33%)
TDMI	20.7	20.2	1.4	6.7	1.9	0.21 (12%)	0.10 (5%)	1.54 (83%)
Zom	22.1	20.2	3.3	16.2	10.7	3.73 (35%)	2.49 (23%)	4.47 (42%)

[1]NorFor (Volden et al., 2011), NRC (NRC, 2001), TDMI (Huhtanen et al., 2011) and Zom (Zom et al., 2012)

As seen in Table 3 the TDMI model has the lowest RMSPE with a mean error of 1.4 kg DM/day. Decomposing MSPE into the three components shows a slight mean bias (12%), a minor line bias (5%), and a considerably part of the error explained by random variation in the data (83%). The NorFor model did nearly as well as the TDMI model, with a RMSPE of 1.5 kg DM/day. Decomposing MSPE of the NorFor model showed a very small mean bias (1%) but a noteworthy line bias (42%). The NRC model being the simplest model did surprisingly well with the third lowest RMSPE of 1.8 kg DM/day. The evaluation of the 'Zom model' showed the highest RMSPE of 3.3 kg DM/day resulting in the most inaccurate prediction result.

Figure 1 presents the centralised residual plot with residuals (observed-predicted) on the y-axis and the centralised predicted DMI on the x-axis. Mean bias is seen as the regression line's deviation from intercept at zero. An intercept at zero is a result of all predictions close to observed or equal amounts of positive and negative diversity from observed. Line bias is the deviation of the slope from zero. The higher the slope for the regression line across the centered residuals, the more line bias is associated with the model. The closer the regression line is to zero the smaller the line bias, resulting in models predicting equally well at low and high DMI. Prediction with the NorFor model results in residuals located in a downwards cloud. Here, the regression line almost intercepts at zero but shows a substantial slope explaining 42% of the error. The regression of the residuals from the NRC model is far from intercepting at zero and mean bias explain 62% of prediction error. The regression line indicates a downwards slope but line bias only explains 5% of prediction error. The regressed residual line from the TDMI model do not intercept zero. Mean bias explains 12% of prediction error and line bias deviation accounts for only 5% of the residual variation. The regressed residual line from the 'Zom model' shows an intercept different from zero, resulting in a mean bias explaining 35% and line bias accounting for 23% of the prediction error.

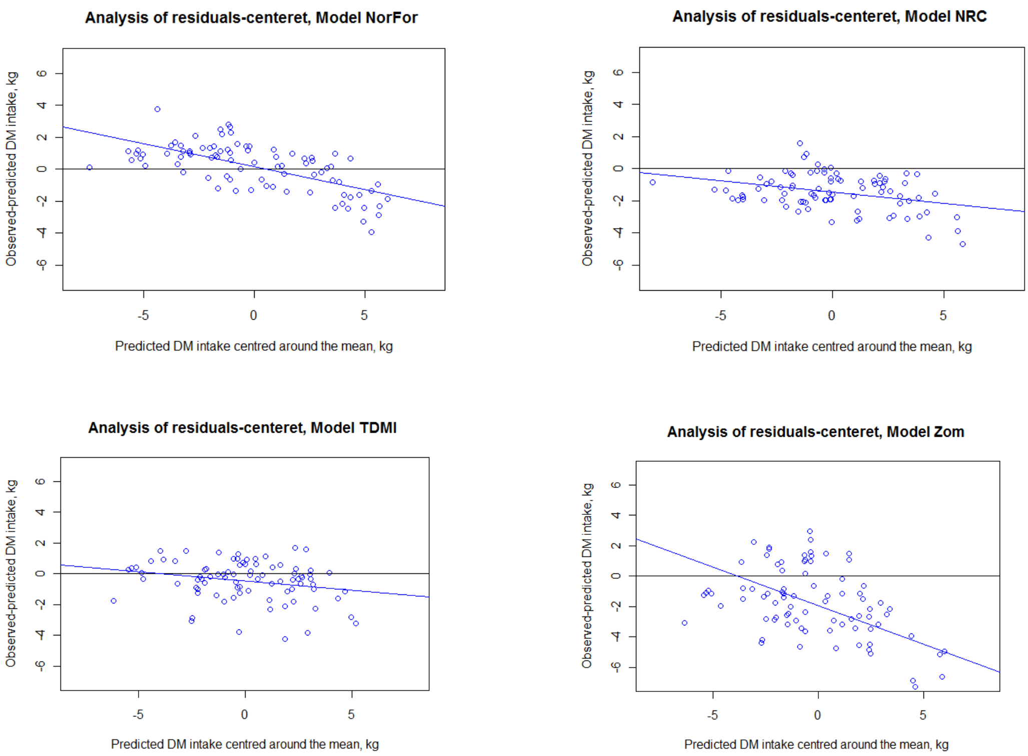

Figure 1 Centralised residual plots of the four models tested on 85 treatment means form Danish dairy cows fed TMR's.

It is noteworthy that the NRC model, despite a general over-prediction of DMI and without inputs of dietary characteristics, predicts feed intake with a lower RMSPE compared with the ‘Zom model’. This could be due to the lack of production traits when estimating FIC. The intention of the model by Zom and co-workers (2012) is to disconnect production traits, i.e. BW and ECM, from intake predictions because BW and ECM known at the time of prediction are a result of the previous diet. The model evaluation conducted in this study hence indicates that animal production characteristics can be necessary for accurate prediction of DMI.

The use of estimated CF in the prediction of DMI by the ‘Zom model’ may induce a minor error on CF compared to the analysed CF. The NorFor model includes parameter settings for IC depending on breed (large breed, Jersey, and Icelandic breed), which is not the case for the three other models. However, the FIC values in the ‘Zom model’ were reduced by 20%, which corresponds to a commonly used breed correction for Jersey cows (Zom, 2013, pers. com.).

Conclusion

The TDMI and NorFor models produce the most accurate prediction of DMI in dairy cows fed typical Danish TMR. Furthermore, this study shows that feed intake models, which include production characteristic, in general are more robust than models lacking these characteristic.

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