Appendix 2 of Section 22 of the ICAR Guidelines - Prediction equations for feed intake, feed efficiency and methane for dairy cattle

Appendix 2 of Section 22 – Sustainability Recording Traits

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Table of Contents

1 Introduction 3

2 Prediction formulas for feed intake 3
- 2.1 TMR Equation (North America based) 3
- 2.2 Pasture equation (North America Based) 3
- 2.3 DMI (kg DM/d) equations by Gruber et al. (2004) 4
- 2.4 References 6
- 2.5 Link to alternative equations based on regions 7
- 2.6 Prediction of voluntary feed intake in NorFor (Nordic Feed Evaluation System) 7
- 2.7 Cornell Net Carbohydrate and Protein System (CNCPS, Cornell University Model), for lactating cows 8
- 2.8 NASEM equation (the updated NRC model) 8

3 Prediction formula's for feed efficiency traits 8
- 3.1 Residual feed intake (in dry matter, DM) 8
- 3.2 Residual energy intake (in MJ ME or MJ NEL) 8
- 3.3 Feed efficiency 8
- 3.4 Energy efficiency 9
- 3.5 References 9

4 Methane Emissions 9
- 4.1 Simplistic (IPPC Tier 2) 9
- 4.2 Comprehensive 9
- 4.3 Link to alternative equations based on regions 11

Tables

Table 1. Evaluation criteria, regression estimates, and significance level of the rive models predicting dry matter intake (DM1) in dairy cows fed total mixed ration, evaluated across the 12 experiments. 4
Table 2. Feed intake equations (total dry matter intake, kg DM per day), n = 25.482, Gruber et al. (2004). 5
Table 3. Multiple regression coefficients used to predict dairy cow intake capacity (IC). 7
Table 4. Methane prediction (g d-1) equations for beef cattle developed in this study 10

Change Summary

Date of Change	Nature of Change
May 2023	Creation of document.

1 Introduction

This appendix is part of the ICAR guidelines for sustainability recording traits, to assess sustainability at herd level. In this document, prediction formulas are described for the traits feed intake, feed efficiency and methane. These prediction formulas can be used to estimate values for these traits, in case no measured data is available for these traits.

2 Prediction formulas for feed intake

2.1 TMR Equation (North America based)

Farm Application:

DMI (kg/d) = [6.89 + 0.305 × MilkE (Mcal/d) + 0.022 × BW (kg) + (−0.689 + parity × −1.87) × BCS] × [1 −0.288× exp(−0.053 × DIM)]

Comprehensive:

DMI (kg/d) = [(3.7 + parity × 5.7) + 0.305 × MilkE (Mcal/d) + 0.022 × BW (kg) + (−0.689 + parity × −1.87) × BCS] × [1 – (0.212 + parity × 0.136) × exp(−0.053 × DIM)]
(mean bias = 0.021 kg, slope bias = 0.059, CCC = 0.72, and RMSEP = 2.89 kg),
where parity is equal to 1 if the animal is multiparous and 0 otherwise.

References:

De Souza, R. A., R. J. Tempelman, M. S. Allen, and M. J. VandeHaar. 2019. Updating predictions of dry matter intake of lactating dairy cows. J. Dairy Sci. 102:7948-7960

2.2 Pasture equation (North America Based)

Farm Application:

Holstein DMI (SE = 0.73 kg/d) was: DMI (kg/d) = 15.36×[1 - $e^{(-0.00220\times BW)}$]

Crossbred DMI (SE = 0.81 kg/d) was: DMI (kg/d) = 12.91×[1 – $e^{(-0.00295\times BW)}$].

Comprehensive:

Holsteins DMI (kg/d) = 15.79×[1 – $e^{(-0.00210\times BW)}$]−0.0820×NDFdv, where NDFdv = (dietary neutral detergent fiber as a % of dry matter) – {22.07 + [0.08714×BW] – [0.00007383×$(BW)^2$]}

Crossbred DMI (kg/d) = 13.48×[1 – $e^{(-0.00271\times BW)}$]-0.0824×NDFdv where NDFdv = (dietary neutral detergent fiber as a % of dry matter) – {23.11 + [0.07968×BW] - [0.00006252×$(BW)^2$]}.

References:

Hoffman, P.C., K.A. Weigel, and R.M. Wernberg. 2008. Evaluation of Equations to Predict Dry Matter Intake of Dairy Heifers. J. Dairy Sci. 91:3699-3709.

2.3 DMI (kg DM/d) equations by Gruber et al. (2004)

Equation 1 considers the concentrate amount (kg DM) for feeding concentrate separately from forage. It can be used for pure forage diets (0 kg concentrate intake) and be adapted to other feeding systems like partial mixed rations (PMR) and TMR via additional mathematical equations. The methodical approach of including concentrate mixed with forage (PMR or TMR) or of including separately fed forage (kg DM) is explained in Ledinek et al. (2016).

Equation 5 is especially applicable for TMR. It was evaluated by Jensen et al. (2015). It was evaluated by Jensen et al. (2015), results are shown in Table 1.

Table 1. Evaluation criteria, regression estimates, and significance level of the rive models predicting dry matter intake (DM1) in dairy cows fed total mixed ration, evaluated across the 12 experiments.

		Evaluation criteria				Regression estimates	
Models	**n**	**MSPE[b]**	**ECT[c]**	**ER[d]**	**ED[e]**	**Intercept (kg DM/clay)**	**Slope (kg DM/clay)**
NRC	94	3.20	2.07	0.13	1.00	-1.44***	-0.14***
NorFor[g]	48	2.32	0.14	0.87	1.30	-0.38*	-0.37***
TDMI	94	2.91	0.01	0.65	2.25	0.10	-0.29***
Zom	94	9.97	2.62	2.78	4.57	-1.62***	-0.56***
Gruber	94	1.37	0.05	0.04	1.28	-0.23	-0.08

[a] NRC (NRC, 2001), NorFor (Volden et al., 2011a), TDMI (Huhtanen et al., 2011), Zorn (Zorn et al., 2012[a]) and Gruber (Gruber et al., 2004).[b] Mean square prediction error (MSPE; Bibby and Toutenberg, 1977).
[c] Error due to central tendency (ECT).
[d] Error due to regression (ER).
[e] Error due to disturbance (ED).
[f] The regression estimates is retrieved from simple linear modelling.
[g] Evaluated on 9 out of 12 experiments as the remaining 3 experiments had been used in the development of this model.
* $p < 0.05$
*** $p<0.001$

Table 2. Feed intake equations (total dry matter intake, kg DM per day), n = 25.482, Gruber et al. (2004).

Parameter	Unit		Equation 1	Equation 5
Intercept			3.878	2.274
Effect Country × Breed		FV [G+A]	-2.631	-2.169
		BS [G+A]	-1.826	-1.391
		HF m [G+A]	-2.720	-1.999
		HF h [G+A]	-1.667	-0.898
		FV [CH]	-0.275	-0.315
		BS [CH]	-0.882	-0.593
		HF [CH]	0.000	0.000
Effect of	n	1	-0.728	-0.658
lactation number		2 - 3	0.218	0.236
		≥ 4	0.000	0.000
Effect of	d	a	-4.287	-5.445
DIM		b	4.153	5.298
Model: a + b × (1 – exp(-c×DIM))		c	0.01486	0.01838
Regression coefficient	kg	a	0.0148	0.0173
for body weight		b_1	-0.0000474	-0.0000514
Model: $a + b_1 \times DIM + b_2 \times DIM^2$		b_2	0.0000000904	0.0000000999
Regression coefficient	kg	a	0.0825	0.2010
for milk performance		b_1	0.0008098	0.0008080
Model: $a + b_1 \times DIM + b_2 \times DIM^2$		b_2	-0.000000966	-0.000001299
Regression coefficient	kg DM	a	0.6962	-
for concentrate amount		b_1	-0.0023289	-
Model: $a + b_1 \times DIM + b_2 \times DIM^2$		b_2	0.0000040634	-
Regression coefficient	% TMR	a	-	0.0631
for concetrate proportion		b_1	-	-0.0002096
Model: $a + b_1 \times DIM + b_2 \times DIM^2$		b_2	-	0.0000001213
Reg.coeff. NEL_{Forage}	MJ /kg DM	-	0.8580	0.6090
R^2	%	-	86.7	83.5
RSD	kg DM	-	1.32	1.46
CV	%	-	7.1	7.9
Correction factorby validation		$DMI = a + b \times DMI_{predicted}$	$0.47+0.930 \times DMI_{p.}$	$0.71+0.920 \times DMI_{p.}$
G Germany; A Austria; CH Switzerland; HF m HF h medium and high management level of farm				

Model 1 (concentrate considered as amount, e. g. as kg DM):

$DMI_{predicted}\ (kg/day) =$

Intercept + Effect breed.country (kg) + Effect of lactation number (kg) + Effect of DIM (kg DMI, non-linear function depending on DIM) + b_body weight (kg DMI/kg BW) × body weight (kg) + b_milk yield (kg DMI/kg milk) × milk yield (daily milk, kg) + b_concentrate amount (kg DMI/kg concentrate in DM) × concentrate amount (daily amount, kg DM) + b_NEL_{Forage} (kg DMI/MJ NEL per kg DM) × Energy content of forage (MJ NEL per kg DM)

Correction factor by validation: $DMI = 0.47 + 0.930 \times DMI_{predicted}$

Model 5 (concentrate considered as proportion, e. g. as % of DM):

$DMI_{predicted}\ (kg/day) =$

Intercept + Effect breed.country (kg) + Effect of lactation number (kg) + Effect of DIM (kg DMI. non-linear function depending on DIM) + b_body weight (kg DMI/kg BW) × body weight (kg) + b_milk yield (kg DMI/kg milk) × milk yield (daily milk. kg) + b_concentrate proportion (% of TMR, DM basis) × concentrate proportion (% of TMR) + b_NEL_{Forage} (kg DMI/MJ NEL per kg DM) × Energy content of forage (MJ NEL per kg DM)

Correction factor by validation: $DMI = 0.71 + 0.920 \times DMI_{predicted}$

Regression coefficients (b_) for body weight, milk performance, concentrate amount and concentrate proportion are depending on DIM and are calculated using quadratic polynomials (see Table 1). The effect of DIM is described by a non-linear function.

2.4 References

1. Gruber L., Schwarz F.J., Erdin D., Fischer B., Spiekers H., Steingass H., Meyer U., Chassot A., Jilg T., Obermaier A., Guggenberger T., 2004. Vorhersage der Futteraufnahme von Milchkühen – Datenbasis von 10 Forschungs- und Universitätsinstituten Deutschlands, Österreichs und der Schweiz [Feed intake prediction in dairy cows based on the data of 10 German, Austrian and Swiss research institutes and universities]. Proceedings of the 116th VDLUFA-Kongress, Sept 13–17, 2004; Rostock, Germany, 484-504.
2. Jensen L.M., Nielsen N.I., Nadeau E., Markussen B., Nørgaard P., 2015. Evaluation of five models predicting feed intake by dairy cows fed total mixed rations. Livest Sci. 176, 91-103.
3. Ledinek M., Gruber L., Steininger F., Fuerst-Waltl B. Zottl K., Royer M. Krimberger K., Mayerhofer M., Egger-Danner C., 2016. Efficient Cow – estimation of feed intake for efficiency traits using on-farm recorded data. Animal Science Day, Ptuj, Acta agric. Slov, Supplement 5, 71-75.

2.5 Link to alternative equations based on regions

1. Development and evaluation of equations for prediction of feed Intake for lactating Holstein dairy cows, 1997. D.K. Roseler, D.G. Fox, L.E. Chase, A.N. Pell, W.C. Stone https://doi.org/10.3168/jds.S0022-0302(97)76010-7
2. NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC tested by https://doi.org/10.3168/jds.2018-16166
3. https://doi.org/10.1007/s11250-022-03275-8

2.6 Prediction of voluntary feed intake in NorFor (Nordic Feed Evaluation System)

Feed intake is predicted from animal fill capacity and dietary fill values. In the intake is regulated both physically by the diet and metabolically by the energy demand of the animal. Each individual feed is assigned a basic fill value (FV; section 6.2) and the animal is assigned an intake capacity (IC) expressed in the same units as the feed When predicting DMI, the following general equation must be fulfilled:

$$IC = FV\_intake$$

where IC is the animal intake capacity and FV_intake is the total feed intake expressed in fill units

The following equation is used to calculate IC in dairy cows:

$$IC\_cow = (a \cdot DIM^{b} \cdot e^{c \cdot DIM} - DIM^{-d} + e \cdot ECM + (BW - f) \cdot g)$$

where IC_cow is the intake capacity of lactating dairy cows; DIM is days in milk; ECM is the energy corrected milk, kg/d; BW is the animal body weight, kg; and a, b, c, d, e, f, g are regression coefficients presented in Table 3.

Table 3. Multiple regression coefficients used to predict dairy cow intake capacity (IC).

	Multiple regression coefficients [1]						
Cow category	**a**	**b**	**c**	**d**	**e**	**f**	**g**
Primiparous large dairy breeds	2.59	0.134	-0.0006	0.55	0.091	500	0.006
Multiparous large dairy breeds	2.82	0.134	-0.0006	0.55	0.091	575	0.006
Jersey primiparous cows	2.25	0.134	-0.0004	0.25	0.110	360	0.006
Jersey multiparous cows	2.40	0.134	-0.0004	0.15	0.110	405	0.006
Icelandic primiparous cows	4.07	0.087	-0.0014	0.65	0.015	400	0.002
Icelandic multiparous cows	4.77	0.071	-0.0013	0.14	0.035	523	0.0013

2.7 Cornell Net Carbohydrate and Protein System (CNCPS, Cornell University Model), for lactating cows

DMI (kg/d) = (0.0185 * BW + 0.305 * FCM) * Lag

Where:

BW = Body Weight (kg),
FCM = fat corrected milk (kg/d) = (0.4 * milk + 15 * milk* fat %, Milk = milk yield (kg/d),
Fat = Fat test (%),
Lag = adjustment for stage of lactation: IF(WOL≤16; 1 – exp(–(0.564 – 0.124 × 2) × (WOL + 2.36)));1) and
WOL = Week of lactation.

2.8 NASEM equation (the updated NRC model)

DMI (kg/d) = (3.7 + parity * 5.7) + 0.305 * MilkEnergy (Mcal/d) + 0.022 * BW (kg) + (-0.689 – 1.87 * parity) * BCS) * (1-(0.212 + parity * 0.136) * e (-0.053 x DIM))

Where:

Parity = 0 for primiparous and 1 for multiparous cows,
BCS = Body condition score (1 to 5),
MilkEnergy = 9.29 * kg fat/kg milk + 5.85[1] * kg true Protein/kg milk + 3.95 * kg lactose/kg milk, [1]) if total protein is used: replace 5.85 by 5.5.

3 Prediction formula's for feed efficiency traits

3.1 Residual feed intake (in dry matter, DM)

RFI = FI_observed – FI_predicted

$Y = \beta 0 + \beta 1\ X1 + \beta 2\ X2 + \varepsilon$

3.2 Residual energy intake (in MJ ME or MJ NEL)

REI = EI_observed – EI_predicted

$Y = \beta 0 + \beta 1\ X1 + \beta 2\ X2 + \varepsilon$

Explanation: Residual traits are mostly defined as difference between an observed and predicted input trait. The input trait can be feed intake for calculating residual feed intake (RFI, in dry matter) or energy intake for calculating residual energy intake (REI, in MJ ME or MJ NEL). The prediction of feed or energy intake considers at least milk performance, metabolic body size for maintenance requirements and body reserve change. Either a standardized formula is used [REI = Energy intake_observed minus Energy intake_predicted; predicted energy intake includes the requirements for milk, maintenance, body reserve change (and pregnancy) calculated based on the energy system of the country]. Or REI and RFI are defined as residuals of a regression model. As regression models and thus the regression coefficients vary very much in scientific literature, the comparability is reduced.

3.3 Feed efficiency

Feed efficiency = ECM (kg) /FI (kg DM)

Explanation: Efficiency is defined as ratio between output and input. Feed efficiency is herd average energy corrected milk (output) divided by herd average feed intake (input). Only milk producing cows are included. Data should be based on one year, in any other case, data should be adjusted for stage of lactation of the cow.

3.4 Energy efficiency

Energy efficiency = Lactation energy (MJ LE) / Energy intake (MJ ME or MJ NEL)

Explanation: Efficiency is defined as ratio between output and input. Energy efficiency is herd average energy in milk (output: lactation energy, LE) divided by herd average energy intake (input). Only milk producing cows are included. Data should be based on one year, in any other case, data should be adjusted for stage of lactation of the cow.

Energy efficiency should be used instead of feed efficiency if possible. Efficiency traits based on energy consider the energy content of diet. They do not rate herds or animals as poor or well performing as diet quality is lower or higher. Additionally they can be adjusted to body reserve change as known from residual traits. The shorter the calculation period, the more important is the consideration of body reserve change and of stage of lactation, because the mobilization of body reserves and a (too) low or late regeneration of body reserves fake a high efficiency.

3.5 References

Ledinek M., Gruber L., Thaller G., Götz, K.-U. Südekum, K.-H. Spiekers H., 2022: Effizienzmerkmale beim Milchrind: Definieren – Einordnen – Anwenden. Züchtungskunde 94, 81-109.

4 Methane Emissions

4.1 Simplistic (IPPC Tier 2)

eCH_4 (g d−1) = DMI (kg d−1) × 18.5 (MJ kg−1 DM) × Ym)/55.65 (MJ kg−1 eCH_4),
where Ym = 3.0% when dietary concentrate proportion is ≥90%, otherwise Ym = 6.5%

4.2 Comprehensive

P. Escobar-Bahamondes, M. Oba, and K.A. Beauchemin, 2016. Universally applicable methane prediction equations for beef cattle fed high- or low-forage diets. Canadian Journal of Animal Science. 97(1): 83-94. https://doi.org/10.1139/cjas-2016-0042.

Table 4. Methane prediction (g d-1) equations for beef cattle developed in this study.

Dataset	Equation ID	*n*	Equations	eCH_4 (g d^{-1})	RMSE	*P*
High forage						
Original high forage	[HF-OR]	123	eCH_4. = 715 (±11.45) + 0.12 (±0.03) x BW + 0.10 (±0.01) x DMI^3 – 244.8 (±56.44) x fat^3 x (NDF-ADF)2 + 0.1 (±0.00)	156.4	27.0	<0.01
Monte Carlo high forage	[HF-MC]	100305	eCH_4 = 25.9 (±0.54) + 0.13 (±0.001) x BW +145.4 (±1.31) x fat+10.3 (±0.16) x DMI^3 - 27.4 (±0.20) x (starch:NDF)	149.6	34.0	<0.01
IPCC (2006) Tier 2	IPCC 2006	123	eCH4 = [DMI x18.5 (MJ kg^{-1} DM) x (6.5 x 10)]/55.65 (MJ kg^{-1} eCH_4)	156.1	-	-
Low Forage						
Original low forage	[LF-OR]	34	eCH_4= -26.4 (±20.17) + 0.21 (±0.04) x BW + 30.1 (±11.83) x CP - 70.5 (±25.48) x fat^2 +10.1 (±5.12) x $(NDF\text{-}ADF)^3$	98.3	22.2	<0.05
Monte Carlo low forage	[LF-MC]	27364	eCH_4 = - 10.1 (±0.62) + 0.21 (±0.001) x BW + 0.36 (±0.003) x DMI^2 - 69.2 (±1.65) x fat^3 +13.0 (±0.45) x (CP:NDF) – 49 (±0.07) x (starch:NDF)	95.2	11.2	<0.001
IPCC (2006) Tier 2	IPCC 2006	34	eCH_4 = [DMI x 18.5 (MJ kg^{-1} DM) x (3.0 x 10)] / 55.65 (MJ kg^{-1} eCH_4)	89.6	-	-
All databases						
Original complete database	[AL-OR]	194	eCH_4 = -35.0 (±17.03) + 0.08 (±0.03) x BW +1.2 (±0.14) x dietary forage content -- 69.8 (±14.4) x fat^3+ 3.14 (±0.36) x GEI	154.9	154.9	<0.05

4.3 Link to alternative equations based on regions

1. https://doi.org/10.3168/jds.2011-4439
2. https://doi.org/10.1080/09064702.2013.851275
3. https://doi.org/10.3168/jds.2012-6095