Evaluating ten methods for predicting feed dry matter intake by lactating dairy cows in the tropics, including predictions based on neutral detergent fibre, for possible use in the Rumen8 software

Martin Staines. Rumen8 Nutrition Pty Ltd, PO Box 151, Cowaramup WA 6284, Australia.

Introduction

Prediction of feed dry matter intake (DMI) by lactating dairy cows is an essential component of diet formulation. The Rumen8 dairy cow nutrition software (www.rumen8.com.au) uses two prediction methods: firstly NRC (2001) and as an alternative the 'NDF intake method' of Mertens (1987; 1997; 2009). Both methods were developed using typical US dairy cows and diets. For Dairy cows, NRC (2001) use a multifactorial approach to predict DMI, based on cow LW, milk yield and week of lactation. Feed quality is not taken into account.

Mertens (1987; 1997; 2009) reported that intake of neutral detergent fibre (NDF) averaged 1.2 ± 0.1% of cow live weight (LW). This observation is now being applied widely around the world to predict feed DMI based on animal LW and dietary NDF content. In fact, it now appears to be applied to almost any class of ruminant livestock fed any type of diet regardless of merit. However, more recently, NASEM (2016) has suggested using an NDF intake of 1.1% of LW for beef cows fed low to medium quality forages. In East Africa most projects and courses managed by SNV recommend an NDF intake by dairy cows of 1.3% of LW.

The purpose of this study was to evaluate the suitability of using NRC (2001) and Mertens (1987) to predict DMI of lactating dairy cows in the tropics (or sub-tropics) fed tropical (or sub-tropical) forages. For brevity, the terms 'tropics' and 'tropical' will be used from here on. In addition, eight other methods for predicting DMI were also assessed. To this effect, a meta-analysis of published research was conducted.

Methods

A meta-analysis was conducted to evaluate various methods to predict *ad libitum* feed DMI by lactating dairy cows in the tropics fed diets containing a wide range of tropical forages. A total of 45 studies published in peer-reviewed international papers on feed intake/quality and milk production of lactating dairy cows in the tropics, were examined. These covered a wide range of cows (LW, milk yield, stage of lactation) and diets, from low quality high-fibre diets to low-fibre high-energy total mixed rations (TMR).

Six papers were excluded because they were deemed not to be sufficiently relevant for diets based on tropical forages. Of the remaining 39 papers, a further seven had to be excluded because there were inadequate data to calculate NDF intake expressed as a % of cow LW when cows were fed *ad libitum*. The 32 papers that were included in the final meta-analysis (see Appendix 1) reported on a total of 37 experiments encompassing 120 dietary treatments, fed to 1071 cows.

Latin-Square experimental designs were used in 14 experiments, while simple or factorial treatments were applied in a further 22. One study was itself a desktop analysis of Brazilian experiments, which enabled the inclusion of several studies reported in Portuguese.

Feed DMI was measured directly using penned animals in 20 of the papers, while 11 papers employed 'markers' to estimate intake of grazed forages (n=10) or penned animals (n=1). Markers used were alkanes (n=6) or others (n=5; chromium (III) oxide, titanium dioxide or ytterbium oxide/cobalt-EDTA).

Descriptive statistics for animals and 120 diets used in the 32 papers are given in Table 1.

Table 1: Descriptive statistics for animals and diets used in the 32 papers that were part of the meta-analysis.

Parameter	n[a]	Mean	Std Dev	Minimum	Maximum	Median
Study length (days)		62	71	14	365	35
Cow LW kg	120	433	75	275	558	430
LW change kg/d	120	0.19	0.62	-0.89	2.43	0.20
ECMY[b] kg	120	11.6	5.8	3.2	27.0	10.6
Milk fat %	94	3.87	0.44	3.00	5.00	3.80
Milk protein %	94	3.15	0.33	2.10	3.80	3.20
Days in milk	120	107	62	10	261	91
Forage % in DMI	120	72%	24%	19%	100%	73%
Dietary NDF content %	120	53%	12%	23%	79%	54%
Dietary ME MJ/kg DM	120	9.3	1.3	5.8	12.3	9.5
Total DMI kg/d	120	12.8	4.1	5.5	23.5	12.9
Total NDF intake kg/d	120	6.51	1.99	2.84	12.45	6.72
Total ME intake MJ/d	120	122	49	39	244	116
DMI as % of LW	120	2.91	0.61	1.51	4.24	3.04
NDF intake as % of LW	120	1.51	0.39	0.66	2.36	1.48

[a] Number of dietary treatments where each statistic was measured
[b] Energy Corrected Milk Yield

Most studies were conducted with cows in early lactation (52%) or mid lactation (36%), while a small number were conducted with cows in late lactation (8%). Two studies covered full lactations (5%). Cow LW ranged from 275 to 558 kg (mean 433), while corresponding figures for energy corrected milk yield (ECMY) were 3.2 to 27.0 kg (mean 11.6).

Total DMI ranged from 5.5 to 23.5 kg (mean 12.8). Forage content of diets ranged from 19 to 100% (mean 72). Corresponding figures for dietary NDF content were: 23 to 79% (mean 54) and for metabolisable energy (ME): 5.8 to 12.3 MJ/kg DM (mean 9.5), respectively.

<u>*Intake prediction methods used and statistical methods applied*</u>

The data presented in the 32 papers were used to evaluate the accuracy of ten prediction methods for DMI as outlined below.

The 'NDF intake' prediction method was applied at the suggested mean NDF intake of 1.2% of cow LW (Mertens 1987; 1997; 2009). In addition, we also examined higher NDF intakes of 1.35% of LW (as per Bateki and Dickhoefer 2019) and 1.5% of LW (given that mean and median NDF intakes reported in Table 1 were ~1.5% of LW).

Also examined were the DMI prediction methods of MAFF (1975), AFRC (1993), Traxler (1997), NRC (2001), Singh (2013) and NASEM (2016) (Methods A and B) (see Table 2 for an overview; see Appendix 2 for equations).

For the prediction methods of Traxler (1997) and NASEM (2016) (B), dietary concentration of ME was converted to 'Net Energy for maintenance (NE-m)' values using a regression equation derived from feed composition data presented in NASEM 2016 (Table 18-1; NE-m = 0.8829 x ME MJ/kg - 2.5859; r2 0.998; n=170). For the prediction methods Singh (2013) and NASEM (2016) B it was assumed that cows will be pregnant 105 days after calving, to account for ME requirements for pregnancy (and thus DMI).

Table 2: Feed intake prediction methods applied in the meta-analysis and the predictors used

Feed intake prediction method	Predictors used						
	Cow LW kg	Milk yield kg	Week of Lactation	Concentrate DM kg/d	Diet NDF %	Diet ME MJ/kg DM	Milk fat %
NDF intake 1.20% LW [a]	✓				✓		
NDF intake 1.35% LW	✓				✓		
NDF intake 1.50% LW	✓				✓		
MAFF (1975)	✓	✓					
AFRC (1993)	✓	✓	✓	✓			
Traxler (1997)	✓	✓				✓	
NRC (2001)	✓	✓	✓				
Singh (2013)	✓	✓	✓				✓
NASEM (2016) (A)[b]	✓					✓	
NASEM (2016) (B)[c]	✓	✓	✓			✓	

[a] *as per Mertens (1987)*
[b] *NASEM (2016); Table 10.1*
[c] *NASEM (2016); Equation 10-5*

Linear regression relationships were developed for the prediction methods, plotting 'measured DMI' against 'predicted minus measured DMI'. In a prefect prediction, all values for 'predicted minus measured DMI' will be zero (*i.e.* intercept and slope not significantly different from zero).

Predictions were ranked by calculating the following measures: the mean error of prediction (mean of 'predicted minus measured' DMI in kg/animal/day and as a % of measured DMI), the mean square error of prediction (MSEP; the mean of errors of prediction squared), and the square root-MSEP (SR-MSEP; in kg/animal/day and as % of measured DMI). SR-MSEP can be seen as the best estimate of the error of prediction for each feed intake prediction method. Therefore, the ten feed intake prediction methods were ranked 1 to 10 on the basis of their SR-MSEP value (lowest value giving best ranking).

<u>Results</u>

Feed DMIs ranged from 5.5 to 23.5 kg/cow/day with a mean of 12.8 kg (see Figure 1 and Table 1). Feed DMI expressed as a percentage % of cow LW varied from 1.51 to 4.24% (mean 2.91), while NDF intake expressed as a % of cow LW ranged from 0.66 to 2.36 % (mean 1.51; see Figure 1 and Table 1).

Total DMI was positively related to dietary ME concentration (coefficient of determination r^2 0.28; P<0.001), and negatively related to dietary NDF content (r^2 0.19; P<0.001) and dietary forage content (r^2 0.12; P<0.001). Dietary ME concentration was negatively related to dietary NDF content (r^2 0.62; P<0.001) and dietary forage content (r^2 0.60; P<0.001). Dietary forage content and NDF content were positively related (r^2 0.51; P<0.001).

Energy corrected milk yield (ECMY; kg) was positively correlated with total DMI (r^2 0.77; P<0.001) and dietary ME concentration (r^2 0.38; P<0.001), whereas it was negatively correlated with dietary NDF content (r^2 0.36; P<0.001).

The regression relationships between 'measured DMI' versus 'measured minus predicted DMI' for each of the ten prediction methods are shown in Figure 2 (see Appendix 3 for the relationship between measured DMI and predicted DMI).

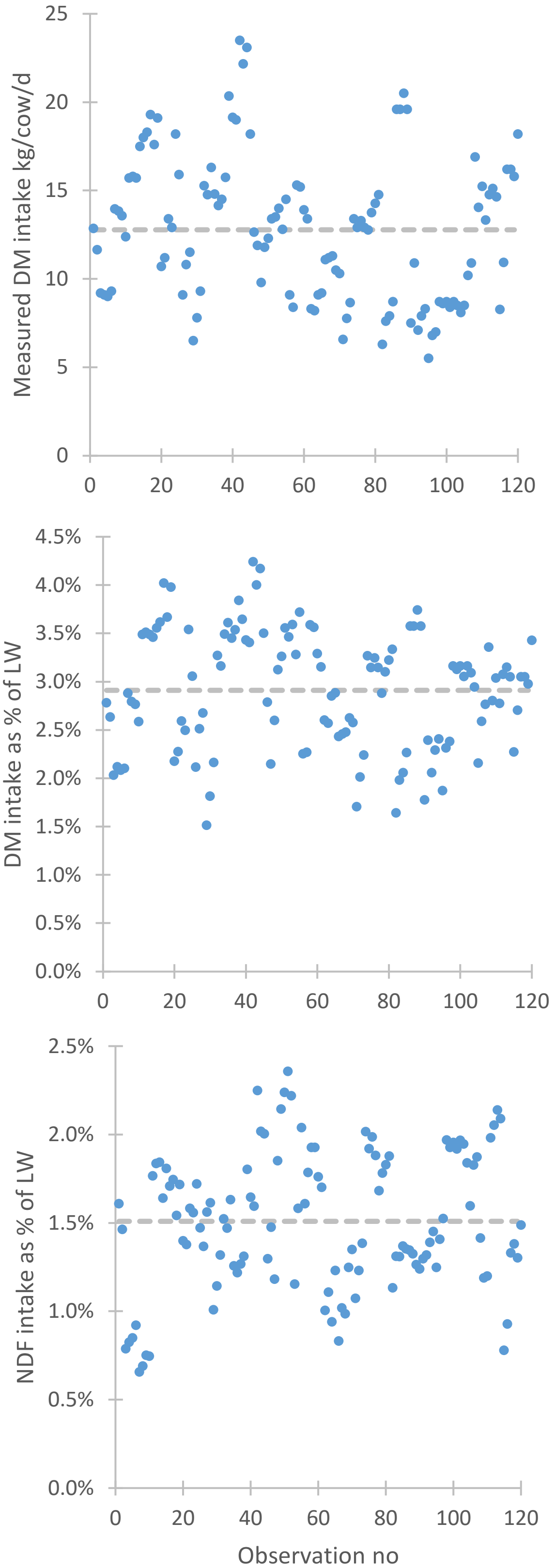

Figure 1: Measured feed DMI in kg/d (top panel), as a % of cow LW (middle panel) and estimated NDF intake as a % of cow LW (bottom panel) for the 120 observations in 32 papers used for the meta-analysis. Means are indicated with the grey broken line in each panel.

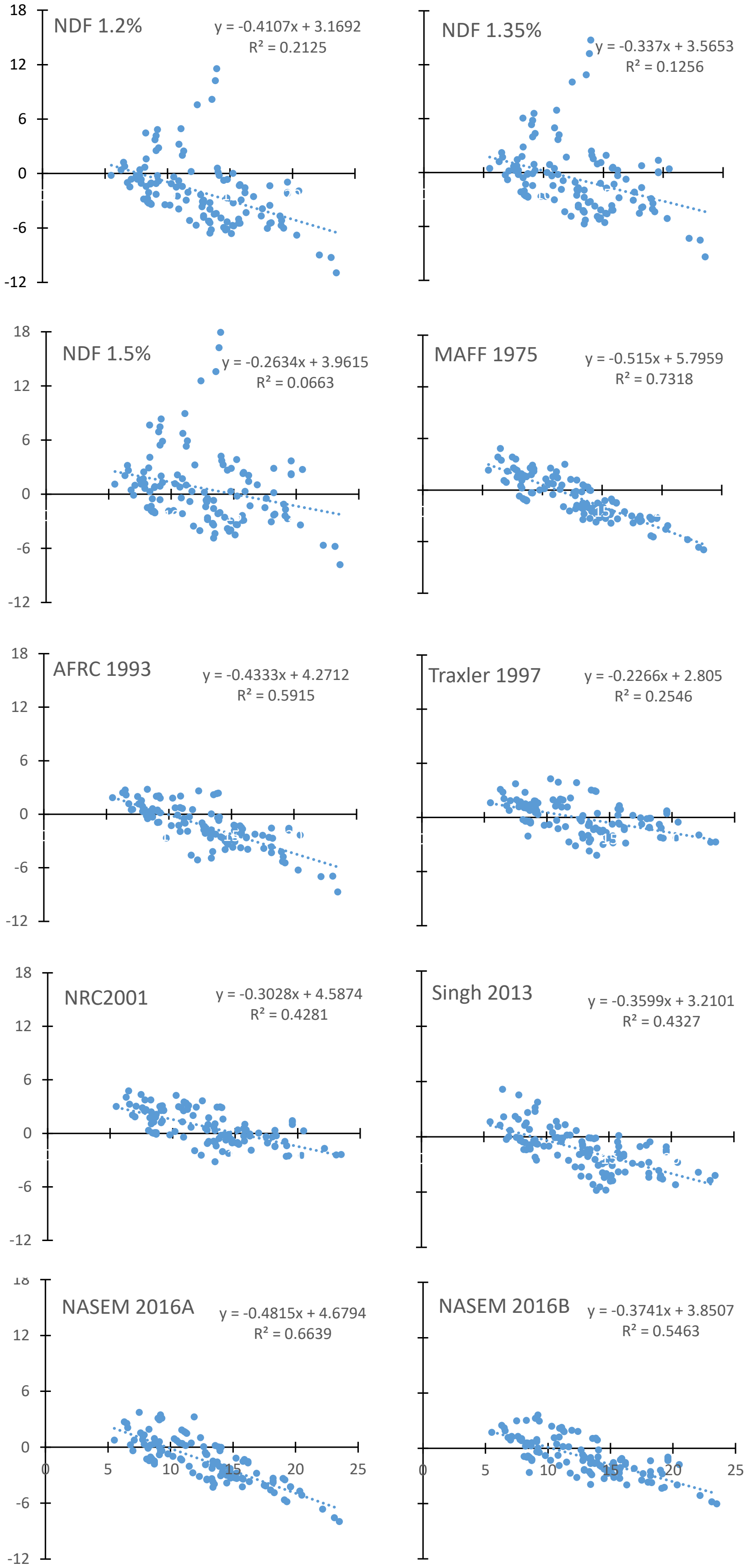

Figure 2: Measured feed DMI (on x-axis) vs 'predicted minus measured feed DMI' (on y- axis) in kg/cow/day for the ten prediction methods used in the meta-analysis (n=120 for each panel). Broken line is line of best fit. Regression equations with coefficients of determination are in given in each panel.

The mathematical evaluation of the ten feed intake prediction methods, including mean errors of prediction, and their ranking based on their SR-MSEP values is given in Table 3.

Table 3: Mathematical evaluation of the ten feed intake prediction methods and their ranking based on 'square root of mean square of prediction error' (SR-MSEP).

	Mean measured DMI	Mean predicted DMI									
		NDF 1.2%	NDF 1.35%	NDF 1.5%	MAFF 1975	AFRC 1993	Traxler 1997	NRC 2001	Singh 2013	NASEM 2016A	NASEM 2016B
DMI (kg/animal/day)	12.77	10.69	12.03	13.37	11.99	11.51	12.68	13.49	11.38	11.30	11.84
Mean error of prediction (kg DM/animal/day)	-	-2.07	-0.74	0.60	-0.78	-1.26	-0.09	0.72	-1.38	-1.47	-0.93
Mean error of prediction (% of measured DMI)	-	-19%	-6%	4%	-6%	-11%	-1%	5%	-12%	-13%	-8%
Mean square error of prediction (MSEP)	-	17.40	15.48	17.62	6.59	6.83	3.34	4.06	6.86	7.92	5.08
SR-MSEP (kg DMI/animal//day)	-	4.17	3.93	4.20	2.57	2.61	1.83	2.01	2.62	2.81	2.25
SR-MSEP (% of measured DMI)		33%	31%	33%	20%	20%	14%	16%	21%	22%	18%
Method Ranking[a]	-	9	8	10	4	5	1	2	6	7	3
<u>Minus Kanjanapruthipong and Thaboot (2006) (see Discussion)</u>											
DMI (kg/animal/day)	12.74	10.27	11.56	12.84	11.92	11.36	12.54	13.38	11.31	11.22	11.74
SR-MSEP (kg DMI/animal//day)		3.86	3.28	3.20	2.61	2.62	1.76	1.97	2.66	2.86	2.28
SR-MSEP (% of measured DMI)		30%	26%	25%	20%	21%	14%	15%	21%	22%	18%
Method Ranking[a]	-	10	9	8	4	5	1	2	6	7	3

[a] *ranking:1 being best and 10 being worst*

Discussion

Mertens (1987; 1997; 2009) reported that NDF intake in US dairy cows averaged 1.2 ± 0.1% of LW. In contrast, this analysis found a much wider range in NDF intakes as a % of LW (mean 1.51% ± 0.39), reflecting the much wide range in NDF content of diets used, ranging from 23 to 79%. Also, on average cows consumed significantly more DM and NDF than what was predicted by the NDF intake method of Mertens (1987; 1997; 2009).

Furthermore, of the ten DMI prediction methods assessed, the three NDF intake methods ranked 9th, 8th and 10th for NDF 1.2%, NDF 1.35% and NDF 1.5% respectively.

The regression relationships for the NDF methods shown in Figure 2 and Appendix 3 were skewed by the four data points from Kanjanapruthipong and Thaboot (2006), who used TMR diets with a low proportion of forages (19-27%), resulting in diets with the lowest NDF contents in this meta-analysis (23 to 29%; below the commonly recommended minimum for lactating dairy cows). These four points are clearly visible at the top of the three NDF panels in Figure 2 and Appendix 3. Removing the four points from the regression analysis increased the 'NDF-intake' coefficients of determination from 0.357 (Appendix 3) to 0.496 (details not shown). In contrast, it resulted in only minor improvements in the coefficients of determination for the 'non-NDF' intake methods (details not shown). However, with the four data points removed, the NDF methods still ranked 8th to 10th based on their SR-MSEP values.

The 'non-NDF' methods all performed much better compared to the NDF methods, with Root MSEP values (in kg DMI/animal/day) ranging from 1.83 to 2.81, compared to 3.93 to 4.20 for the three NDF intake methods. This is equivalent to 14-22% of measured DMI for the 'non-NDF methods' vs 31-33% for the NDF methods.

Therefore, the NDF intake method cannot be recommended for predicting DMI by lactating dairy cows in the tropics. This applies to both the 'original NDF method' of Mertens, and the 'adjusted NDF methods' we used here (1.35% and 1.5% of LW).

The Rumen8 dairy cow nutrition software uses NRC (2001) as the preferred intake predictor, with the NDF intake prediction method given as an alternative. Given these results, use of the NDF feed intake prediction method for dairy cows in the tropics must therefore discouraged and consideration should be given to its removal from future updates of Rumen8.

Feed intake prediction as per NRC (2001) ranked second in this meta-analysis, behind the method developed by Traxler (1997), with mean errors of prediction of 5% and -1% respectively and values of SR-MSEP of 2.01 kg and 1.83 kg per cow per day (=16% and 14% of mean daily DMI). The other 'non-NDF' feed intake prediction methods become progressively more biased and less accurate, in the order of NASEM (2016B), MAFF (1975), AFRC (1993), Singh (2013) and NASEM (2016A) respectively.

It was investigated if the parameters provided by Traxler (1997; see Appendix 2) could be 'fine-tuned' to further improve the accuracy of the method. Removing the addition of 1.7 kg DMI for ECMY >15 kg, while adjusting the factor of 0.305 per kg ECMY to 0.34 per kg ECMY, and adjusting the factor of 0.0074 to 0.0061, reduced the mean error of prediction from 1% to 0%, but did not alter the SR-MSEP value. The overall impact of these changes was therefore small, but the benefit was the removal of the arguably arbitrary addition of 1.7 kg DMI for ECMY >15 kg.

Based on this meta-analysis, it is concluded that the method of Traxler (1997) shows the highest accuracy and least bias for predicting DMI by lactating dairy cows in the tropics. It is recommended that this method is included in future updates of Rumen8. The method of NRC (2001) was somewhat less accurate and showed somewhat more bias. Until such time when the prediction method of Traxler (1997) becomes available in Rumen8, use of the NRC (2001) method is recommended for predicting feed intake for dairy cows in the tropics. Use of the NDF intake method should be avoided altogether.

Recommendations

It is recommended that the method of Traxler (1997) is added to the Rumen8 software as the preferred method for predicting DMI for lactating dairy cows in the tropics. The prediction method is straight-forward to calculate, requiring data on cow LW, ECMY and dietary ME concentration (to be converted to NE-m as described above), and a correction factor of + 1.7 kg DMI for cows producing over 15 kg ECMY. Minor fine-tuning of the method as described above simplifies the method and slightly improved its (low) mean error of prediction.

It is also recommended that an explicit warning is displayed in Rumen8 when users of the tropical feed library select the NDF intake predictor, stating that this meta-analysis has found NDF the method to be grossly inadequate for predicting DMI by lactating dairy cows in the tropics.

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<u>Appendix 1</u> List of 32 papers used for the meta-analysis

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Appendix 2 Equations for the ten prediction methods used in the meta-analysis

NDF 1.2% of LW

Predicted DMI = (Cow LW kg * 1.2%)/Dietary NDF content (%)

NDF 1.35% of LW

Predicted DMI = (Cow LW kg * 1.35%)/Dietary NDF content (%)

NDF 1.5% of LW

Predicted DMI = (Cow LW kg * 1.5%)/Dietary NDF content (%)

MAFF (1975)

Predicted DMI = (Cow LW kg * 0.025) +(0.1 * ECMY kg)

AFRC (1993)

Predicted DMI =0.076 +(0.404 * Concentrate DM kg) + (0.13 * Cow LW kg) –(0.129 * week of lactation) + 4.12$\log_{10}$(week of lactation) + (0.14 * milk yield kg)

Traxler (1997)

Predicted DMI = Cow $LW^{0.75}$× (0.1462NEm − 0.0517$(NEm)^2$− 0.0074) +0.305 * ECMY. A correction factor of +1.7 kg DMI is applied to cows producing > 15kg ECMY

NEm is net energy for maintenance in Mcal/kg DM is calculated as follows:

NEm (MCal/kg DM) = (Diet ME (in MJ/kg DM) * 0.8829 -2.5859[#]) / 4.184

[#] see main report for details on origin of this regression equation.

NRC (2001)

Predicted DMI =(0.372 * ECMY (kg) + 0.0968 * Cow $LW^{0.75}$) x (1 - $e^{(-0.192 \times (\text{week of lactation} + 3.67))}$)

e = 2.71828

Singh (2013)

Predicted DMI = (MER-maintenance + MER-milk + MER-pregnancy) / diet ME (MJ/kg DM)

MER-maintenance = 0.0917 * Cow LW (kg) + 12.135

MER-milk = milk yield (kg) * (0.6192* milk fat % + 2.5355)

MER-pregnancy = (0.3395 * weeks pregnant) + 0.1412 (assumes cows pregnant 15 weeks after calving)

Note: MER= ME requirements (MJ/d)

NASEM (2016) A

Equations developed from data in Table 10-1 (lactating cows only)

DMI as % of cow LW = dietary ME concentration (MJ/kg DM) * 0.2482 + 0.3647 (where result greater than 2.8, use 2.8 as maximum).

NASEM (2016) B

Predicted DMI:

NEm intake Mcal/d = Cow $LW^{0.75}$ X (0.04997 x NEm^2 +0.04631) for pregnant cows.
(assumes cows pregnant 15 weeks after calving)

NEm intake Mcal/d = Cow $LW^{0.75}$ X (0.04997 x NEm^2 +0.03840) for non-pregnant cows.

Increase DMI by 0.2 x daily milk yield (kg) for lactating cows.

DMI is calculated by dividing total daily NEm intake (Mcal/d) by dietary NEm concentration (Mcal/kg DM). For feeds with a dietary NEm concentration less than ≤0.95 Mcal/kg DM, the divisor should be set to a constant of 0.95 to avoid biologically unrealistic intakes (see NASEM 2016, page 167).

NEm is net energy for maintenance in Mcal/kg DM is calculated as follows:
NEm (MCal/kg DM) = (Diet ME (in MJ/kg DM) * 0.8829 -2.5859[#]) / 4.184
[#] see main report for details on origin of this regression equation.

Appendix 3 *Measured DMI (on x-axis) vs predicted DMI (on y- axis) in kg/cow/day for the ten prediction methods used in the meta-analysis (n=120 for each panel). Light-grey solid lines are lines of unity. Black broken lines are lines of best fit. Regression equations are given in top right of each panel.*