Excretion of nitrogen and organic matter in cattle manure – an evaluation of Nex and VS models from Norwegian dairy cows and growing cattle

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Content

Summary

The purpose of this report is to evaluate current models for calculating the amount of manure and the excretion of nitrogen in feces and urine in dairy cows and growing cattle. The report also proposes revised models for calculating the excretion of volatile solids of organic matter in different cattle categories. The report also provides suggestions for possible improvements to future models. With the exception of heifers for slaughter, it is recommended to continue the current nitrogen models from NIR 2021 for dairy cows, breeding heifers and slaughter bulls. For heifers for slaughter, new models are recommended. Revised models are proposed for calculation of volatile solids excreted in feces and urine. The report also proposes various measures to improve future models.

Introduction

The basic for calculating methane and nitrous oxide from livestock manure is based on the predicted amount of manure and the excretion of nitrogen in feces and urine. The Norwegian cattle models for calculating the amount of manure and the excretion of nitrogen are based on a study by Karlengen et al. (2012). The empirical equations developed by Karlengen et al. (2012) is based on the feed evaluation system NorFor (Volden, 2011), which is a dynamic mechanistic feed evaluation system that estimates the digestibility of the feed, excreted amount of feces and urine as well as nitrogen in feces and urine.

In the last 10 years, the annual milk yield per cow has increased from 7370 to 8620 kg energy corrected milk (EKM). At the same time, both the amount of concentrate and the proportion of protein ingredients in the concentrate have increased, not only for dairy cows but for all cattle categories. These changes will affect the amount of manure and the excretion of nitrogen in feces and urine. As a result of changed yield performance and protein feeding, there is need for a review of the current national figures of the amount of manure and nitrogen excreted in feces and urine in cattle.

This report presents a review and describes equations used int NIR 2022for calculating nitrogen and volatile solids excreted in feces and urine in dairy cows, replacement heifers, heifers for slaughter and bulls for slaughter. The report will also make suggestions on how the models can be further developed and improved.

Evaluation of models for calculating nitrogen excretion in feces and urine

The basic for the Norwegian models is the feed evaluation system NorFor (Volden, 2011), which predicts the excretion of nitrogen in feces and urine. Figure 1 shows a test of the system for the digestibility of protein in dairy cows. The test shows a good agreement between observed and predicted values with a prediction error of 8.1%. A similar test was done for growing cattle (Figure 2) and shows a prediction error of 14.5%. The NorFor system was first published in 2011 and has undergone continuous development. Therefore, it is important to test the current model against more recent experimental data. In 2021, Spanghero and Kowalski (2021) published a meta-study of nitrogen balance experiments in dairy cows. The paper describes equations to calculate the excretion of nitrogen in feces and urine. The study includes nitrogen balance experiments with dairy cows carried out in the period 1997 to 2020 and consists of data from 86 studies and 307 feed rations.

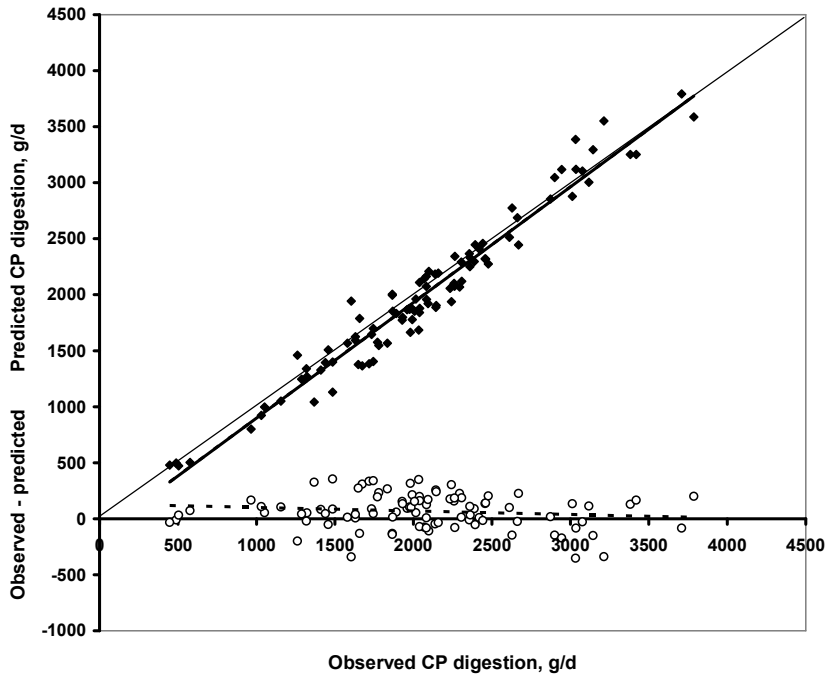

Figure 1. Test of the NorFor system. Predicted *vs.* observed crude protein (CP) digestion in dairy cows. From Volden, (2011). Black symbols (♦) describe observed and predicted values. White symbols (◦) describe differences between observed – predicted values.

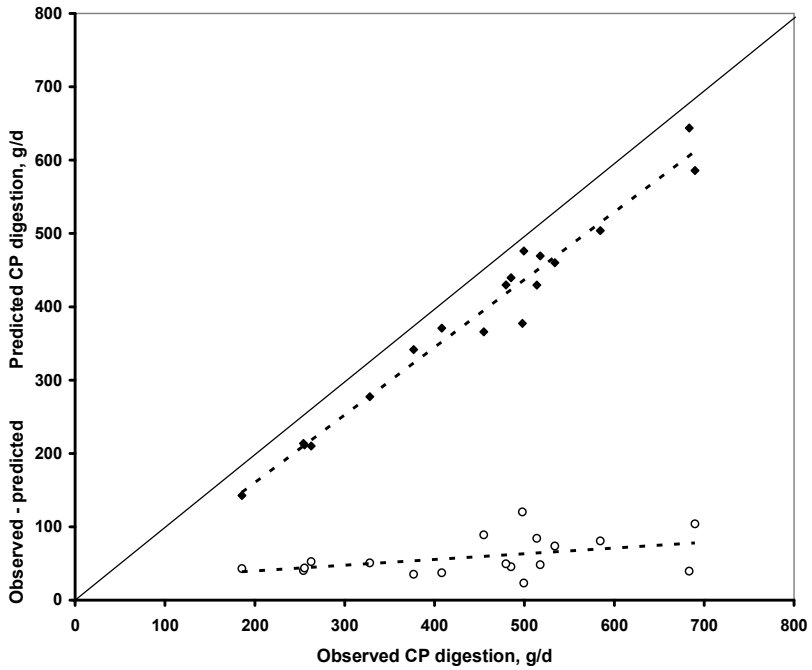

Figure 2. Test of the NorFor system. Predicted *vs.* observed crude protein (CP) digestion in growing cattle From Volden, (2011). Black symbols (♦) describe observed and predicted values. White symbols (◦) describe differences between observed – predicted values.

Figure 3 shows a comparison between an equation developed by Spanghero and Kowalski (2021) and NorFor in the amount of nitrogen excreted in feces and urine. The results showed a high correlation ($R^2 = 0.99$), and there is no line bias. The figure shows a general bias of 45 grams, which means that NorFor gives on average 9% higher excretion of nitrogen. This agrees well with the results of Spanghero and Kowalski (2021), who concluded that nitrogen balance experiments in dairy cows overestimate nitrogen retention and underestimate the excretion of nitrogen in feces and urine by 5-8%. From this test we can conclude that NorFor gives a reliable estimate in the excretion of nitrogen in feces and urine in dairy cows, and that the empirical equations developed by Karlengen et al. (2012) can be used as a basic for predicting nitrogen excretion. Test of the NorFor system for growing cattle showed a prediction error of 14.5% (Volden, 2011) and it is concluded that the empirical equations of Karlengen et al. (2012) also gives a reliable estimate of nitrogen excretion in growing cattle.

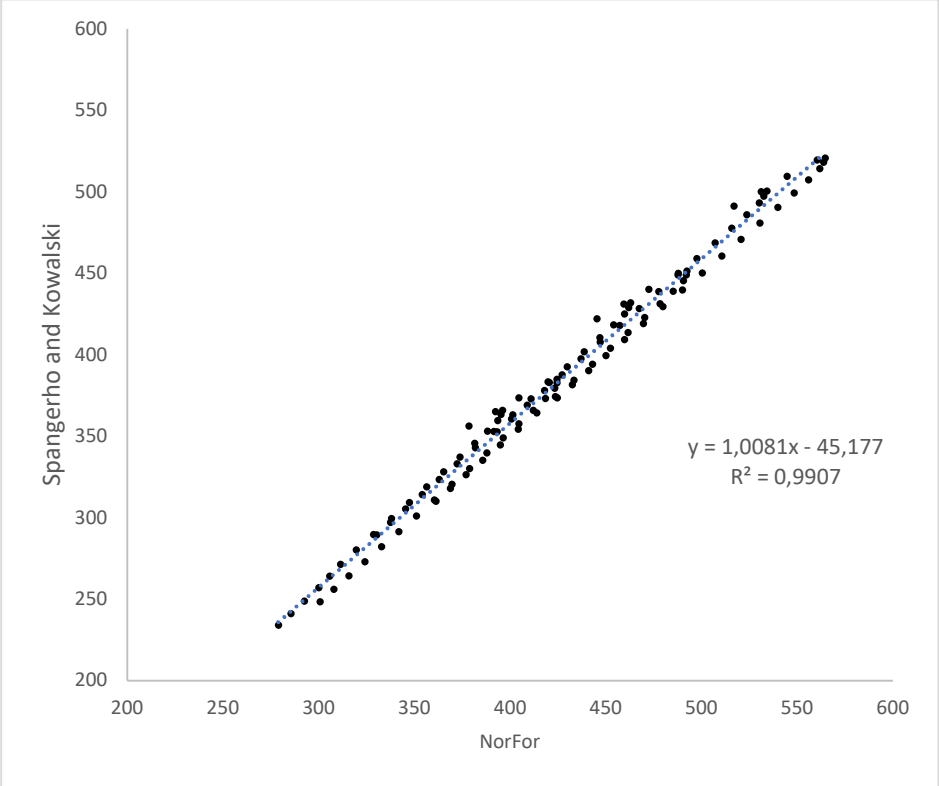

Figure 3. Nitrogen excretion from urine and feces. A comparison between a meta-analysis published by Spangherro and Kowalski (2021) and NorFor.

Proposed equations to predict nitrogen excretion

The next section describes the proposed equations to predict nitrogen excretion

Dairy cows

N excreted in manure = -120.827 + (0.00798 * Y) + (0.0433 * V) + (0.605 * PG) + (0.355 * PK)

N excreted in feces = 13.956 + (0.00452 * Y) + (0.00920 * V)

N excreted in urine = N excreted manure -N excreted feces

Where:

N excreted in manure = nitrogen excreted in feces and urine, kg/year
N excreted in feces = nitrogen excreted in feces, kg/year
N excreted in urine = nitrogen excreted in urine, kg/year
Y = milk yield, kg energy corrected milk per year
V = live weight, kg
PG = content of crude protein in the forage, g/kg dry matter
PK = content of crude protein in the concentrate, g/kg dry matter

Breeding heifers

N excreted in manure = -166.680+ (0.221 * V) + (1.689 * FT) + (0.513 * PG) + (0.119 * PK)

N excreted feces = -14.850 + (0.0737 * V) + (0.485 * FT) - (0.0220 * PG)

N excreted urine = N excreted manure -N excreted feces

Where:

N excreted in manure = kg nitrogen excreted in feces and urine, kg for the entire breeding period
N excreted in feces = nitrogen excreted in feces, kg for the entire breeding period
N excreted in urine = nitrogen excreted in urine, kg for the entire breeding period
FT = breeding period until calving, months
V = live weight, kg
PG = content of crude protein in the forage, g/kg dry matter
PK = content of crude protein in the concentrate, g/kg dry matter

Heifers for slaughter

In the NIR 2021, polynomial equations are used to calculate excretion of total nitrogen and nitrogen in urine.

Equation for total nitrogen:

$$Y = 9.7675 \times 10^{-8}\, a^4 - 0.000209333\, a^3 + 0.242937\, a^2 + 8.77947\, a - 9.7675 \times 10^{-8}\, b^4 + 0.000209333\, b^3 - 0.242937\, b^2 - 8.77947\, b$$

Where:

Y = kg nitrogen excreted in feces and urine, kg for the defined period
a = end of the calculating period, days
b = start of the calculating period, days

Equation for urinary nitrogen

$$Y = -0.0000363333\, a^3 + 0.112968\, a^2 + 5.82073\, a + 0.0000363333\, b^3 - 0.112968\, b^2 - 5.82073\, b$$

Where:

Y = kg nitrogen excreted in urine, kg for the defined period
breeding period
a = end of the calculating period, days
b = start of the calculating period, days

Data for slaughter weight and slaughter age are available for heifers at a national level. To obtain consisting data it is suggested that the same equations as for breeding heifers are used for slaughter heifers. The following equations should be used:

N excreted in manure = -166.680+ (0.221 *2.06*SW) + (1.689 * SA) + (0.513 * PG) + (0.119 * PK)

N excreted feces = -14.850 + (0.0737 * 2.06* SW) + (0.485 * SA) - (0.0220 * PG)

N excreted urine = N excreted manure -N excreted feces

Where:

N excreted in manure = kg nitrogen excreted in feces and urine, kg for the entire breeding period
N excreted in feces = nitrogen excreted in feces, kg for the entire breeding period
N excreted in urine = nitrogen excreted in urine, kg for the entire breeding period
SA = age at slaughter, months
SW = slaughter weight, kg
PG = content of crude protein in the forage, g/kg dry matter
PK = content of crude protein in the concentrate, g/kg dry matter

In the equations the parameter value of 2.06 describe the inverse of the slaughter percentage in heifers (2.06=1/0.485).

Bulls for slaughter

N excreted in manure = -130.554 + (0.319 * SV) + (1.283 * SA) + (0.342 * PG) + (0.168 * PK)

N excreted feces = -13.845+ (0.115 * SW) + (0.355 * SA)

N excreted urine = N excreted manure -N excreted feces

Where:

N excreted in manure = kg nitrogen excreted in feces and urine, kg for the entire breeding period
N excreted in feces = nitrogen excreted in feces, kg for the entire breeding period
N excreted in urine = nitrogen excreted in urine, kg for the entire breeding period
SA = age at slaughter, months
SW = slaughter weight, kg
PG = content of crude protein in the forage, g/kg dry matter
PK = content of crude protein in the concentrate, g/kg dry matter

For the variables milk yield, calving age for heifers, slaughter age and slaughter weight for heifers and bulls, there is a national and systematic collection of data and these provides high quality data. For the variable crude protein content in forage, there is a common database (NorFor FAS) of analyzed forage samples, although they represent about 30% of the Norwegian cattle herds. The number of analyzes is sufficient to capture annual variations of crude protein content in forage.

Data for slaughter weight and slaughter age are also available for heifers. To obtain consisting data it is suggested that the same equations as for breeding heifers is used for slaughter heifers.

Beef cattle

Equations for nitrogen excretion in beef cattle has been described in a report by Åby et al. (2018).

Sensitivity analysis

To assess the effect of data quality, a sensitivity analysis has been performed for the empirical equation in dairy cows. The sensitivity analysis has been carried out as described by Volden (2011) and the sensitivity has been calculated according to the following equation:

$$\text{Sensitivity} = \left(\frac{\left(\frac{r_{min} - r_{max}}{r_{basal}} \right)}{\left(\frac{p_{min} - p_{2max}}{p_{basal}} \right)} \right) \cdot 100$$

where sensitivity is calculated in %, r_{min} is the minimum response value, r_{max} is the maximum response value, r_{basal} is the basal response value, p_{min} is the minimum parameter value, p_{max} is the maximum parameter value, and p_{basal} is the basal parameter value.

Table 1 present the results of the sensitivity analysis. The most sensitive variable is the crude protein content in the forage and thereafter the milk yield and crude protein content in the concentrate. The data quality for milk performance is good, while data for the crude protein content in feed is more uncertain, especially for concentrate mixtures. The sensitivity analysis shows that it is important to increase the quality of data collection for crude protein content in feed. Figure 4 shows the content of crude protein in forage in the period 2007 to 2020. The results are from the NorFor feed database where the laboratories report farm feed results. The number of samples per year varies from 7,000 to 10,000 samples. Since the crude protein content in forage is the most sensitive variable for predicting the excretion of nitrogen in manure, the figure shows that there will be a significant variation between years and that these results should be included as an annual input variable in the calculations.

Table 1. Sensitivity analysis of the empirical equation for calculating nitrogen excretion in manure from dairy cows

Item	Unit	Parameter value			Sensitivity, %
		Basis	min	max	
Milk yield	kg EKM/Yr	8500	7650	9350	49.7
Animal weight	kg	600	540	660	19.0
Crude protein, forage	g/kg dry matter	156	140	172	69.1
Crude protein, concentrate	g/kg dry matter	195	176	215	50.7

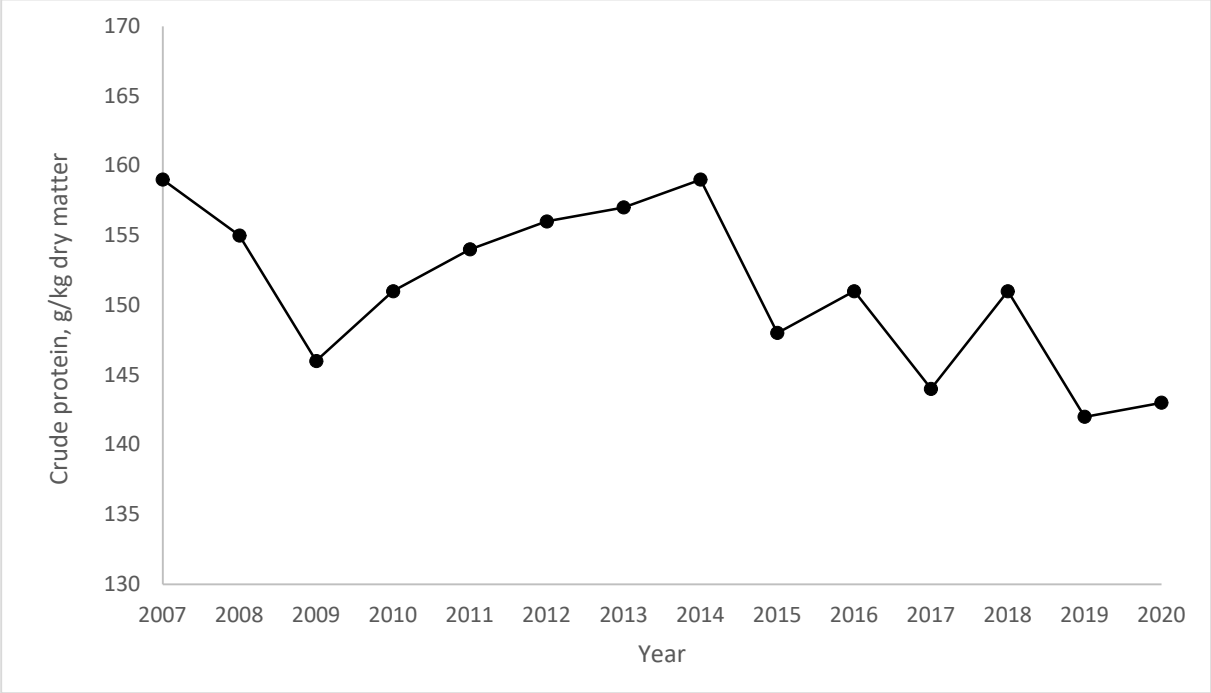

Figure 4. Crude protein content in Norwegian forage from 2007 to 2020.

About 90% of the concentrate used in Norwegian cattle production is sold as pelleted compound feed. The crude protein content of the concentrate mixtures is reported in a common database (NorFor FAS), but a challenge is that the distribution of sales of the various mixtures is not known, which makes it difficult to calculate a weighted average for the crude protein content in concentrates mixtures sold. To improve future models the following points should be considered:

1. Continue to use the empirical equations developed by Karlengen et al. (2012)
2. The equations used for heifers for slaughter should be changed according to the equations proposed in the report
3. Strengthen the data quality for crude protein in forage by using data reported in NorFor FAS database
4. Discuss with the feed industry about access to data for crude protein in concentrate mixtures that are in accordance with the sales statistics for different types of company feed.

Evaluation of models for calculating excretion of volatile solids in manure

Volatile solids (VS) define the excretion of organic matter in feces and urine and according to the IPCC, VS can be calculated from the following equation:

EQUATION 10.24
VOLATILE SOLID EXCRETION RATES

$$VS = \left[GE \bullet \left(1 - \frac{DE\%}{100} \right) + (UE \bullet GE) \right] \bullet \left[\left(\frac{1 - ASH}{18.45} \right) \right]$$

Where:

VS = volatile solid excretion per day on a dry-organic matter basis, kg VS day^{-1}

GE = gross energy intake, MJ day^{-1}

DE% = digestibility of the feed in percent (e.g. 60%)

(UE • GE) = urinary energy expressed as fraction of GE. Typically 0.04GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet or for swine). Use country-specific values where available.

ASH = the ash content of manure calculated as a fraction of the dry matter feed intake (e.g., 0.08 for cattle). Use country-specific values where available.

18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg^{-1}). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

In the equation, GE is an expression of feed intake, DE expresses the digestibility of dry matter and ASH expresses the ash content in feces. UE · GE is an expression of urine excretion. In the IPCC equation, the feed digestibility is the most sensitive variable and to estimate this one can use the NorFor system. Figure 5 shows a test (Volden, 2011) for the digestibility of organic matter in dairy cows and Figure 6 shows a test for bulls and heifers. For dairy cows the prediction error is 4.8% while for growing cattle it is 7.5%.

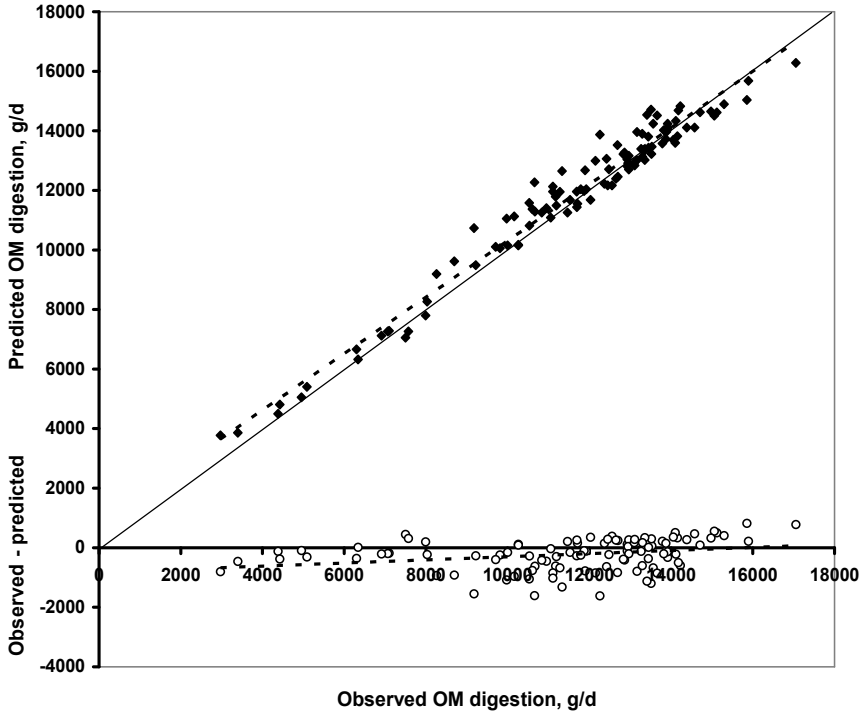

Figure 5. Test of the NorFor system. Predicted *vs.* observed organic matter (OM) digestion in dairy cows. From Volden, (2011). Black symbols (♦) describe observed and predicted values. White symbols (◦) describe differences between observed – predicted values.

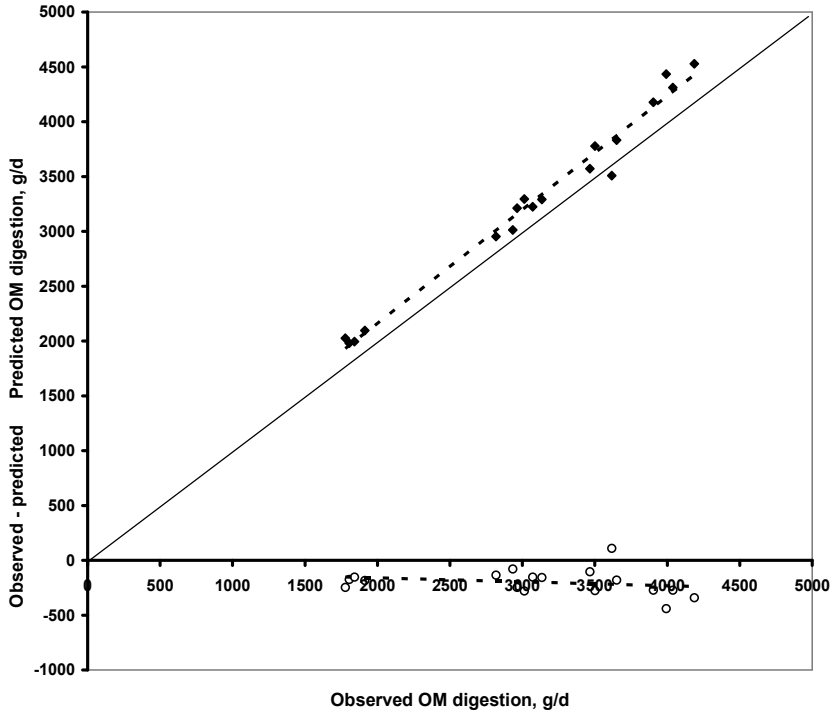

Figure 6. Test of the NorFor system. Predicted *vs.* observed organic matter (OM) digestion in growing cattle From Volden, (2011). Black symbols (♦) describe observed and predicted values. White symbols (◦) describe differences between observed – predicted values.

Based on simulations in NorFor, Karlengen et al (2012) developed empirical equations to calculate the excretion of feces and urine in dairy cows, heifers and bulls. A prerequisite was that the input variables should be robust and easy to obtain from practical livestock production. The IPCC equation for VS is expressed on an organic matter basis, while the equations developed by Karlengen et al. (2012) are expressed on a dry matter basis. It is therefore necessary to modify the equations of Karlengen et al. (2012) and based on digestion experiments with both dairy cows and young cattle, an average ash content in feces was found to be 10.5% (Volden, unpublished) and this is used in the modified equations. Below is a description of the modified equations for different cattle categories. The equation described for dairy cows has been used in the NIR 2021 report.

Dairy cows

ManureOM exc=(514.719+(0.115*Y)+(0.561*V))*1.23*0.895

Where:

ManureDM exc = organic matter excreted in feces and urine, kg/year
Y = milk yield, kg energy corrected milk per year
V = weight, kg

Breeding heifers

ManureOM exc =(-677.46+(2.436*V)+(27.32*FT)-(1.326*PG))*1.27*0.895

Where:

ManureOM exc = organic matter excreted in feces and urine, kg for the entire breeding period
FT = breeding period until calving, months
V = weight, kg
PG = content of crude protein in the forage, g/kg dry matter

Heifers for slaughter

In the NIR 2021 a polynomial equation is used to calculate excretion of VS. The following equation is used:

$$Y = -9.98667 \times 10^{-7}\, a^3 + 0.0024625\, a^2 + 0.177304\, a + 9.98667 \times 10^{-7}\, b^3 - 0.0024625\, b^2 - 0.177304\, b$$

Where:

Y = kg dry matter excreted in feces and urine, kg for the defined period
a = end of the calculating period, days
b = start of the calculating period, days

This equation describes the excretion of dry matter and not organic matter. No correction for ash content in the feces is used in the Norwegian NIR 2022. To obtain consisting data it is proposed that the equation for slaughter heifers is changed to the same equation as for breeding heifers but corrected for slaughter weight and slaughter age. The following equation should be used:

ManureOM exc =(-677.46+(2.436*2,06 SW)+(27.32*SA)-(1.326*PG))*1.27*0.895

Where:

ManureOM exc = organic matter excreted in feces and urine, kg for the entire breeding period
Slaughter age = age at slaughter, months
SW = slaughter weight, kg
PG = content of crude protein in the forage, g/kg dry matter

In the equations the parameter value of 2.06 describe the inverse of the slaughter percentage of heifers (2.06=1/0.485).

Bulls for slaughter

ManureOM exc =(-520.898+(3.202*SV)+(27.967*SA)-(0.671*PG))*1.26*0.895

Where:

ManureOM exc = organic matter excreted in feces and urine, kg for the entire breeding period
SA = age at slaughter, months
SV = slaughter weight, kg
PG = content of crude protein in the forage, g/kg dry matter

Evaluation of present VS equations

A weakness of today's equations is that they do not capture changes in the diet composition over time. This can be illustrated by Figure 7, which shows the change in the proportion of concentrates in the diet of dairy cows in the period 1990 to 2020. Concentrates have a higher digestibility than roughage and an increase in the concentrate proportion from 33 to 44% has increased the digestibility of the feed ration and thus given a relatively lower excretion of feces. In the same period, analysis of the roughage (Volden, unpublished) has shown a small variation in the digestibility of organic matter (70 ± 1.5%). If we want to improve the equations for prediction of VS, the ratio between roughage and concentrate should be included in the models.

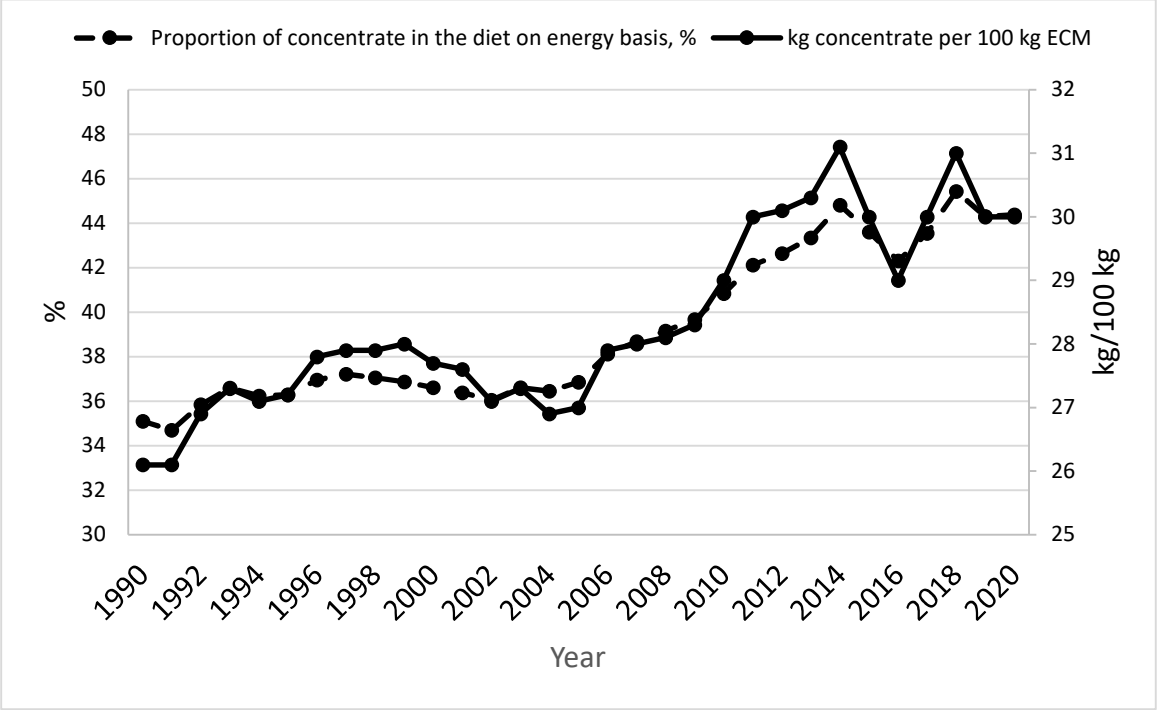

Figure 7. Concentrate in the dairy cow diet from 1990 to 2020

Recommendations for calculation of organic matter excretion in manure

1. In the dairy cow equation, the proportion of concentrate in the diet should be included
2. The equations used for heifers for slaughter should be changed according to the equations proposed in the report
3. The equations for young cattle should be revised as it is unclear why the crude protein content in roughage is included in the equations.

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