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Samenvatting NL
Het project "Voeding op Maat" onderzoekt of en hoe het huidige eiwitwaarderingssysteem voor melkvee (het DVE systeem) verbeterd kan worden. In het DVE systeem zijn de afbraak (Kd) en passage (Kp) in en door de pens belangrijke parameters voor het voorspellen van de fermentatie van de verschillende componenten (bijv. Eiwit, Zetmeel, Vezels (NDF), suiker) in de pens. Het voorliggende rapport onderzoekt de voorspelling van de passagesnelheid van de potentieel pensfermenteerbare NDF (Kp-D-NDF) door de pens. Dit is gebeurd door verschillende modellen te fitten op een dataset van verteringsproeven. Deze dataset bestond uit gegevens uit de wetenschappelijke literatuur van experimenten waarin voor Europese rantsoenen de pensfermentatie is gemeten van NDF. De modellen die getest werden onderzochten de invloed van verschillende factoren (Kd van NDF, voeropname, ruwvoer versus krachtvoer en krachtvoerratio) op de voorspelling van Kp-D-NDF. Het model dat rekening houdt met het effect van voeropname resulteerde in de beste voorspelling van de Kp-D-NDF. Echter, dit model geeft bij hogere voeropnames onverwachte resultaten. Het voorliggende rapport kan als basis dienen voor verdere besluitvorming hoe een verbeterd DVE model te bouwen.

Summary UK
The "Voeding op Maat" project investigates whether and how the current protein feed evaluation system for dairy cattle (the DVE system) can be improved. In the DVE system, the degradation (Kd) and passage (Kp) in and through the rumen are important parameters for predicting the fermentation of the different components (e.g. Protein, Starch, Fiber (NDF), sugar) in the rumen. The present report investigates the prediction of the passage rate of potential rumen fermentable NDF (Kp-D-NDF) through the rumen. This was done by fitting different models to a dataset of digestion experiments. The dataset consisted of data from scientific literature of experiments in which the rumen fermentation of NDF was measured on European rations. The models tested examined the influence of various factors (Kd of NDF, feed intake, forage vs. concentrate and concentrate ratio) on the prediction of Kp-D-NDF. The model that takes into account the effect of feed intake provided the best prediction of the Kp-D-NDF. However, that model produces unexpected results at higher feed intakes. The present report can serve as a basis for further decision making on how to build an improved DVE model.

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Foreword

The present study ‘Prediction of rumen passage rate of neutral detergent fiber (NDF)’ was conducted by a collaboration of Wageningen Livestock Research (WLR), the Flanders Research Institute for Agriculture, Fisheries and Food (ILVO) and the foundation CVB as part of the Public Private Partnership “Voeding op Maat” with the aim to reduce nitrogen emission in production animals through improved nutrition. This project was funded by the foundation CVB and the Dutch Ministry of Agriculture, Nature and Food Quality. The authors thank the members of the Ad hoc committee and the technical committee of CVB for their support.

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Summary

The “Voeding op Maat” project investigates whether and how the current protein feed evaluation system for dairy cattle (the DVE system) can be improved. In the DVE system, the degradation rate in the rumen (Kd) and the passage rate through the rumen (Kp) are important parameters for predicting the fermentation of the different dietary components (e.g. Protein, Starch, Fiber (NDF), sugar) in the rumen. The present report investigates the prediction of the passage rate of potential rumen fermentable NDF (Kp-D-NDF) through the rumen.

This was done by fitting various models to a dataset. Initially a dataset was composed from international literature containing 84 studies and a total of 395 treatment means. From the original dataset 17 studies with 67 treatments from European countries (EU) was used. The dataset contained experiments in which the rumen fermentation of NDF was measured. This dataset was used to examine the explanatory value of several models. This was done with a leave one out evaluation, where the model was developed on the dataset minus one experiment and the model was then tested on that experiment. This was done repeatedly for all experiments. The models tested examined the influence of various factors such as the kd of potential rumen fermentable NDF (Kd-D-NDF), feed intake and dietary concentrate ratio on the prediction of Kp-D-NDF. This was done with two approaches, with in the first approach only Kp-D-NDF was modelled and in the second approach a two step procedure was employed where first Kp-D-NDF was modelled and subsequently Kd-D-NDF was modelled. In this second approach also the effect of starch level on Kd-D-NDF was investigated. Only the results of 4 models according to the first approach are presented as the models based on the second approach did not improve prediction. The 4 fitted models were 1. Constant Kp-D-NDF values for concentrate and roughage feed materials. 2. Kp-D-NDF was related to Kd-D-NDF. 3. Kp-D-NDF was related to the feeding level of the animals and 4. Kp-D-NDF was related to both feeding level and dietary concentrate ratio. Model 3, the model that takes into account the effect of feed intake provided the best prediction of Kp-D-NDF. Average Kp-D-NDF for roughages and concentrates in this model were 1.28 and 1.33 %/h respectively, with feeding level increasing the passage rate with 0.86 and 0.16 %/h respectively per unit increase of feeding level (feeding level calculated as (kg dry matter intake per day/kg bodyweight) × 100). However, this model has some issues when applying it to cows with feed intake levels above a certain level. For example, at an intake level of 23 kg dry matter per day the equation results in higher Kp-D-NDF for roughages than for concentrates, which is contrary to expectation based on available literature. It might therefore more prudent to use Kp-D-NDF values estimated from the simpler model 1 with estimated Kp-D-NDF values of 1.25 and 1.74 %/h for, respectively, roughages and concentrates. The present report can serve as a basis for further decision making on how to build an improved DVE model.

1 Introduction

Empirical equations that predict flows of dietary nutrients through the gastro intestinal tract of dairy cows are essential for quantifying the extent of dietary nutrients fermented in the rumen and of dietary nutrients reaching the small intestine. Based on these estimates of dietary protein reaching the small intestine and nutrients fermented in the rumen (resulting in the synthesis of rumen microbial protein) various protein evaluation models for dairy cows (NRC, 2001, van Duinkerken et al., 2011, Noziere et al., 2018) use this information to predict the amount of intestinal available protein for the cow. In the Dutch DVE/OEB system (van Duinkerken et al., 2011), each feedstuff has an intestinal available protein value (called DVE) which is the sum of (1) digestible true feed protein escaping rumen degradation, (2) microbial protein synthesized in the rumen, and (3) a correction for endogenous protein losses in the digestive tract. In order to quantify rumen microbial protein synthesis in the rumen (MPS) it is required to estimate first the quantity of nutrients fermented in the rumen for the various feedstuffs (Van Duinkerken et al., 2011). In the DVE/OEB system (Van Duinkerken et al., 2011), the efficiency of MPS (expressed as g of microbial protein formed per kg of nutrient fermented) is related to the various fractions S (soluble fraction), W (washout fraction), W-S (insoluble washout fraction), and D (potentially rumen degradable fraction) of the dietary chemical components (e.g., crude protein, starch, NDF, sugars, fermentation products, and residual non-starch polysaccharides) and their associated fractional passage rates in the rumen. Neutral detergent fiber (NDF) is the most common measure of fiber used for animal feed analysis. The DVE/OEB model includes two equations to predict fractional passage rates for the potential degradable NDF fraction (D-NDF), one for roughages and one for concentrates. A realistic estimation of MPS heavily depends on an accurate estimation of fermented NDF in the rumen. For example, comparing measured quantities of rumen fermented NDF based on a dataset of digestibility studies used in this study with predicted rumen fermented quantities of rumen fermented NDF using the Dutch DVE/OEB system (van Duinkerken et al., 2011) showed for the European data that 50% of the error could be attributed to bias instead of random error (Appendix, Table-5). The main objective of this study was to improve the estimation of the amount of rumen fermented dietary NDF by establishing models that predict the rumen passage rate of potentially rumen fermentable NDF (Kp-D-NDF; %/h) of a given feedstuff. These Kp-D-NDF models include dietary factors (such as type of NDF (from leguminous, hay, straw, concentrates, or roughages), degradation rates of potential rumen fermentable NDF (Kd-D-NDF; %/h) of feedstuffs, and dietary concentrate ratios) and feed intake level as an animal factor as predictors. In order to do this, a dataset of digestion studies reported in scientific literature was compiled in which rumen digestion of NDF was measured. Using this dataset, Kp-D-NDF was estimated by minimizing differences between observed rumen fermented NDF (kg/d) and estimated rumen fermented NDF (kg/d). The dataset contained mainly digestibility studies from Europe (EU) and North America (NA). After fitting of models it became apparent that model outcomes for NA data were substantially different than model outcomes for EU data. As the aim of this project is to develop models to predict Kp-D-NDF under European conditions, it was decided to split the data and to only use the EU data for establishing models for Kp-D-NDF.

2 Material and methods

2.1 Dataset

A literature research on digestibility trials reported in scientific journals was carried out in 2019 in which rumen digestibility of NDF was determined. This was carried out using the search terms “digestibility or digestion”, “rumen”, “dairy cattle or dairy cows”. Only those studies were included in the meta-analysis dataset that 1) were based on dairy cattle, 2) had recorded the dry matter intake, and 3) did not include NDF-containing feedstuffs for which there is no CVB information with respect to in situ rumen degradation characteristics of NDF and starch. The literature research resulted in an original dataset with 84 studies and included a total number of 395 observations (treatment means). From the original dataset, 17 EU studies (67 observations) were used to develop models for predicting Kp-D-NDF in roughages and concentrates. CVB information (CVB, 2016) on D-NDF and Kd-D-NDF on individual feedstuffs was used in order to calculate Kd-D-NDF of individual feedstuffs in the diets. If the body weight was missing, it was assumed to be 650 kg. A summary of the used EU-dataset is given in Table 1. In Appendix 1 in Table 4 a summary is given of the NA-dataset.

Table 1 *Overview of animal, diet, and NDF digestibility characteristics for the European dataset (17 studies and 67 observations from the period 1986 – 2019).*

Animal characteristics	**Mean**	**Std Dev**	**Min**	**Max**
BW (kg)	617	34	538	667
Milk (kg/d)	23.2	6.13	12.3	33.2
DMI (kg/d)	17.1	3.05	9.8	21.6
DMI (%BW)	2.78	0.462	1.64	3.56
Diet characteristics				
Concentrate (% in DM)	41.3	14.96	5.2	65.0
OM (g/kg DM)	920	15.4	877	950
CP (g/kg DM)	170	29.8	126	293
NDF (g/kg DM)	387	54.7	287	557
Starch (g/kg DM)	154	74.6	2.7	344
Legumes in roughage (ratio)	0.07	0.23	0.00	1.00
Hay/straw in roughage (ratio)	0.11	0.31	0.00	1.00
Digestibility characteristics				
Total tract digestibility of NDF (%)	62.3	9.20	43.0	84.0
Rumen degradability of NDF (%)	57.7	12.10	34.3	87.2
Ruminally degradable NDF (g/kg DM)	223	53.5	113	375

2.2 Equation development and evaluation

2.2.1 Optimization procedure

The main objective of the optimization procedure was to improve the estimation of rumen fermented NDF (RFNDF; kg/cow/d) by fitting models that select Kp-D-NDF values for roughages and concentrate feedstuffs such that differences between observed and predicted RFNDF are minimized. Furthermore, models were set up in which Kp-D-NDF was related to dietary characteristics (e.g., concentrate ratio, Kd-D-NDF of feedstuffs, type of NDF (concentrate, roughage, hay/straw, leguminous) and the animal feed intake level.

For each individual feedstuff in a diet the amount of NDF fermented in the rumen ($RFNDF_{feedstuff}$; kg/cow/d) was calculated using the CVB information on rumen degradation characteristics such as Kd-D-NDF, D-NDF and the fitted Kp-D-NDF

$$RFNDF_{feedstuff} \text{ (kg/cow/d)} = NDF_{feedstuff} \text{ (kg/cow/d)} \times D\text{-}NDF_{feedstuff} / 100 \times Kd\text{-}D\text{-}NDF_{feedstuff} / (Kd\text{-}D\text{-}NDF_{feedstuff} + Kp\text{-}D\text{-}NDF)$$

The total dietary amount of RFNDF is calculated as the sum of the individual $RFND_{feedstuff}$ amounts. There are no direct measurements of Kp-D-NDF (for individual feedstuffs and for the complete diet) available in the dataset and this means it is not possible to compare predicted Kp-D-NDF-values with observed values. Therefore, the model estimated RFNDF of the diet was compared with the observed RFNDF of the diet in the dataset. The difference (residual error) between the estimated RFNDF (the result of the model) and the observed RFNDF was calculated. The model parameters in the models estimating Kp-D-NDF were optimized such that the sum of the squared residual errors was minimized. This minimization was done by using the "nlminb" optimization method in the "opm" function in the "optimx" package of the software program R (version 4.0.3). The "opm" function is a general-purpose optimization function that compares multiple optimization functions based on different optimization methods (e.g., "Nelder-Mead", "nlminb", "BFGS (a quasi-Newton method)", "nmkb"). The "nlminb" method was chosen based on preliminary optimization tests. Two approaches were used for the optimization. In the first approach, only the Kp-D-NDF-values were optimized, and for the Kd-D-NDF-values, the current CVB values for the individual feedstuffs were used. In the second approach, the Kp-D-NDF-values were optimized and the Kd-D-NDF-values of individual feedstuffs were corrected based on dietary characteristics (e.g., dietary concentration of starch). In the second approach, the error minimization was performed in two ways: 1) by means of a one-step procedure in which both Kp-D-NDF and Kd-D-NDF values were optimized simultaneously, and 2) a two-step iterative procedure in which in the first step, Kp-D-NDF-values were optimized using approach 1, and in the next step, the Kd-D-NDF-values were optimized with a fixed value (obtained in the first step) for Kp-D-NDF, in the following step again optimization of the Kp-D-NDF-values with the fixed values of Kd-D-NDF (obtained in the previous step), etc. The estimation converged when the sum of the squared residual errors became constant (relative difference between two steps is, in that case, less than 0.00000000001 kg/cow/d).
The models investigated in the two approaches are described below.

The first approach

Only the Kp-D-NDF-values were optimized, and for the Kd-D-NDF-values, the current CVB values for the individual feedstuffs were used.

Model 1a:
Kp-D-NDF-roughages = INTr
Kp-D-NDF-concentrates = INTc

Model 2a:
Kp-D-NDF-roughages = INTr + B_0 × Kd-D-NDF
Kp-D-NDF-concentrates = INTc + B_1 × Kd-D-NDF

Model 3a:
Kp-D-NDF-roughages = INTr + B_2 × FL
Kp-D-NDF-concentrates = INTc + B_3 × FL

Following a recommendation from the Ad Hoc committee, we tested this model using the NA-dataset, resulting in different parameter estimates (3aNA) compared to those obtained using the EU-dataset (3a). Parameter estimates and overall model performances for both models are presented in Table 3.
Model 4a:
Kp-D-NDF-roughages = INTr + B_2 × FL + B_4 × CL
Kp-D-NDF-concentrates = INTc + B_3 × FL + B_5 × CL

Model 5a:
Kp-D-NDF-roughages = INTr + B_6 × LEG + B_7 × HS
Kp-D-NDF-concentrates = INTc

Where:
INTr is a fixed (intercept) Kp -D-NDF value for roughage feedstuffs (%/h).
INTc is a fixed (intercept) Kp-D-NDF value for concentrate feedstuffs (%/h).
Kd-D-NDFr and Kd-D-NDFc are the current CVB Kd-D-NDF values for, respectively roughages and concentrates (%/h).
FL (%BW) is the feeding level calculated as dry matter intake (DMI; kg/cow/d) as a percentage of body weight (BW; kg).
CL (ratio) is the concentrate ratio in the diet on a dry matter (DM) basis.
LEG (ratio) is the proportion of leguminous feedstuffs (such as Lucerne silage or Lucerne hay and clover) in the roughage part of the diet on DM basis.
HS (ratio) is the proportion of hay and straw in the roughage part of the diet on DM basis.
B_0 – B_7 are regression coefficients for Kd-D-NDF, FL and, CL.

Another model was later tested as suggested by the ad hoc group that will be called “Extra” from now on and can be explained as follows:
Kp-D-NDF-roughages = INTr + B_0 × Kd-D-NDF + B_2 × FL
Kp-D-NDF-concentrates = INTc + B_1 × Kd-D-NDF+ B_3 × FL
Table parameter estimates and overall model performance for this model for predicting rumen digested NDF using the "EU" dataset can be found in the Appendix (Table 8).

The second approach
In the second approach, both Kp-D-NDF and Kd-D-NDF values were optimized, and this was done iteratively by first optimizing Kp-D-NDF (keeping Kd-D-NDF values fixed), then by optimizing Kd-D-NDF (keeping Kp-D-NDF values fixed), etc.

Model 1b:
Kp-D-NDF-roughages = INTr
Kp-D-NDF-concentrates = INTc
Kd-D-NDF = Kd-D-NDF + B_8 × SL

Model 3b:
Kp-D-NDF-roughages = INTr + B_2 × FL
Kp-D-NDF-concentrates = INTc + B_3 × FL
Kd-D-NDFi = Kd-D-NDF + B_8 × SL

Model 4b:
Kp-D-NDF-roughages = INTr + B_2 × FL + B_4 × CL
Kp-D-NDF-concentrates = INTc + B_3 × FL + B_5 × CL
Kd-D-NDFi = Kd-D-NDF + B_8 × SL

Model 5b:
Kp-D-NDF-roughages = INTr + B_6 × LEG + B_7 × HS
Kp-D-NDF-concentrates = INTc
Kd-D-NDFi = Kd-D-NDF + B_8 × SL

Where:
SL (ratio) is the starch level in the diet calculated as a ratio on DM basis.
B_8 is the regression coefficient for SL.

2.2.2 Cross-validation and goodness-of-fit evaluation of the models

Cross-validation was carried out by optimizing the model on a training set of all data, excluding one study (leave one cluster out method). Then the fitted model was used to predict RFNDF of the observations in the study that was excluded (validation set). In this way, for all individual studies, the RFNDF was predicted instead of being estimated.
For evaluating the different models, the goodness of fit of the predicted RNDF-diet, based on the cross-validation, was compared to observed values using two methods as described by Ellis et al. (2010). The first method consisted of calculating the mean square prediction error (MSPE) as follows:

$$\mathrm{MSPE} = \sum_{i-1}^{n}(Oi - Pi)^2/n$$

Where n is the total number of observations, O_i is the observed RNDF, and P_i is the predicted RNDF. The square root of the MSPE (RMSPE), expressed as a percentage of the observed mean, gives an estimate of the overall relative prediction error. The RMSPE was further decomposed into error due to overall bias (ECT), error due to deviation of the regression slope from unity (ER), and error due to disturbance or random error (ED) (Bibby and Toutenburg, 1977).
The second method consisted of calculating the concordance correlation coefficients (CCC) according to Lawrence and Lin (1989). The evaluation was done while accounting for a random study effect. Next to calculating goodness of fit parameters also the resulting average Kp-D-NDF- and Kd-D-NDF-values of the roughages and concentrates in the dataset were calculated.

For comparison purposes, next to the development of new models to predict Kp-D-NDF of roughages and concentrates, it was also tested how current feed evaluation systems such as described by Volden (2011) for the NorFor (2011) system, by van Duinkerken et al. (2011) for the DVE/OEB (2007) system and by Noziere et al. (2018) for the INRA (2018 system, were able to predict RFNDF. The results of this comparison are not discussed, but can be found in Appendix 1 for the current DVE/OEB system (van Duinkerken et al., 2011) for both the EU and the NA dataset (Table 5), for the NorFor (2011) system (Volden, 2011) for both the EU and the NA dataset (Table 6) and for the INRA (2018) system (Noziere et al., 2018) for both the EU and NA dataset (Table 7).

3 Results and discussion

Based on the model performance and biological relevance of the regression coefficients, only models 1a, 2a, 3a, and 4a were selected to be discussed in this document (referred to as models 1 to 4, respectively) as the more complicated models using the second approach did not result in improved model fits. Parameter estimates and goodness-of-fit characteristics for models 1 – 4 of the EU dataset are presented in Table 2.

Table 2 *Parameter estimates (+/- se) and overall model performance for models 1a, 2a, 3a and 4a for predicting rumen fermented NDF (kg/cow/d) using the EU dataset.*

Parameter[1]	**Model**			
	1a	2a	3a	4a
INTr	1.25 ± 0.02	2.13 ± 0.08	-1.12 ± 0.04	-1.34 ± 0.04
INTc	1.74 ± 0.16	4.29 ± 0.17	0.87 ± 0.12	-0.51 ± 0.18
B_0 (Kd-D-NDFr)		-0.24 ± 0.02		
B_1 (Kd-D-NDFc)		-0.57 ± 0.02		
B_2 (FLr)			0.86 ± 0.01	0.74 ± 0.01
B_3 (FLc)			0.16 ± 0.02	0.33 ±0.03
B_4 (CLr)				2.14 ± 0.08
B_5 (CLc)				0.36±0.033
Calculated parameters				
Mean Kp-D-NDF (roughage)	1.25	0.88	1.28	1.64
Mean Kp-D-NDF (concentrate)	1.74	1.34	1.33	0.57
Mean Kd-D-NDF	5.16	5.16	5.16	5.16
Model performance parameters[2]				
RMSPE (% Mean observed)	15.99	16.48	14.09	13.95
ECT (% MSPE)	0.78	0.69	0.03	0.04
ER (% MSPE)	3.08	8.22	4.07	1.66
ED (% MSPE)	96.14	91.09	95.89	98.31
R^2	0.64	0.64	0.72	0.72
CCC	0.79	0.80	0.81	0.82
AIC	90	95	82	84

[21] INTr is a fixed (intercept) Kp-D-NDF value for roughage feedstuffs (%/h); INTc is a fixed (intercept) Kp-D-NDF value for concentrate feedstuffs (%/h); Kd-D-NDFr and Kd-D-NDFc are the current CVB Kd-D-NDF values for, respectively roughages and concentrates (%/h); FL is the feeding level calculated as dry matter intake (DMI; kg/cow/d) as a percentage of body weight (BW; kg) where an effect of FL on Kp-D-NDF is estimated for roughage feedstuffs (FLr) and for concentrate feedstuffs (FLc); CL (ratio) is the concentrate ratio in the diet on a dry matter (DM) basis where an effect of CL on Kp-D-NDF is estimated for roughage feedstuffs (CLr) and for concentrate feedstuffs (CLc).

[2]RMSPE: Root mean square prediction error expressed as a percentage of the observed mean; ECT: Error due to bias, as a percent of total MSPE; ER: Error due to regression, as a percent of total MSPE; ED: Error due to disturbance, as a percent of total MSPE; R^2: Coefficient of determination; CCC: Lin Concordance correlation coefficient; AIC: Akaike information criterion. All model performance parameters are based on the cross-validation results.

The best goodness of fit parameters were obtained from model 4 (except for AIC), and the worst goodness of fit parameters was obtained from model 2 (except for CCC). In the Appendix in Fig. 2 -5 the relationships between predicted RFNDF and observed RFNDF are graphically shown for model 1a (Fig. 2), model 2a (Fig. 3), model 3a (Fig. 4) and model 4a (Fig. 5).
Model 1 is the simplest model with a constant Kp-D-NDF for roughage and a constant Kp-D-NDF for concentrate. Model 2 is based on the model presently used in the DVE/OEB system (van Duinkerken et al. 2011). Compared with the values in the DVE/OEB system, in Model 2, the intercept values changed from 1.86 to 4.29 for concentrates and from 1.39 to 2.13 for roughages. Furthermore, the coefficient for Kd-D-NDF in the DVE equation is 0.1755 for both roughages and concentrates, but they are -0.24 for roughages and -0.57 for concentrates in Model 2. This is in contrast with the current interpretation of the relationship between Kd-D-NDF and Kp-D-NDF. The low ED and R^2 and high RMSPE and AIC (Table 2) indicate that model 2 is not a good candidate.
Model 3 has FL (DMI, % of BW) as an explanatory variable in the model. The performance parameters for model 3 were substantially better than models 1 and 2, with higher R^2 and CCC values and lower RMSPE and AIC values (Table 2). Since model 3 seems to be a good candidate, Parameter estimates for predicting rumen digested NDF were also investigated for the NA dataset (Table 3). A summary of the NA dataset is provided in the Appendix (Table 4). Model 3 estimates and model performance parameters estimated on the NA and EU dataset are presented in Table 3. The coefficients of model 3 estimated on the NA dataset are substantially different from those estimated on the EU dataset.

Table 3 *Parameter estimates (+/- se) and overall model performance for model 3a for predicting rumen fermented NDF in the NA dataset and EU dataset.*

Parameter[1]	**Approach**	
	A (NA-dataset)	B (EU-dataset)
INTr	0.24 ± 0.05	-1.12 ± 0.04
INTc	8.46 ± 0.35	0.87 ± 0.12
B_2 (FLr)	0.31 ± 0.01	0.86 ± 0.01
B_3 (FLc)	-1.34 ± 0.09	0.16 ± 0.02
Calculated parameters		
Mean Kp-D-NDF (roughage)	1.31	1.28
Mean Kp-D-NDF (concentrate)	3.98	1.33
Mean Kd-D-NDF	3.91	5.16
Model performance parameters[2]		
RMSPE (% Mean observed)	23.73	14.09
ECT (% MSPE)	0.01	0.03
ER (% MSPE)	0.17	4.07
ED (% MSPE)	99.82	95.89
R^2	0.53	0.72
CCC	0.70	0.81

[1]INTr is a fixed (intercept) Kp-D-NDF value for roughage feedstuffs (%/h); INTc is a fixed (intercept) Kp-D-NDF value for concentrate feedstuffs (%/h); FL is the feeding level calculated as dry matter intake (DMI; kg/cow/d) as a percentage of body weight (BW; kg) where an effect of FL on Kp-D-NDF is estimated for roughage feedstuffs (FLr) and for concentrate feedstuffs (FLc).
[2]RMSPE: Root mean square prediction error expressed as a percentage of the observed mean; ECT: Error due to bias, as a percent of total MSPE; ER: Error due to regression, as a percent of total MSPE; ED: Error due to disturbance, as a percent of total MSPE; R^2: Coefficient of determination; CCC: Lin Concordance correlation coefficient.

As indicated by other researchers, the rumen fractional passage rate of NDF is affected by DMI (Seo et al., 2006, Krizsan et al., 2010, Pino et al., 2018).

This is also confirmed in this study with a better goodness-of-fit of model 3 compared to the goodness-of-fit of models 1 and 2. However, for DMI level > 2.85% of BW/d, this model predicts higher Kp-D-NDF for roughages than for concentrates (Fig. 1) which from a physiological point of view is unexpected. In Fig. 1 the relationship between DMI and Kd-D-NDF for roughages and concentrates is shown for a DMI range of 10 to 24 kg/cow/d for a cow with a BW of 650 kg.

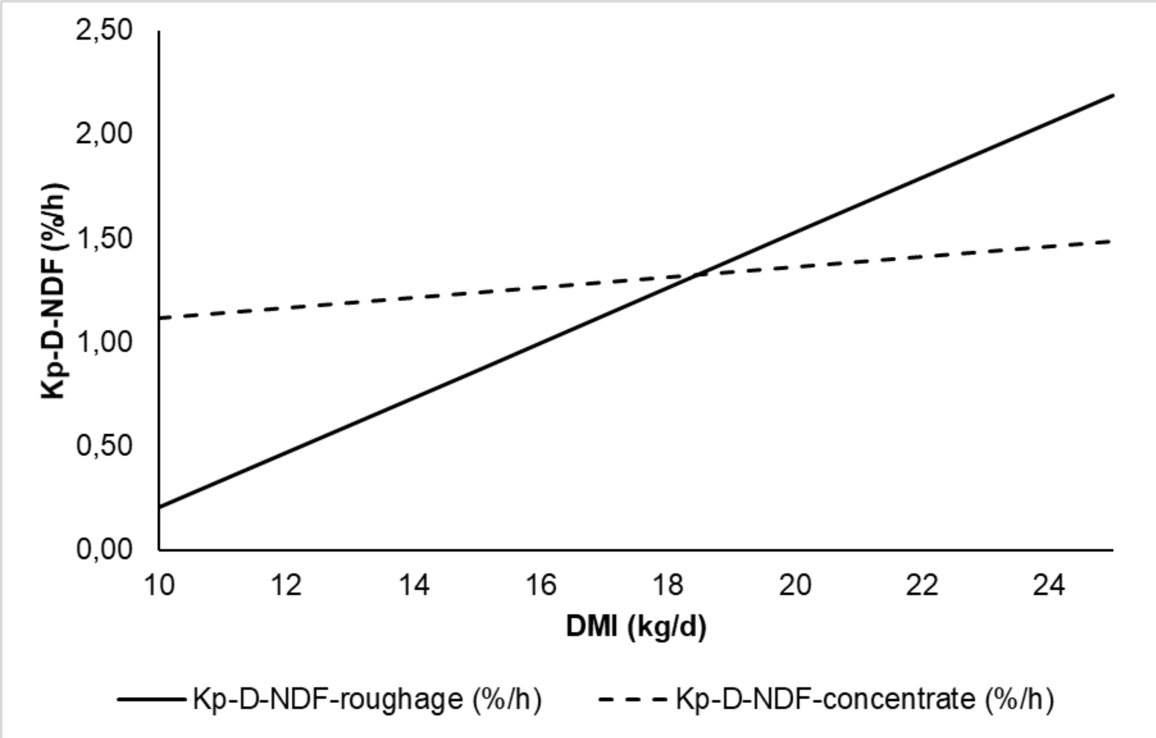

Figure 1 *Predictions of Kp-D-NDF for roughage and concentrate using model 3a model outcomes based on the EU dataset for a dry matter intake (DMI) range of 10 to 24 kg/cow/d for a cow with a body weight of 650 kg. The DMI level at which the Kp-D-NDF of roughage is equal to concentrate is 18.5 kg at a feeding level of 2.85 % of BW.*

Model 4 has CL as an additional factor for predicting Kp-D-NDF compared to model 3. Including CL in the model enhanced the model's performance by increasing ED and lowering RMSPE relative to the other models (Table 2). However, despite the improvement in these goodness-of-fit parameters, adding CL as an additional factor for the prediction of Kp-D-NDF did not increase R^2 and resulted in a higher AIC value for model 4 compared to model 3, suggesting that adding CL is not justified. In addition, implementing model 4 resulted in an average Kp-D-NDF of 1.64 %/h for roughage NDF and 0.57 %/h for concentrate NDF which is not logical from a physiological point of view. Kammes and Allen (2012) studied particle size kinetics and rumen fractional passage rates of particles in diets containing either alfalfa or orchard grass silage as the sole source of roughage using rumen evacuation and duodenal sampling in Holstein cows. They reported that fractional passage rates of small particles of potentially digestible NDF (<2.36 mm) and large particles of potentially digestible NDF (≥2.36 mm) were, respectively, 3.80 and 1.05 %/h for the alfalfa diet and, respectively, 2.50 and 0.75 %/h for the orchard grass silage diet. Assuming that concentrate NDF mainly represents small particle NDF and that large particles NDF is mainly represented by roughage NDF, the average Kp-D-NDF of roughage should be lower than the average Kp-D-NDF of concentrate. In the Nordic dairy cow model Karoline, a proportionality factor of 1.6 was introduced to account for the higher Kp of concentrates in relation to Kp of roughages (Danfær et al., 2006), which is very close to the reported slope of 1.57 when regressing concentrate Kp on roughage Kp by (Cannas et al., 2000). A number of feed evaluation models use separate Kp prediction equations for concentrate and roughage feed particles and do not distinguish between nutrients (NRC, 2001, Danfær et al., 2006, Seo et al., 2006, Sauvant and Noziere, 2016).

For example, the NRC (2001) gives separate Kp prediction equations for concentrate and roughage as follows:

Kp of concentrates (%/h) = 2.904 + 1.375 × DMI (% of BW) – 0.020 × X2

Kp of dry roughages (%/h)= 3.362 + 0.479 × DMI (% of BW) – 0.007 × X2 – 0.017 × X3

Kp of wet roughages (silages and fresh; %/h) = 3.054 + 0.614 × DMI (% of BW)

where X2 = percentage of concentrate in diet DM, X3 = percentage of NDF in DM.

The CNCPS model (Seo et al., 2006) also give separate kp prediction equations for concentrate and roughage feed:
Kp of concentrates (%/h) = 1.169 + 0.1375 × FpBW + 0.1721 × CpBW
and
Kp of roughages (%/h) = 2.365 + 0.0214 × FpBW + 0.0734 × CpBW + 0.069 × FDMI

where, FpBW = roughage DMI (g/kg of BW), CpBW = concentrate DMI (g/kg of BW), and FDMI = roughage DMI (kg/d).

The Kp prediction equations in the National Research Council (NRC) and the Cornell Net Carbohydrate and Protein System (CNCPS) were evaluated in a metanalysis by Krizsan et al. (2010). They reported that the Kp estimates derived from rumen evacuation data were lower than predictions of ruminal particulate matter Kp from NRC and the CNCPS that were developed based on external marker excretion data. Lund et al. (2007) compiled a dataset from four experiments (60 observations) with fistulated dairy cows subjected to rumen evacuation technique. An average passage rate of 0.75 %/h for digestible NDF was reported (ranging from a minimum of 0.45%/h to a maximum of 1.3%/h), which is considerably lower than the average Kp-D-NDF of roughage and concentrate estimated in this study (Table 2). This difference might also reflect the difference between Kp values obtained by rumen evacuation vs. marker-based data.
A modified version of the NRC equation (NRC, 2001) is used in the NORFOR model to calculate the fractional passage rate of NDF out the rumen in concentrate particles (r_kpNDFc; %h):

$$r\_kpNDFc=[2.504+0.1375\times(\sum_i DMI_i\times 1000)/BW]\times 0.43$$

Where:
DMI_i is the dry matter intake of the i=1...n'th feedstuff, kg/d and BW is the animal body weight. In the NORFOR system, a dataset based on the rumen evacuation technique was used to develop an equation to predict the fractional passage rate of roughage NDF (r_kpNDFr) out of the rumen:

$$r\_kpNDFr=0.480+1.5106/(1+[(\sum_i DMI\times NDF_i)/(BW\times 7.484)]^{-3.198})$$

Although equations used in the NORFOR system share the DMI (divided by BW) as a predictor for passage rate with Model 3 in the present study, they result in different estimated/predicted Kp-D-NDF values. Based on these equations, at a DMI of 25 g/kg BW, the passage rate of NDF out the rumen in concentrate particles is estimated to be 2.6%/h, while at the same intake level, the fractional passage rate of roughage NDF is estimated to be 1.56%/h (Volden, 2011). Using the NORFOR equations to calculate average Kp-D-NDF values for roughage and concentrate for the EU dataset resulted in Kp-D-NDF values of 1.1 and 2.8 %/h for roughages and concentrates, respectively. Lower Kp-D-NDF for roughages with NORFOR rules compared to model 3 predictions can be related to the fact that the NORFOR system used a dataset from evacuation studies to develop the equation to predict the fractional passage rate of roughage NDF (r_kpNDFr) out of the rumen. Using NORFOR equations for calculating Kp-D-NDF of concentrates resulted in a much higher value than the Model 3 predictions in the present study. The NORFOR equation for calculating Kp-D-NDF of concentrates is based on the NRC equation (NRC, 2001) that has been developed based on marker data.

The noticeable difference between our results and NORFOR calculations might be due to the fact that the NORFOR formula is a modified version of the NRC formula based on a sensitivity study (Volden, 2011) and where external markers were used compare to results in this study in which Kp-D-NDF values for concentrates of the various models was fitted based on minimizing differences between observed and predicted RFNDF.

4 Conclusions

Among the tested models, Model 3a is the best candidate model for predicting Kp-D-NDF in roughage and concentrates based on the model performance parameters. This model is based on DMI (in literature generally considered to be positively related to rumen fractional passage rate) and resulted in reasonable goodness of fit parameters. However, for DMI levels > 2.8% of BW/d, this model predicts higher Kp-D-NDF for roughages than for concentrates, which seems unrealistic from a physiological point of view and shows that extrapolation of model results outside the range in which the model was developed is dangerous. Therefore it seems more prudent to use fixed Kp-D-NDF estimates for roughages and concentrates as estimated by model 1a.

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Appendix

Table 4 *Overview of the North American (NA) datasets for animal, diet, and NDF digestibility characteristics of studies published in the period 1982 – 2018 (n=161).*

Animal characteristics	**Mean**	**Std Dev**	**Min**	**Max**
BW (kg)	611	50.1	500	697
Milk(kg/d) (n = 130)	31.9	5.94	18.2	43.8
DMI (kg/d)	21.2	3.82	5.8	27.4
Feed intake Level (% of BW/d)	3.47	0.570	0.95	4.32
Diet characteristics				
Concentrate (% in DM)	52.3	9.61	30.7	77.0
OM (g/kg DM)	918.7	14.19	884.0	952.6
CP (g/kg DM)	174.1	16.30	129.6	231.3
NDF (g/kg DM)	314.1	54.23	221.7	478.7
Starch (g/kg DM)	268.4	68.92	49.8	404.9
Legumes in roughage (ratio)	0.49	0.28	0.00	1.00
Hay/straw in roughage (ratio)	0.04	0.16	0.00	1.00
Digestibility characteristics				
Total tract digestibility of NDF (%)	47.6	8.95	30.5	73.7
Rumen degradability of NDF (%)	41.0	9.84	16.6	71.2
Ruminally degradable NDF (g/kg DM)	130.9	47.10	38.1	276.5

Table 5 *Overall performance of the current DVE/OEB system (van Duinkerken et al., 2011) for predicting rumen femented NDF using the EU and NA datasets.*

Model performance parameters[1]	**Dataset**	
	EU	NA
RMSPE (% Mean observed)	20.34	22.66
ECT (% MSPE)	50.32	1.22
ER (% MSPE)	0.58	0.14
ED (% MSPE)	49.10	98.64
R^2	0.70	0.57
CCC	0.68	0.73

[1]RMSPE: Root mean square prediction error expressed as a percentage of the observed mean; ECT: Error due to bias, as a percent of total MSPE; ER: Error due to regression, as a percent of total MSPE; ED: Error due to disturbance, as a percent of total MSPE; R^2: Coefficient of determination; CCC: Lin Concordance correlation coefficient.

Table 6 *Overall performance of the NorFor (2011) system (Volden, 2011) for predicting rumen fermented NDF using the EU and NA datasets.*

Model performance parameters[1]	**Dataset**	
	EU	NA
RMSPE (% Mean observed)	15.81	26.35
ECT (% MSPE)	7.30	23.26
ER (% MSPE)	0.14	0.33
ED (% MSPE)	92.55	76.41
R2	0.66	0.55
CCC	0.78	0.67

[1]RMSPE: Root mean square prediction error expressed as a percentage of the observed mean; ECT: Error due to bias, as a percent of total MSPE; ER: Error due to regression, as a percent of total MSPE; ED: Error due to disturbance, as a percent of total MSPE; R^2: Coefficient of determination; CCC: Lin Concordance correlation coefficient.

Table 7 *Overall performance of the INRA (2018) system (Noziere et al., 2018) for predicting rumen fermented NDF using the EU and NA datasets.*

Model performance parameters[1]	**Dataset**	
	EU	NA
RMSPE (% Mean observed)	25.52	35.21
ECT (% MSPE)	29.45	54.25
ER (% MSPE)	22.02	9.37
ED (% MSPE)	48.53	36.39
R2	0.54	0.62
CCC	0.65	0.62

[1]RMSPE: Root mean square prediction error expressed as a percentage of the observed mean; ECT: Error due to bias, as a percent of total MSPE; ER: Error due to regression, as a percent of total MSPE; ED: Error due to disturbance, as a percent of total MSPE; R^2: Coefficient of determination; CCC: Lin Concordance correlation coefficient.

Table 8 *Parameter estimates and overall model performance for models 1, 3, 4 and "Extra" for predicting rumen fermented NDF using the EU dataset.*

Parameter[1]	**Model**			
	1a	Extra	3a	4a
INTr	1.25 ± 0.02	-0.50 ± 0.08	-1.12 ± 0.04	-1.34 ± 0.04
INTc	1.74 ± 0.16	3.35 ± 0.26	0.87 ± 0.12	-0.51 ± 0.18
B_0 (Kd-D-NDFr)		-0.25 ± 0.02		
B_1 (Kd-D-NDFc)		-0.53 ± 0.02		
B_2 (FL)		0.96 ± 0.02	0.86 ± 0.01	0.74 ± 0.01
B_3 (FL)		0.07 ± 0.09	0.16 ± 0.02	0.33 ±0.03
B_4 (CLr)				2.14 ± 0.08
B_5 (CLc)				0.36±0.033
Calculated parameters				
Mean Kp-D-NDF (roughage)	1.25	0.89	1.28	1.64
Mean Kp-D-NDF (concentrate)	1.74	0.82	1.33	0.57
Mean Kd-D-NDF	5.16	5.16	5.16	5.16
Model performance parameters[2]				
RMSPE (% Mean observed)	15.99	14.68	14.09	13.95
ECT (% MSPE)	0.78	0.03	0.03	0.04
ER (% MSPE)	3.08	0.02	4.07	1.66
ED (% MSPE)	96.14	99.95	95.89	98.31
R^2	0.64	0.68	0.72	0.72
CCC	0.79	0.81	0.81	0.82
AIC	90	100	82	84

[21] INTr is a fixed (intercept) Kp-D-NDF value for roughage feedstuffs (%/h); INTc is a fixed (intercept) Kp-D-NDF value for concentrate feedstuffs (%/h); Kd-D-NDFr and Kd-D-NDFc are the current CVB Kd-D-NDF values for, respectively roughages and concentrates (%/h); FL is the feeding level calculated as dry matter intake (DMI; kg/cow/d) as a percentage of body weight (BW; kg) where an effect of FL on Kp-D-NDF is estimated for roughage feedstuffs (FLr) and for concentrate feedstuffs (FLc); CL (ratio) is the concentrate ratio in the diet on a dry matter (DM) basis where an effect of CL on Kp-D-NDF is estimated for roughage feedstuffs (CLr) and for concentrate feedstuffs (CLc).

[2]RMSPE: Root mean square prediction error expressed as a percentage of the observed mean; ECT: Error due to bias, as a percent of total MSPE; ER: Error due to regression, as a percent of total MSPE; ED: Error due to disturbance, as a percent of total MSPE; R^2: Coefficient of determination; CCC: Lin Concordance correlation coefficient; AIC: Akaike information criterion. All model performance parameters are based on the cross-validation results.

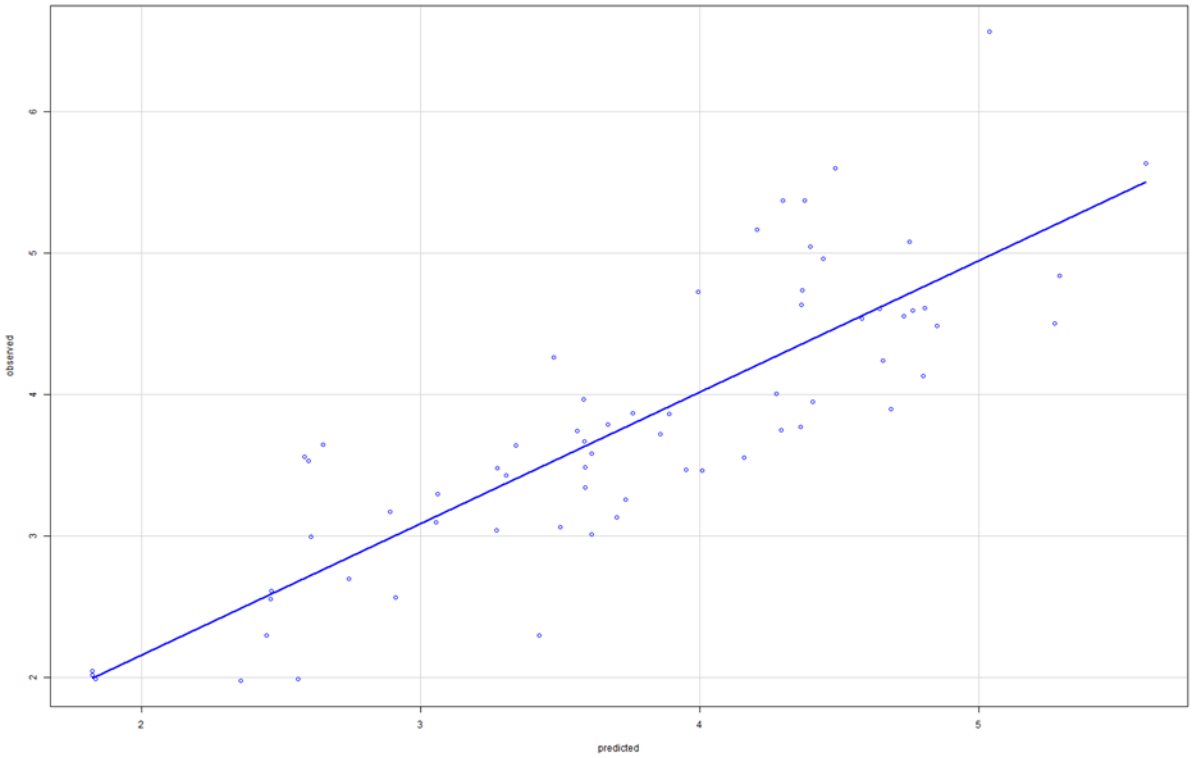

Figure 2 *Observed vs. predicted rumen fermented NDF (kg/cow/d) by model 1a using data from the EU dataset (n=67).*

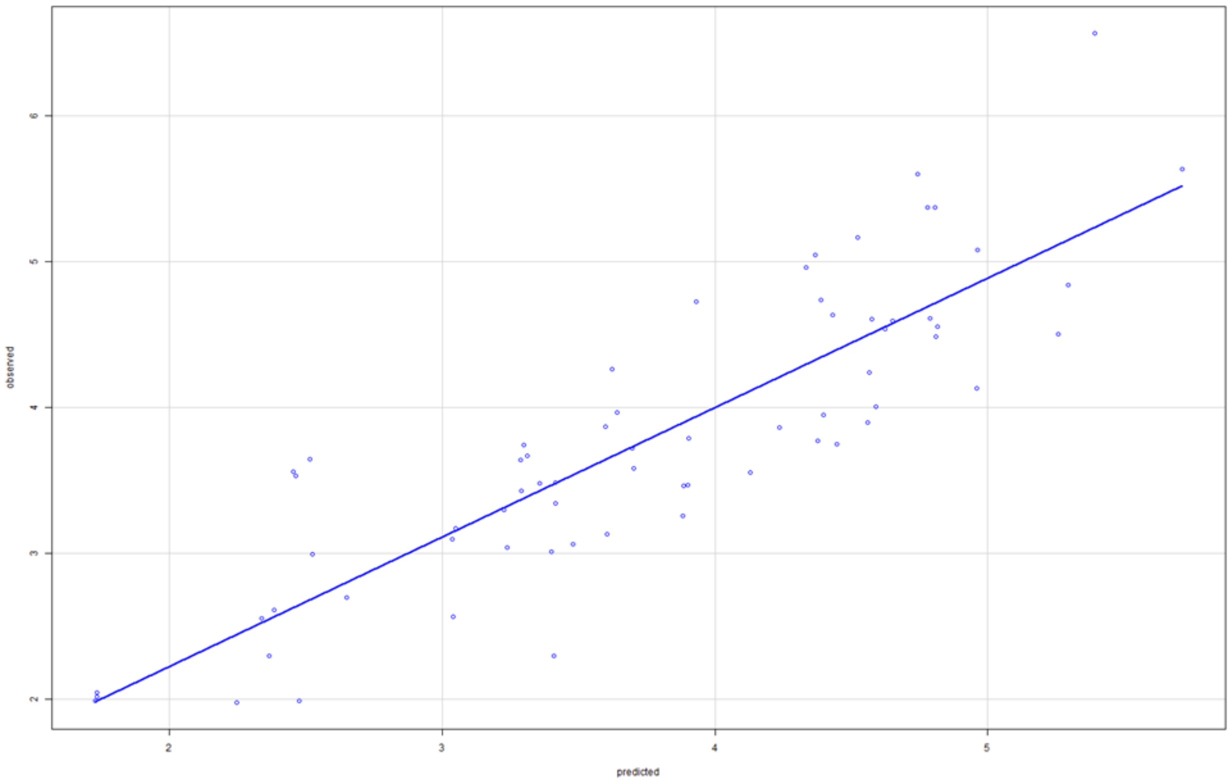

Figure 3 *Observed vs. predicted rumen fermented NDF (kg/cow/d) by model 2a using data from the EU dataset (n=67).*

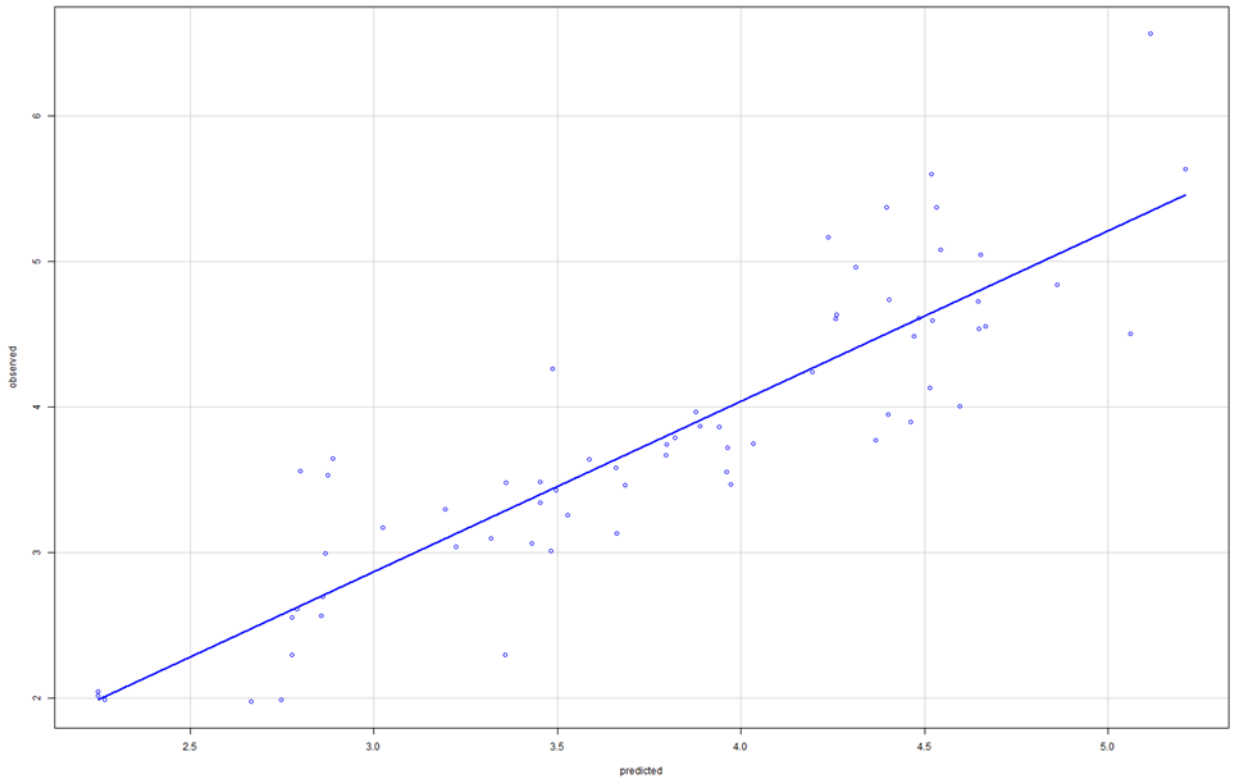

Figure 4 *Observed vs. predicted rumen fermented NDF (kg/cow/d) by model 3a using data from the EU dataset (n=67).*

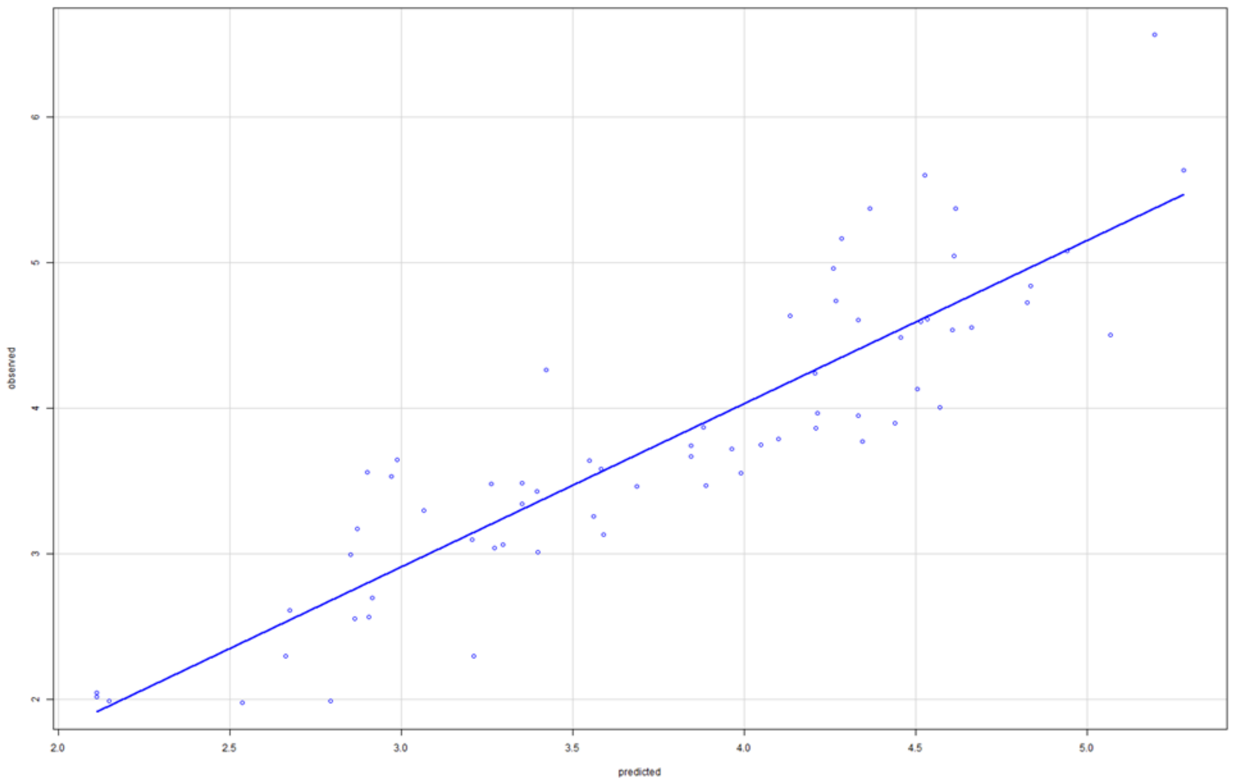

Figure 5 *Observed vs. predicted rumen fermented NDF (kg/cow/d) by model 5a using data from the EU dataset (n=67).*

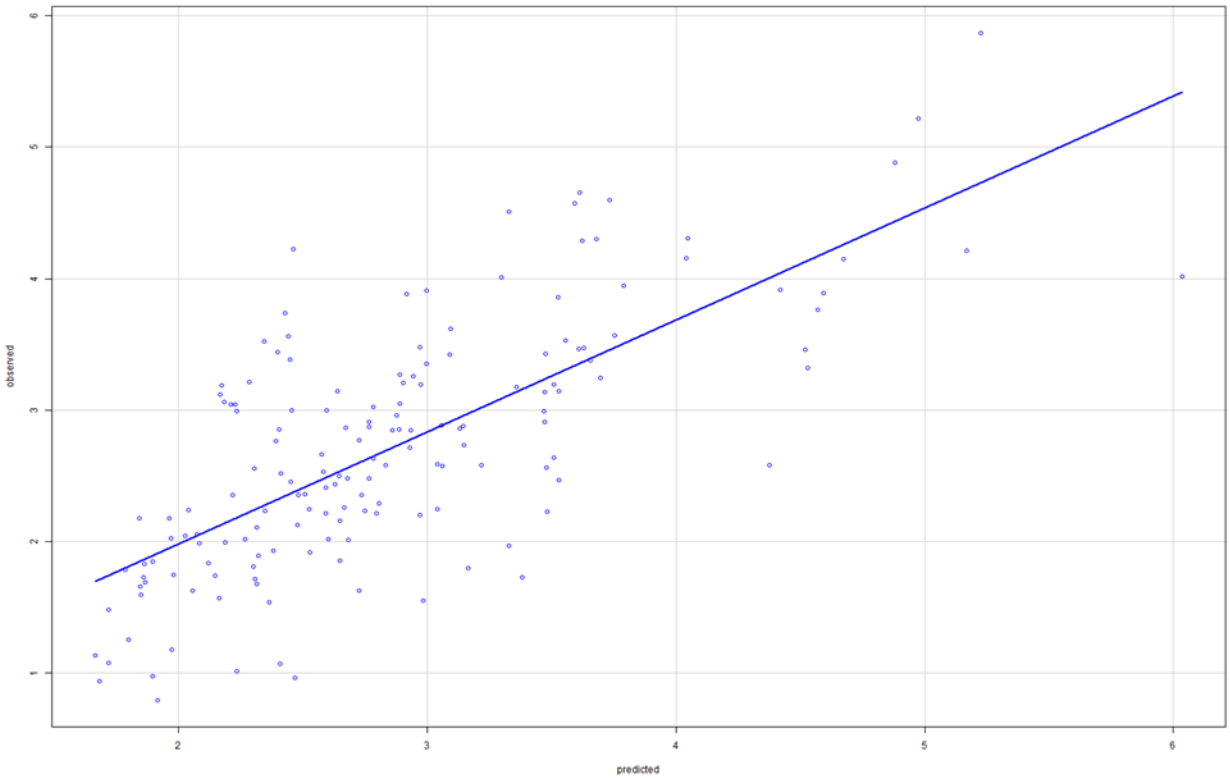

Figure 6 *Observed vs. predicted rumen fermented NDF (kg/cow/d) by model 3a using data from the NA dataset (n=161).*

To explore the potential of nature to improve the quality of life

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