Effect of energy-protein interactions on N excretion in dairy cows

REDNEX

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SEVENTH FRAMEWORK PROGRAMME

Innovative and practical management approaches to reduce nitrogen excretion by ruminants

Introduction

- Maximizing nutrient output in animals has many benefits to livestock industry
- Overall efficiency of N utilization is
  - 13-31% in ruminants (Kebreab et al. 2001)
  - 40-45% is theoretically possible
  - 28-39% in sows, 71% in nursery & 32-38% in growing finishing pigs from the prairies (Kebreab et al. 2010)

Introduction

- Efficiency of N utilization is affected by:
  - Dietary N intake (e.g. Castillo et al. 2000)
  - Energy content of diet (Reynolds & Firkins 2005)
  - Feed quality (Metabolizability, q = ME/GE, AFRC, 1993)
- Therefore, N intake, ME and q have been considered in the analysis

Objective

- Investigate the effects of diet quality and ME intake on the efficiency of utilizing dietary N intake for
  - Milk production
  - Excretion of N in faeces and urine

Data Analysis

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- Meta-analysis of N utilization in dairy cows
- Data sources:
  - Kebreab et al. (2003) [J. Dairy Sci. 86:2904-2913]
  - 470 individual cow observations from 28 studies using calorimetry techniques
  - Nitrogen in faeces, urine and milk were all measured

Data Analysis

- Four types of analyses conducted
  - Univariate normal mixed model
  - Univariate multiple covariates model
  - Index of N efficiency mixed model
  - Multivariate (Bayesian model)

Univariate Normal Mixed Model

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$$y_{ij} = \beta_0 + b_{0_i} + (\beta_1 + b_{1_i}) \times NI_{ij}$$

where y_{ij} denote N output for the *j*th observation from the *i*th study. $(\beta_0, \beta_1)^T$ and $(b_{0i}, b_{1i})^T$ are fixed and random effects regression coefficients related to N intake (*NI*)

Univariate Multiple Covariate Model

$$y_{ij} = \beta_0 + b_{0_i} + (\beta_1 + b_{1_i}) \times x_{1ij} + (\beta_2 + b_{2_i}) \times x_{2ij} + e_{ij}$$

y_{ij} = N output for the *j*th observation from the *i*th study.
Study effect was considered to be random.

Standard assumptions were $(b_{0i}, b_{1i}, b_{2i})^T \sim N(0, \Omega)$ and $e_{ij} \sim N(0, \sigma^2)$. The matrix Ω was an unstructured positive-definite variance-covariance matrix.

Univariate N Efficiency Index Model

$$y_{ij} = \beta_0 + b_{0_i} + (\beta_1 + b_{1_i}) \times x_{1ij} + e_{ij}$$

y_{ij} = milk N/excreta N for the *j*th observation from the *i*th study. Study effect was considered to be random.

Standard assumptions were $(b_{0i}, b_{1i})^T \sim N(0, \Omega)$ and $e_{ij} \sim N(0, \sigma^2)$.

Multivariate Mixed Model

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Multivariate multiple covariates model:

$$
\begin{aligned}
y_{1ij} &= \beta_1 + \beta_2 \times (x_{1ij} - \overline{x}_1) + \beta_3 \times (x_{2ij} - \overline{x}_2) + b_{1_i} + e_{1ij} \\
y_{2ij} &= \beta_4 + \beta_5 \times (x_{1ij} - \overline{x}_1) + \beta_6 \times (x_{2ij} - \overline{x}_2) + b_{2_i} + e_{2ij} \\
y_{3ij} &= \beta_7 + \beta_8 \times (x_{1ij} - \overline{x}_1) + \beta_9 \times (x_{2ij} - \overline{x}_2) + b_{3_i} + e_{3ij}
\end{aligned}
$$

Correlations introduced in random effects and residual variances, i.e. $(b_{1i}, b_{2i}, b_{3i})^T \sim N(0, \mathbf{\Omega}^{-1})$ and $(e_{1ij}, e_{2ij}, e_{3ij})^T \sim N(0, \mathbf{\Sigma}^{-1})$.

The matrices $\mathbf{\Sigma}$ and $\mathbf{\Omega}$ were unstructured positive-definite variance-covariance matrices. The populations' effects were denoted by parameters $\boldsymbol{\mu}=(\beta_1,\ldots, \beta_9)^T$.

Multivariate Mixed Model

- Priors:

$$\bar{\mu} \sim MVN\left(0,\ 1\times10^{-6}\times\mathbf{I}\right)$$

$$\mathbf{\Omega}^{-1} \sim W\left(0.001\times\mathbf{I},\ 3\right)$$

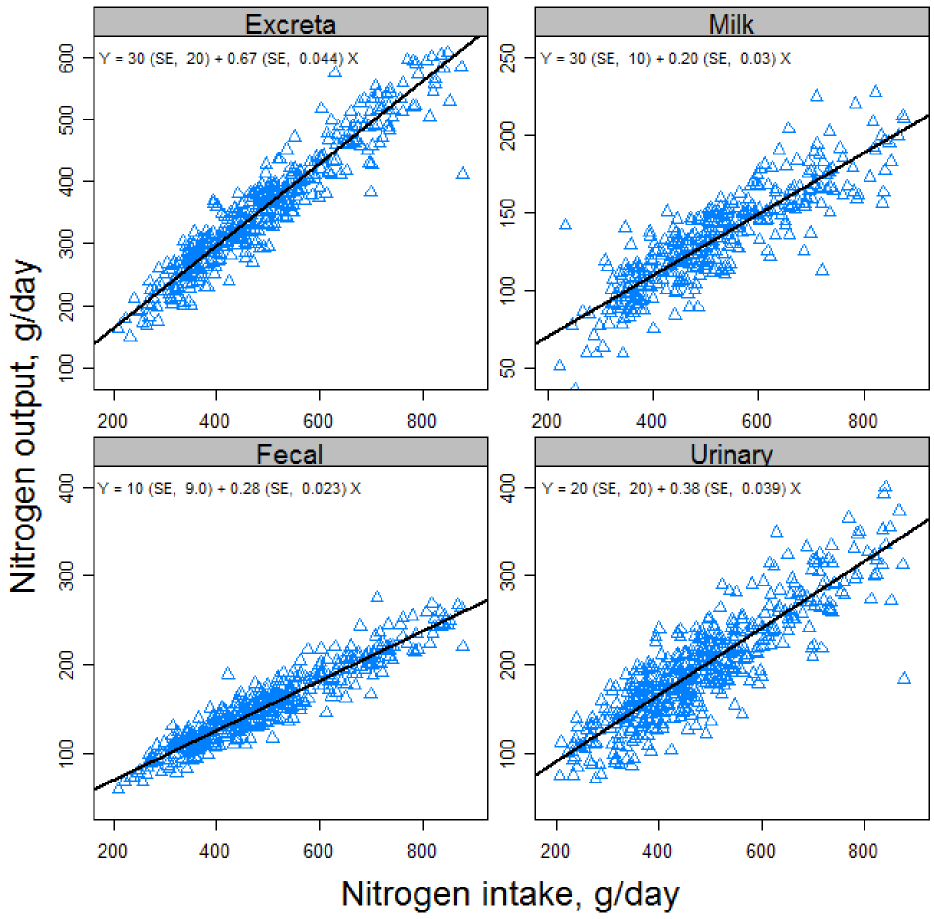
$$\Sigma^{-1} \sim W\left(0.001\times\mathbf{I},\ 3\right)$$

- All non-informative priors, because the likelihood should dominate the posterior densities – “The data should speak”
- The convergence diagnostic and output analysis (CODA) package – 3 chains, 100,000 iterations and thinning the chains of 10
- Data analysis was performed using OpenBUGS software

Model Evaluation

- Bayesian Information Criteria (BIC) for univariate models
- Deviance Information Criteria (DIC)
  - 5 unit difference was considered substantial

Results (Univariate)



Covariates

- Variation in urinary N up to 3.5 times greater than faecal N (Weiss et al. 2009)
- Greater than milk N (Mills et al. 2009)
- In our analysis RSD for faeces, urine and milk N was 14.6, 32.5, 17.5, respectively
- High RSD may be opportunity for dietary manipulation to increase efficiency
- Metabolizability or ME may offer explanation

Results (Multiple covariates)

Response	Covariate	Estimate (SE)	P-value	BIC[1]
Faecal N				
	Nitrogen intake	0.28 (0.022)	<0.001	3496
	Nitrogen + ME	0.27 (0.023)	<0.001	
	ME	1.14 (6.1)	0.85	3546
	Nitrogen + *q*	**0.29 (0.023)**	**<0.001**	
	q	**-305 (31.5)**	**<0.001**	**3410**
Urinary N				
	Nitrogen intake	0.38 (0.038)	<0.001	4651
	Nitrogen + ME	**0.56 (0.031)**	**<0.001**	
	ME	**-71.4 (12.2)**	**<0.001**	**4606**
	Nitrogen + *q*	0.38 (0.037)	<0.001	
	q	-174 (80.6)	0.03	4660
Milk N				
	Nitrogen intake	0.20 (0.031)	<0.001	3051
	Nitrogen + ME	**0.10 (0.024)**	**<0.001**	
	ME	**45.9 (5.4)**	**<0.001**	**2986**
	Nitrogen + *q*	0.20 (0.033)	<0.001	
	q	-96.1 (41.2)	0.02	3069

Results (Multiple covariates)

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$N\ faeces = 10.1\ (SE=8.1) + 0.29\ (SE=0.02) NI - 305\ (SE=31.5)\ q$

$N\ urine = 47.8\ (SE=20.1) + 0.56\ (SE=0.03) NI - 71.4\ (SE=12.2)\ ME$

$N\ milk = 2.04\ (SE=11.7) + 0.10\ (SE=0.023) NI + 45.9\ (SE=5.43) ME$

- For every 0.1 unit increase in feed quality [*q* = (ME/GE)], N in faeces is reduced by 30.5 g/d

- For every 0.1 unit increase in ME intake, urine N is reduced by 7.1 g/d and milk N increased by 4.6 g/d

Metabolizability (*q*)

- Low quality diet may have lower digestible CP which increases N excreted in faeces
- Lower *q* values indicate lower digestible energy in the diet
- Greater hindgut fermentation of fibre/starch and increase in faecal microbial protein

Metabolizable Energy (ME)

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- Positive effect of ME on milk N and the reverse for urine N was clear
- Cohen et al. (2006) also reported higher milk N at expense of urine N with ME
- The site and type of ME supplementation affects N excretion patterns
- Abomasal infusion of pectin decreased shifted N excretion from urine to faeces

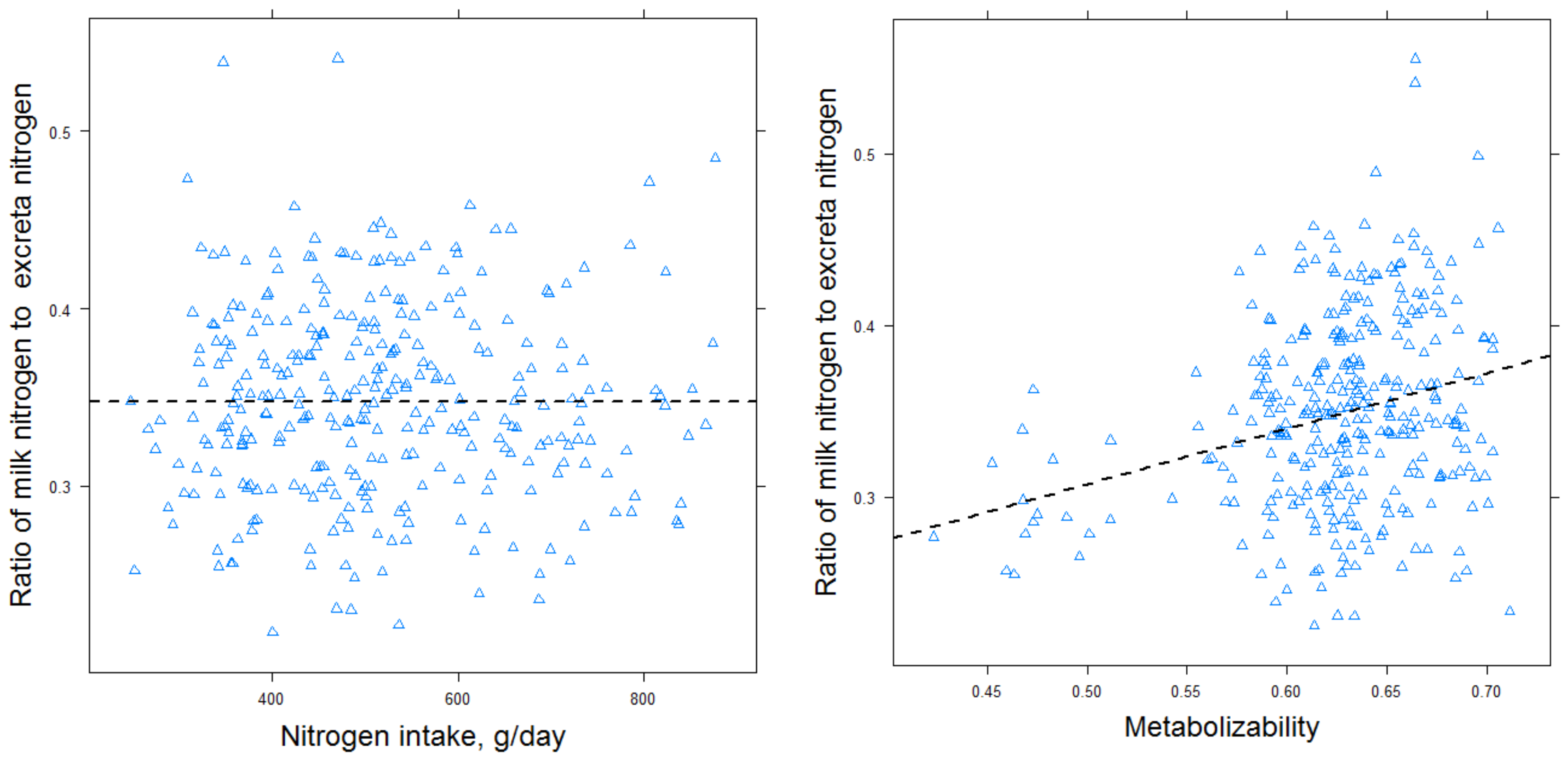
Type of ME Supplementation

	Treatments[1]				
	HNDF	LDS	HDS	SS	SEM
N intake, g/d	354	341	369	365	6.21
N output, g/d					
Feces	112	137	125	140	7.75
Urine	**95.8[a]**	**86.7[a]**	**134.0[b]**	**96.5[a]**	6.77
Milk	98.4	102.1	99.3	95.2	3.61
Balance	47.9	15.0	9.9	33.8	16.0

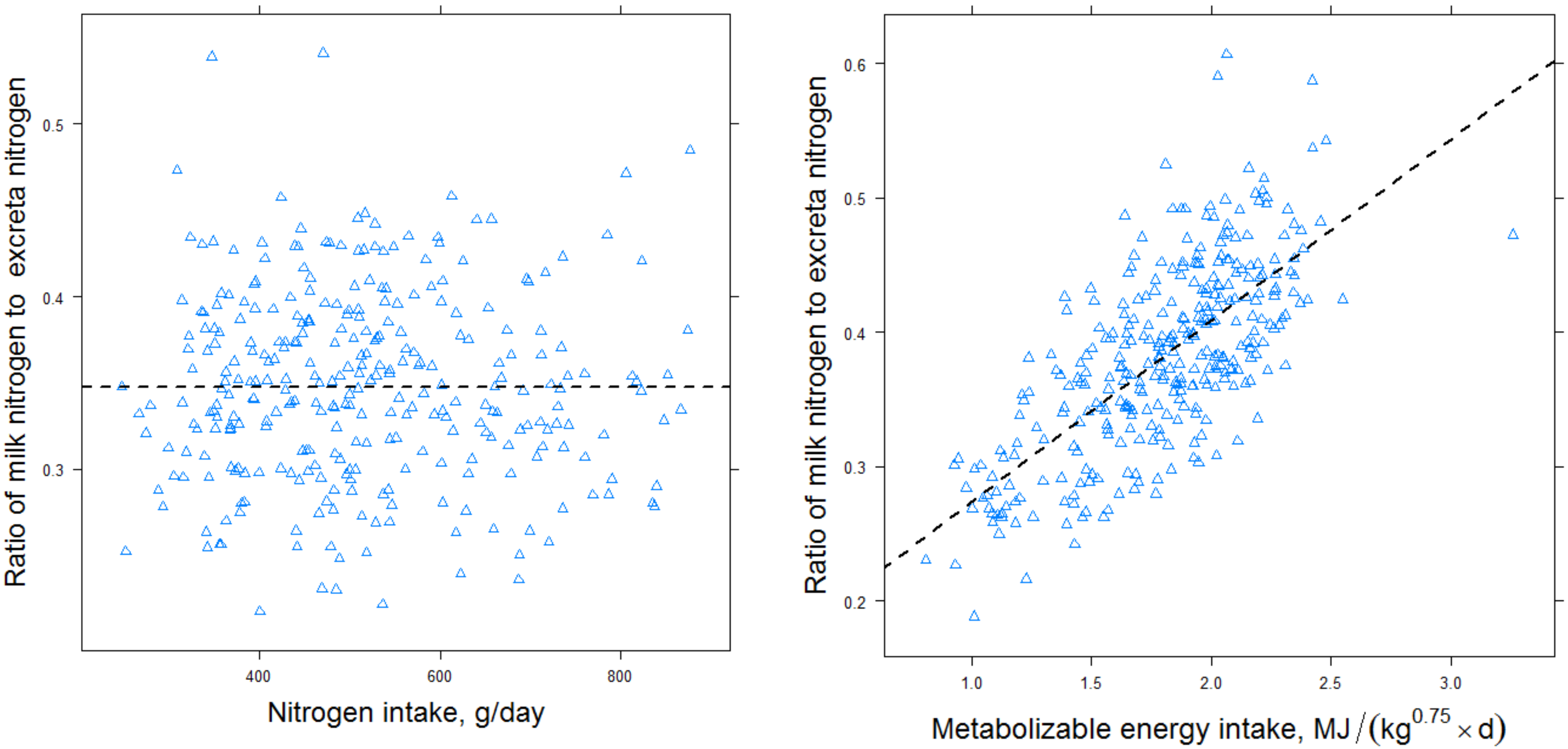
[1]Concentrates offered to cows containing high in NDF (HNDF), low degradable starch (LDS), high degradable starch (HDS), and soluble sugars (SS)

Castillo et al. (2001). *J. Anim. Sci.*, 79: 240-246

Results (N Efficiency Index)



Results (N Efficiency Index)



Results (N Efficiency Index)

- Huhtanen et al. (2008) found CP conc. to explain N efficiency better than N intake
- If N intake increases due to CP conc.
  - Higher ruminal N losses
  - Higher metabolic N losses
- In our analysis we found
  - ME > Metabolizability > CP conc. > N intake

Results (Multivariate)

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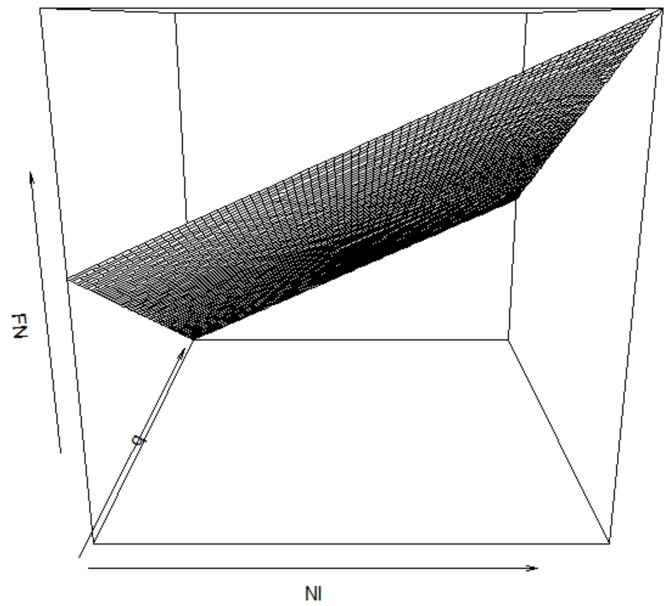
- The DIC for multivariate model was 8800 compared to 8876 for univariate models

$$N\ faeces = 244\ (SE=23.3) + 0.25\ (SE=0.01)\ NI - 346\ (SE=36.5)\ q$$

$$N\ urine = 150\ (SE=53.6) + 0.46\ (SE=0.02)\ NI - 257\ (SE=85.4)\ q$$

- For every 0.1 unit increase in feed quality [q = (ME/GE)], N in faeces is reduced by 35 g/d
- For every 0.1 unit increase in q, N in urine is reduced by 2.6 g/d

Multivariate Model



A three dimensional representation of a multivariate relationship between nitrogen intake (NI), faecal N (FN) and diet quality or metabolizability (q).

Mechanistic N Utilization Model

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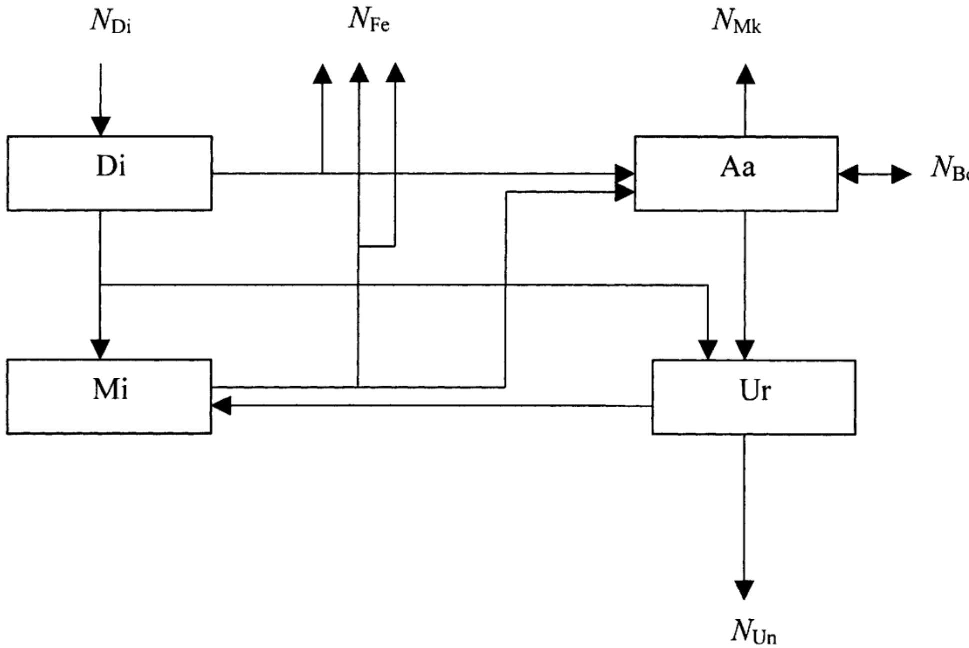
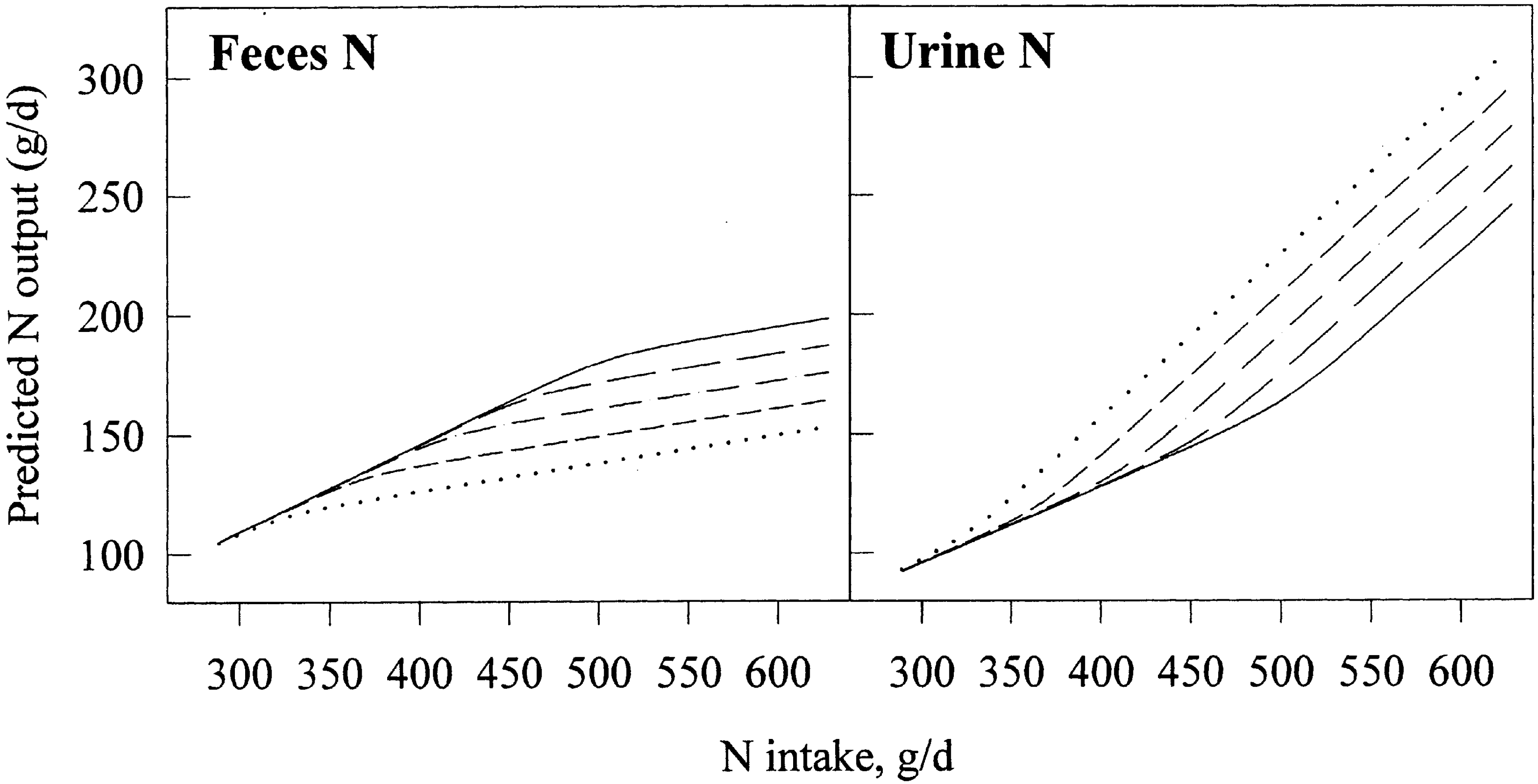
- Mechanistic model includes effects of
  - Dietary N concentration
  - Source of energy
  - Microbial community
  - Urea recycling etc



Kebreab et al. 2002. *J. Anim. Sci.* 80: 248

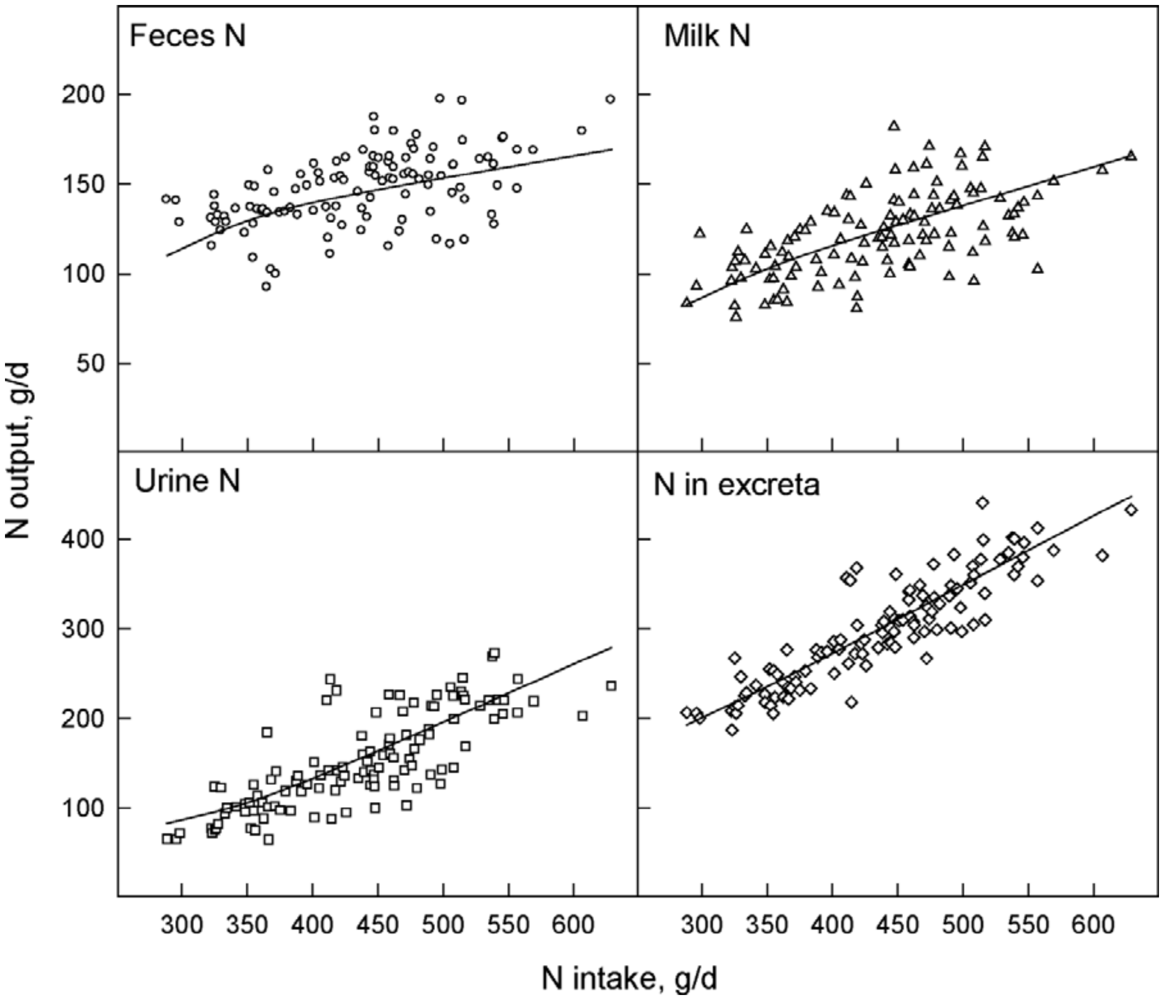
Mechanistic Model – Simulation



The model assumed intakes of 7 (... ...), 8 (– – –), 9 (– – –), 10 (— —) and 11 (——) fermentable ME/kg DM.

Kebreab et al. 2002. *J. Anim. Sci.* 80: 248

Mechanistic Model – Simulation



Kebreab et al. 2002. *J. Anim. Sci.* 80: 248

Other Sources of Variation

- Post-rumen N metabolism
- Splanchnic tissues
  - 50% of whole body protein synthesis (Lapierre et al. 2005)
  - Liver removes 45% of absorbed AA
- What is the true efficiency of milk N synthesis?
  - 0.64 g milk protein/g metabolizable MP (INRA)
  - 0.67 (NRC), 0.68 (AFRC)
  - 0.24 based on 23 experiments (Cant 2005)
  - Perhaps non-linear?

Other Sources of Variation

- Profile of absorbed AA in absorbed protein (Dijkstra et al. 2007)
  - Differential absorption for milk synthesis
  - Lower conc. of Lys or Met reduce actual milk yield relative to MP allowable milk yield (NRC 2001)
  - Improving AA balance improves milk N efficiency (Schwab et al. 2005)
- Future attempts of modeling N utilization
  - Effect of individual AA as non-linear & saturable
  - Energy supply

Conclusion

- Clear interaction between N and energy and their effect on N partitioning
- Nitrogen intake an metabolizability were best predictors for faecal N while N intake and ME were best for urine and milk N
- Multivariate models fit data better
- When reducing CP conc. in feed (e.g. low fertilizer) changes in energy conc. should be taken into account

Acknowledgment

- Anders Strathe, UC Davis, USA
- Jan Dijkstra, Wageningen U, NL
- Jonathan Mills, U of Reading ,UK
- Chris Reynolds, U of Reading, UK
- Les Crompton, U of Reading, UK
- Tianhai Yan, Agri-Food & Biosciences, NI
- James France, U of Guelph, CA

This presentation has been carried out with financial support from the Commission of the European Communities, FP7, KBB-2007-1.

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It does not necessarily reflect its view and in no way anticipates the Commission's future policy in this area.

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