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A model to predict nitrogen excretion from dairy cattle using the PDI protein system

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Introduction

There is increased pressure on agriculture to reduce nitrogen (N) excretion from different production systems. In order to do so, it is of value to know how diets compare in terms of N excretion, as this could have both financial and environmental consequences. A mechanistic model describing the N digestion and metabolism in ruminants was developed from the PDI protein system to enable this comparison. The aims of the exercise were to develop a model that predicts the N excretion in urine and faeces of dairy and beef cattle, and to relate model predicted faecal and urinary N excretion to experimentally measured faecal and experimentally estimated urinary N excretion from grazing dairy cows.

Materials and Method

The model described takes account of six different body sites where fundamental N transactions take place, with surplus N being excreted from the animal in faeces (site 4) and urine (site 8). The model and the relationship between the different sites and N excretion is summarised in *Figure 1*.

Figure 1. PDI nitrogen excretion model outline

Site 1 - The Rumen	
1A Excess degradable protein N	[((PDIN-PDIA / 0.64) / 0.9)-(1B × 6.25)] / 6.25
1B Microbial protein N	[(The least of PDIN or PDIE-PDIA) / 0.64] / 6.25
1C Feed undegradable protein N	[PDIA / dsi] / 6.25

Site 2 - The small intestine	
2A Amino acid N from microbial protein N	1B × 0.64
2B Undigested microbial protein	1B × 0.2
2C Non amino acid N from microbial protein	1B × 0.16
2D Undigested feed undegradable protein N	1C × (1-dsi)
2E Non amino acid N in feed undegradable protein	1C × AA (in the PDI system AA = 0)

Site 3 - The large intestine	
3A Undigested microbial ruminal N + large intestine microbial N	[4.62 × (((PDIE-PDIA) / 0.64) / 145)] / 6.25
3B Undigested feed undegradable protein N	2D
3C Truly endogenous faecal N	2.4 × DMI (kg)
Site 5 - The liver	
5A Amino acid N in excess of requirement (*maintenance, milk, growth and pregnancy)	PDI intake - (*AA requirement) / 6.25
5B Urea N from the excess of rumen degradable protein	1A
5C Purine derivative N from the absorption of nucleic acids	2C + 2E = 2C
Site 6 - Body protein	
6A Endogenous urinary N loss not accounted for in the inefficiency of absorbed amino acid utilisation for production	(3.25 × $LWT^{0.75}$ / 6.25) - 3C
6B Inefficiency in the AA utilisation for growth or pregnancy production	
Growth:	(300 × LWG) × 0.6 to 0.32 / 6.25
Pregnancy: (Beef)	47 (6^{th} month), 88 (7^{th}) 148 (8^{th}) or 222 (9^{th}) × 0.4 / 6.25
Pregnancy: (Dairy)	75 (7^{th}), 135 (8^{th}) or 205 (9^{th}) × 0.4 / 6.25
Site 7 - Milk N	
7A Inefficiency in the use of AA in milk production	((Milk CP output in g/d) / 0.64) × 0.36 / 6.25

Site 4 & 8 - Nitrogen excretion (g/day)

Faeces N output = 2D + 3A + 3C

Urine N output = 1A + 5A + 5C + 6A + 6B + 7A

PDI values were calculated according to the following equations:

PDIA = 1.11 × CP (1-deg) × dsi
PDIMN = 0.64 × CP × (deg-0.10)
PDIME = 0.093 × FOM
PDIE = PDIME+PDIA
PDIN = PDIMN+PDIA

deg (degradability of dietary protein in the rumen)
dsi = digestibility in small intestine
FOM = fermentable organic matter,
(DOMD – undegradable protein – ether extract - fermentation products in silage)

Nitrogen transactions by site

Site 1 – The rumen (1A-1C) The balance between rumen degradable protein and the amount of microbial protein produced (1B), yields an excess of rumen degradable N (1A). The rumen undegradable protein fraction (1C) is made up of dietary rumen undegradable protein potentially digestible in the small intestine (PDIA) and undegradable protein that is indigestible in the small intestine (2D). In the model, it is

assumed that 0.9 of rumen degraded N can be of utilised for microbial protein synthesis if energy is not limiting.

Site 2 – The small intestine (2A-2E) The amino acid (AA) N yield absorbed from microbial protein (2A) is the yield of microbial protein after an adjustment for the digestibility of the amino acids in the small intestine (0.8) and the AA concentration of microbial protein (0.8). The undigested fraction of the microbial protein (2B) is hence the rumen microbial protein N (1B) yield × 0.2 and the digested non amino acid N microbial protein (2C) 1B × 0.16 or (0.8 × 0.2). The undigestible fraction of the rumen bypass protein N is 2D, where *dsi* is the true digestibility in the small intestine of the bypass protein. This value does vary between diets and can be measured using the mobile nylon bag technique or estimated from available data. In the PDI system the content of non-amino acid N in rumen bypass protein (2E) is assumed to be 0.

Site 3 – The large intestine (3A-3C) The undigested ruminal microbial N and large intestinally produced microbial N (3A) is assumed to amount to 4.62 g N / kg FOM intake (Vérité and Peyraud, 1989). Endogenous faecal N (3C) has been estimated to amount to approximately 2.4 g/kg DM intake (Vérité and Peyraud, 1989). Undigested dietary undegradable protein N (3B) equals 2D, as this will not be digested in the intestine.

Site 5 – The liver **(5A-5C)** The liver deals with the N available in the body in excess of requirement. Amino acids and ammonia from the rumen are converted to urea and excreted in the urine (Site 8). These products are the total PDI intake less amino acid requirement (5A), urea N from the excess of rumen degradable protein 5B (= 1A) and purine derivative N from the absorption of nucleic acids 5C (= 2C).

Site 6 – Body protein **(6A & 6B)** The body protein site consists of endogenous N in urine associated with maintenance (6A) as well as the inefficiency of amino acid utilisation associated with growth and pregnancy (6B). Depending on age of the animal the efficiency of AA utilisation will vary (0.32-0.6). Pregnancy in dairy cattle is taken into consideration from month 7 to 9, as most of the growth of the foetus will take place at this time.

Site 7 – Milk N An inefficiency in use of amino acids for milk protein production is also taken into consideration.

Site 4 & 8 – Faeces and urine

Faecal N excretion:
- Undigested feed undegradable protein N (2D)
- Undigested microbial N + large intestine microbial N (3A)
- Truly endogenous faecal N (3C)

Urinary N excretion:
- Excess rumen degradable protein N (1A)
- Amino acid N in excess of requirement (5A)
- Purine derivative N from the absorption of nucleic acids (5C)
- Endogenous urinary N loss associated with maintenance (6A)
- Inefficiency in amino acid utilisation for growth, pregnancy, (6B) and milk production (7A).

Data required for model input

The information required for comparison of model predictions and measured / estimated data was obtained from two datasets (1 & 2) described below. Model input:

- Total PDI, PDIA, PDIE, PDIN and DM intake
- Milk CP
- Live weight (LWT)
- Amino acid requirement (maintenance, milk, growth and pregnancy)

  Maintenance = $3.25 \times \text{LWT}^{0.75}$ g PDI *Growth* = 250-350 g PDI/kg LWT gain

  Milk = Milk (CP × 0.95) / 0.64 *Pregnancy* = Efficiency of PDI = 0.60 (Vérité and Peyraud, 1989)

Dataset 1

Holstein-Friesian dairy cows at Moorepark Research Centre (47 & 38 (DIM) in May 2001 and 2002 respectively) were grazing perennial ryegrass pastures sampled twice in 2001 and four times in 2002 during periods of intake and digestibility measurement. Concentrate (0.88 kg/day) was offered in May 2001 only. Average milk and milk protein yields were in May 2001; 29.0 ± 3.18 kg/d and 934 ± 108 g/d, and in May 2002; 27.46 ± 5.63 kg/d and 914 ± 180 g/d respectively. PDI values representative of the grass selected by the grazing dairy cows were calculated from *in situ* rumen degradability and chemical analysis data.

Dataset 2

Data was obtained from one spring and one autumn experiment with Holstein-Friesian dairy cows grazing predominantly perennial ryegrass pasture at Lyons Research Farm, University College Dublin. Average milk and milk protein yields were at the start of the experiment in spring (92 DIM) 32.3 ± 3.9 kg/d and 1084 ± 135 g/d and in autumn (211 DIM) 19.6 ± 2.22 kg/d and 694 ± 82.1 g/d respectively. Cows were supplemented up to 6 kg concentrate (24% CP) in spring, and 1 kg dairy compound and 4 kg barley (rolled or NaOH treated) in autumn. Based on chemical composition data and other information on the samples e.g. time of year, species etc. PDI values were estimated for the grazed grass.

Urine and Faecal data

Individual intake and diet digestibility for each animal was measured by the n-alkane technique (Mayes *et al.* 1986) in all cases. Faecal output was estimated from measured diet digestibility. Urine N was calculated from the difference between total N intake less faecal and milk N output as earlier described (Mulligan *et al.* 2004, Astigarraga *et al.* 2002, Van Vuuren *et al.* 1993). The average PDIE and PDIN intake as well as the measured / estimated average N excreted in faeces and urine is shown in *Table 1*.

Table 1. Average daily PDI intake and faecal and urinary N output

Dataset & Period	PDIE (g/d)	PDIN (g/d)	Faecal N (g/d)	Urine N (g/d)
2 – Spring*	1902 (±319)	2224 (±426)	156 (±35)	252 (±81)
2 – Autumn*	2348 (±348)	2413 (±386)	184 (±40)	359 (±78)
1 - May 2001*	1663 (±181)	2201(±237)	150 (±28)	279 (±48)
1 - July 2001	1565 (±153)	2050 (±227)	99 (±14)	326 (±51)
1 - May 2002	1668 (±284)	2084 (±381)	134 (±27)	274 (±75)
1 - July 2002	1543 (±291)	1657 (±308)	119 (±20)	213 (±59)
1 - August 2002	1613 (±227)	2041 (±292)	65 (±11)	376 (±54)
1 - September 2002	1655 (±229)	2286 (±327)	69 (±10)	452 (±70)

* supplemented

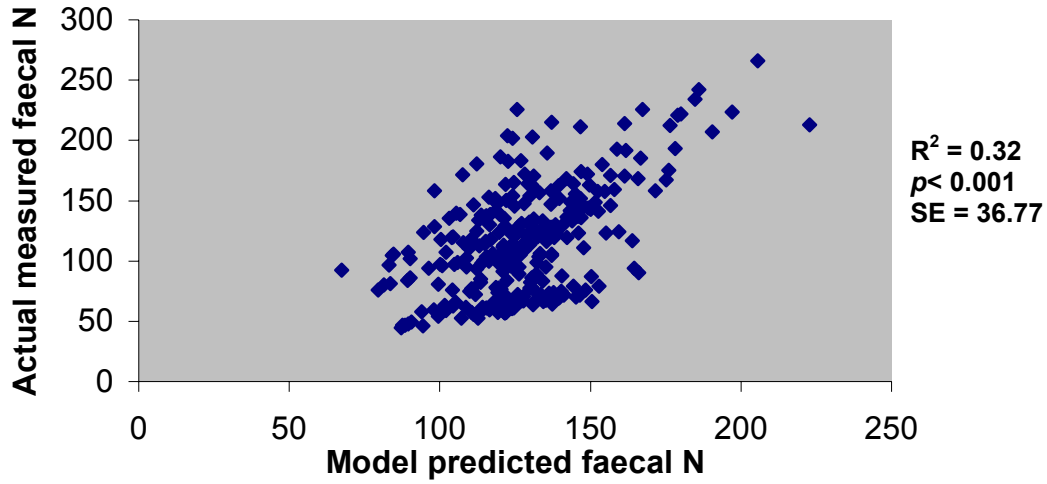
Statistical analysis

Measured data and model predictions for faecal and urine output were analysed in SAS using regression analysis (PROC REG).

Results and Discussion

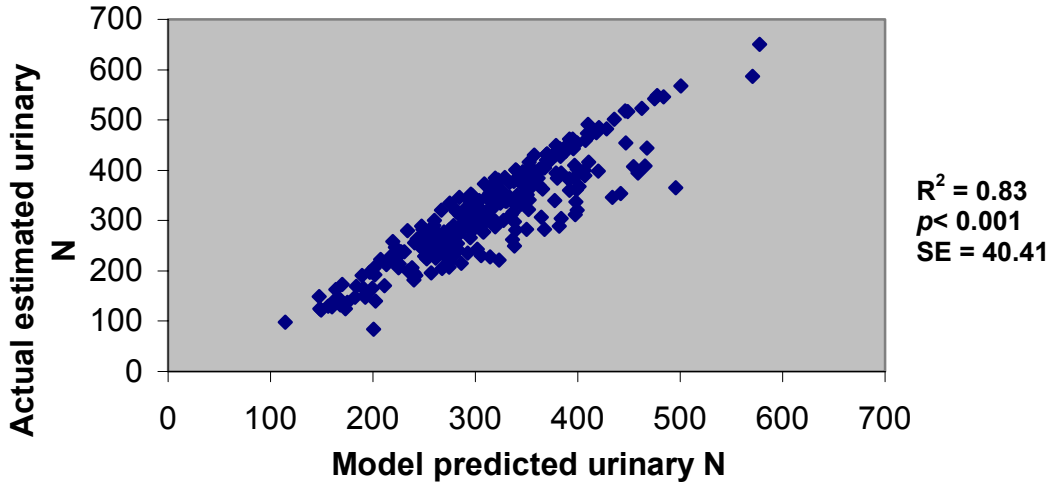
Regressing measured and model predicted faecal N excretion and experimentally estimated and model predicted urine N excretion yielded two equations (*Figure 2&3*).

Figure 2. Model predicted faecal N v. actual measured faecal N excretion (g/day)



Actual measured faecal N =
1.13 (± 0.098) × model predicted faecal N – 27.86 (± 12.705)

Figure 3. Model predicted urine N v. actual estimated urine N excretion (g/day)



Actual estimated urine N =
1.14 (± 0.031) × model predicted urine N – 39.88 (± 9.906)

The model prediction for urine N excretion was more accurate than for faeces for the different N intakes investigated. The accuracy of the model for predicted urine N excretion (R^2= 0.83) was quite high using the combined data set. As urine N excretion is of most concern in an environmental context, it could be argued that it is more important to accurately predict urine N before faecal N excretion. It is possible that more simple predictions of urine and faecal N output from N or PDI intake, milk N yield etc also could offer satisfactory estimates, as the empirical relationships established by Castillo *et al.* (2000). Based on daily N intake, the equations of Castillo *et al.* predicted urinary N excretion relatively accurately (R^2= 0.74) in contrast to faecal N excretion (R^2= 0.32). The results from our model are similar but the accuracy of prediction is greater at R^2= 0.83 for urine N. However mechanistic models like the model discussed here and by others (Van Straalen, 1995, Kebreab *et al.* 2002) might be less sensitive to changing environmental and animal factors as they account for some of these factors. Kebreab *et al.* (2002) fitted lines of model predictions with R^2 of 0.52 and 0.79 to observed values of faeces and urine N excretion respectively. From our own data and other models mentioned here it seems possible to predict urinary N excretion with relatively high accuracy. Future development of calibrations for alternative methods to predict PDI values such as NIRS (Near Infrared Reflectance Spectroscopy) could offer options to rapidly obtain the data necessary for input in models like the one discussed here. Provided the model input data is available, prediction models could be used in ration formulation to evaluate effects of different diets on N excretion. It would be desirable to further evaluate the developed model with actual measured urine excretion data from different feeding situations under Irish conditions in the future.

Conclusion

The developed model was more accurate in predicting urine N excretion than faecal N excretion. It is desirable to further test the model with different data sets to establish the sensitivity of this model for animals in different dietary and metabolic situations.

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