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Excretion of faecal, urinary urea and urinary non-urea nitrogen by four ruminant species as influenced by dietary nitrogen intake: A meta-analysis

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ABSTRACT

The quantification of faecal nitrogen (FN) and of urinary urea-N (UUN) and urinary non-urea-N (UNUN) excretion at varying N contents in ruminant rations is an important tool in assessing endogenous N turnover via the rumino-hepatic cycle. Using a statistical analysis based on an extensive database, the aim of this meta-analysis was to evaluate correlations derived previously by deduction. The data were categorised into dairy cattle, growing cattle (bulls and heifers), sheep and goats. Data from 50 publications were considered. The independent variable was the daily N intake (NI, g/day). The dependent variables were the daily quantities (g/day) of FN, urinary N (UN) , UUN, UNUN and N retention. The NI influenced FN to differing extents in goats, dairy cattle, growing cattle and sheep (listed in descending order of influence). Except in sheep, the effect was statistically significant. The influence on UN varied in the order goats, growing cattle, dairy cattle and sheep; the effect was statistically significant only for dairy cattle and growing cattle ($P < 0.001$). The UUN was influenced in the order sheep, goats, dairy cattle and growing cattle ($P < 0.05$). The UNUN could be assessed only in dairy cattle, growing cattle and sheep and was not influenced by NI. The UUN is therefore more strongly dependent on NI than is UNUN and the latter can therefore continue to be seen as obligatory. The FN is indeed influenced by NI but, as a result of higher digestibility of the total ration with increasing crude protein content, an improvement in microbial crude protein synthesis can also be assumed, which is reflected in higher FN levels.

1. Introduction

Nitrogen (N) in the form of amino acids is an essential nutrient for ruminants. Besides all the ideas about reducing or avoiding N losses in the feed chain (Tamminga, 1992; Yang et al., 2010), it is important to avoid an inadequate N supply not tailored to the animals' needs, and its influence on performance (Fanchone et al., 2013). An N supply optimised for ruminants is not necessarily accompanied by maximum growing or milking performance, even though this would be desirable (Spek et al., 2013).

Ultimately, all ruminants need absorbable amino acids in the small intestine originating largely from rumen microbial crude protein (MCP) synthesis and, in smaller quantities, from ruminally undegraded dietary CP (UDP). To improve N utilization efficiency, it is vital to expand current data and knowledge. The amino acid content of MCP and UDP, and models for estimating the intermediary, i.e. post-absorptive availability and utilization of these amino acids, especially methionine and lysine, represent an important basis for providing ruminants with a tailored supply of amino acids (Schuba and Südekum, 2013).

To use N-containing feed resources as efficiently as possible, it is important to quantify the minimum supply of N compounds that ruminants require (Pfeffer et al., 2016). The potential of N recycling via the rumino-hepatic cycle can be fully utilised only if the feed N content is as low as possible (Walker et al., 2005), e.g., only 80% of recommended supply with a shortage in rumen-degradable N compounds (Fanchone et al., 2013).

A sufficient volume of reliable data on the N content of faeces (FN) and urine (UN) (including appropriate fractionation into urinary urea-N (UUN) and urinary non-urea-N (UNUN)) is necessary in order to assess N turnover in ruminants and thus to derive recommendations for N supply. From the proportions of UUN in particular, it is possible to draw conclusions regarding the efficiency of MCP synthesis. For example, protein utilization and MCP (indirectly) can be estimated

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based on the ratio of UUN to allantoin-N (e.g., Kehraus et al., 2006). Moreover, UN and UUN correlate closely with N intake (NI). The UN or UUN fractions can therefore be predicted based on the concentration of CP in the ration (or the urea excreted in milk) (Spek et al., 2013). In contrast to UUN, UNUN and FN are only marginally affected by CP levels in the feed and are therefore unavoidable (Pfeffer et al., 2010). This approach has been confirmed repeatedly in both growing cattle and small ruminants. For example, Cox (2013) showed a 13–88% variation in the fraction of UUN in UN in growing goats fed an increasing supply of CP. In general, therefore, UUN increases with increasing feed N content, whereas UNUN should be seen as virtually independent of N supply.

The UNUN (UNUN=UN-UUN) consists primarily of purine derivatives (mainly allantoin), creatine, hippuric acid and ammonium. In addition, the purine derivative allantoin is a good indicator of the efficiency of microbial protein synthesis, while hippuric acid can be seen as an indicator of the digestibility of plant material. Hippuric acid is an indicator of plant material containing lignocellulose (Kehraus et al., 2006).

Previous studies on the relationship between NI, other dietary factors and N excretion used data of only one ruminant species (cattle; e.g., Reed et al., 2015; Johnson et al., 2016) or category within species (lactating dairy cattle; e.g., Spek et al., 2013; beef cattle, e.g., Waldrip et al., 2013) and some authors also did not differentiate UN into UUN and UNUN (Waldrip et al., 2013; Reed et al., 2015; Johnson et al., 2016). This study used data on small and large ruminants and differentiated UN into UUN and UNUN because the assumption was that, biologically, the response of all ruminant species to increasing NI is not dependent on the species or category (e.g., dairy vs. beef), as surplus N will always result in greater UN, and in particular, UUN excretion.

This meta-analysis therefore aims to pursue and investigate the following hypothesis on the basis of an updated, expanded data set: Regardless of the species or category of ruminant (dairy cattle, growing cattle, sheep or goats), both FN and UNUN are unaffected by a variation in N supply and can therefore be seen as obligatory for derivations of N requirements.

Table 1
Statistical description of the database.

Animal species/category		Variables (g/day unless otherwise stated)					
		DMI[a] (kg/day)	NI[d]	FN[e]	UN[f]	UUN[g]	UNUN[h]
Dairy Cattle							
	n[b]	136	136	136	136	26	26
	Mean	20.3	548.4	190.3	196.7	172.6	45.8
	Maximum	30.2	827.0	386.0	342.0	240.0	77.0
	Minimum	7.2	104.8	51.0	41.0	63.0	13.0
	SD[c]	4.6	154.9	66.2	68.5	47.6	14.2
Growing Cattle	n	29	29	29	23	18	18
	Mean	6.4	130.5	40.5	50.2	30.3	18.0
	Maximum	15.5	272.0	115.0	120.8	95.8	25.0
	Minimum	3.9	87.6	21.1	13.6	1.5	12.1
	SD	2.9	42.3	18.5	32.1	32.8	4.3
Sheep							
	n	27	27	27	21	27	10
	Mean	1.0	21.9	6.6	11.6	8.3	3.8
	Maximum	2.2	45.3	10.9	26.6	20.8	9.4
	Minimum	0.5	3.5	4.1	1.8	0.8	0.9
	SD	0.4	9.5	1.7	5.4	5.6	2.6
Goat							
	n	17	17	17	17	14	11
	Mean	1.1	24.9	7.8	9.7	4.5	1.8
	Maximum	1.8	43.9	12.0	18.1	14.6	2.5
	Minimum	0.6	7.2	2.6	1.3	0.2	1.2
	SD	0.5	12.4	3.3	5.0	4.1	0.5

[a] DMI=Dry matter intake.
[b] n=Number of rations.
[c] SD=Standard deviation.
[d] NI=Nitrogen intake.
[e] FN=Faecal nitrogen excretion.
[f] UN=Urinary nitrogen excretion.
[g] UUN=Urinary urea-nitrogen excretion.
[h] UNUN=Urinary non-urea-nitrogen excretion.

2. Materials and methods

2.1. Description of database

The database used in this meta-analysis was constructed from 50 publications (see Appendix A). The breakdown is as follows: 27 publications on dairy cattle, 6 publications on growing cattle, 10 publications on sheep and 7 publications on goats. The crucial selection criterion in each case was that all relevant N fractions in faeces and urine were quantified, rather than calculated or derived. The data set included the species and sample size studied in each publication, plus dry matter intake (DMI), CP, NI, FN, UN, UUN and UNUN. For dairy cattle, the data also included milk urea, milk fat, milk protein and milk yield. All data were expressed both as absolute quantities and as concentrations. However, for reasons of clarity and to improve comparability, this publication only presents the absolute figures (g/day) except for milk fat and protein and milk urea, which were expressed as concentrations. Table 1 summarises the statistical distribution of the variables tested in the data for each animal species or category. For ease of reading, the term ‘species’ is used throughout, also when referring to a category within the species ‘cattle’.

2.2. Statistical analyses

Data compiled in the database were analysed using mixed model regression methodology (St-Pierre, 2001; Sauvant et al., 2008). The NI (g/day) was treated as the independent variable and considered as fixed effect. Different studies were considered as random effects. The dependent variables were FN, UN, UUN, UNUN, N retention (NRet), milk yield, milk protein, milk fat and milk urea. Accordingly, the following model was used:

$$Y_{ij} = B_0 + B_1X_{ij} + B_2X_{ij}^2 + s_i + b_iX_{ij} + e_{ij},$$

where Y_{ij}=the dependent variable, B_0=overall inter-study intercept (fixed effect), B_1=the overall linear regression coefficient Y on X (fixed effect), B_2=the overall quadratic regression coefficient Y on X (fixed effect), X_{ij}=the value of the continuous predictor variable, s_i=the random effect of the ith study, b_i=the random effect of study on the regression coefficient of Y on X, and e_{ij}=the residual error. The model was applied for each ruminant species, i. e. dairy cattle, growing cattle, sheep and goats. Model statistics used for this study was Akaike's information criterion (AIC), which was applied in model selection to measure the relative goodness of fit of a statistical model. In this study, AIC was used to select whether a model is quadratic or linear (lower AIC indicates better model fit), together with the P-value. When a quadratic model did not significantly explain the relationship between independent and dependent variables, the model was modified into a linear model by eliminating out the $B_2X_{ij}^2$ component. Since data were unbalanced among ruminant species and different variables, the meta-analyses were performed based on the available data.

3. Results

The regression analysis results are shown in Table 2, differentiated by species, with NI (g/day) serving as an independent variable in