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Synchronization of energy and nitrogen release in the rumen: A modelling approach for forages

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SUMMARY - In the study, 2 grasses and 2 legumes were harvested at 2 stages of growth. Duplicate samples were incubated *in sacco* in the rumen of 3 mature, fistulated cows for 2, 4, 8, 16, 24, 48 and 72 hours, and the degradability of DM and nitrogen was measured. Degradability data were fitted with a Gompertz model, which offers the opportunity of studying two aspects of rumen degradation: degradation kinetics, represented as cumulative curves and degradation rate kinetics. The synchronicity in the release of nitrogen and dry matter or structural carbohydrates was calculated from the ratio between the quantity of nitrogen and dry matter or fibre degraded per unit time, using the first derivative of the Gompertz equation. This provided a dynamic description of the degradation process for each forage which would allow the combination of feeds in a ration to maintain these ratios constant throughout the rumen digestion process.

Key words: Dry matter degradability, nitrogen degradability, rumen, Gompertz model.

RESUME - *"Synchronisation de la libération d'énergie et d'azote dans le rumen : Une approche modélisée pour fourrages". Dans cette étude, 2 graminées et 2 légumineuses ont été récoltées à 2 stades différents de croissance. Des échantillons en double ont été incubés* in sacco *dans le rumen de 3 vaches matures et fistulées pendant 2, 4, 8, 16, 24, 48 et 72 heures, et la dégradabilité de la matière sèche et de l'azote a été mesurée. Les données de dégradabilité ont été ajustées avec un modèle de Gompertz, qui offre la possibilité d'étudier deux aspects de la dégradation dans le rumen : cinétique de dégradation, représentée par des courbes cumulatives, et cinétique du taux de dégradation. Le synchronisme de la libération d'azote et de matière sèche ou d'hydrates de carbone structurels a été calculé d'après le ratio entre la quantité d'azote et de matière sèche ou de fibre dégradée par unité de temps, en utilisant la première dérivée de l'équation de Gompertz. Ceci a permis une description dynamique du processus de dégradation pour chaque fourrage, pour pouvoir ainsi mettre au point une combinaison d'aliments dans la ration qui maintienne constants ces ratios tout au long du processus de digestion ruminale.*

Mots-clés : *Dégradabilité de la matière sèche, dégradabilité de l'azote, rumen, modèle de Gompertz.*

Introduction

The sigmoidal Gompertz model can be applied to degradation curves to give a description of three phases:

(i) The initial phase with slow or no degradation, during which hydration, microbial attachment and colonization of the feed take place.

(ii) The exponential phase, where rapid degradation occurs and the substrate is saturated with microbes and enzymes.

(iii) The asymptotic phase of degradation, during which the degradation slows until an asymptotic value is reached, due to the lack of fermentable material.

Beuvink and Kogut (1993) suggested that the use of the fermentation rate at the inflection point (maximum degradation rate; MDR), time of maximum fermentation rate (TMDR) and the time when 95% of the substrate is fermented allowed a more comprehensive evaluation of feedstuffs.

The first and second derivatives of the Gompertz model were used to describe degradation rates of dry matter and nitrogen in 4 representative forages harvested at two dates. The concepts mentioned above (MDR, TMDR) were also used to study the synchrony between nitrogen and energy (carbohydrates) release in the rumen.

Material and methods

The forage species studied were tall fescue (TFE; *Festuca arrundinacea*), Italian rye grass (IRG, *Lolium multiflorum*), lucerne (LUC; *Medicago sativa*) and red clover (RCL; *Trifolium pratense*), harvested at two dates.

Each forage was incubated in the rumen of three cows for 2, 4, 8, 16, 24, 48 and 72 hours, following the procedure of CPNAP (1994). Feed samples were analysed for dry matter (DM) and crude protein (CP). The chemical composition of the forages is presented in Table 1.

Table 1. Dry matter degradability kinetic parameters estimated with Gompertz model (Bidlack and Buxton, 1992)

Forage and harvest†	Dry matter				Crude protein			
	IAF††	A	B	C	IAF	A	B	C
TFE-III	21.2	0.092	86.8	1.41	30.0	0.109	89.1	0.96
TFE-V	18.4	0.070	65.2	1.26	32.4	0.088	63.6	0.67
IRG-III	43.0	0.125	95.2	0.80	31.2	0.153	95.3	1.12
IRG-V	33.2	0.114	88.3	0.98	6.0	0.230	79.6	2.64
LUC-III	26.0	0.147	84.5	1.18	40.3	0.153	93.4	0.84
LUC-V	22.1	0.107	70.8	1.17	31.0	0.122	88.0	1.04
RCL-III	30.5	0.136	88.6	1.07	37.6	0.153	93.5	0.91
RCL-IV	28.3	0.126	92.1	1.18	28.6	0.133	94.3	1.19

†Harvest date: III, end of March; IV, end of April; V, beginning of May
††IAF: Immediately available fraction, calculated from the coefficients A, B and C at t=0

DM and CP degradability data were fitted with the Gompertz model (Bidlack and Buxton, 1992):

$$Y(t)=B*\exp(-C*\exp(-A*t))$$

where: Y(t) is the fraction degraded at time "t"; "B" is the asymptotic value of the component (total potentially degradable fraction); "C" is the relative degradation rate as affected by a constant factor of microbial efficiency (A) and "t" is the time in hours.

The estimated parameters were used to calculate the first and second derivatives of the Gompertz equation:

first derivative:

$$dY/dt = BCA*\exp(-A*t)*\exp[(-C)*\exp(-A*t)]$$

second derivative:

$$d^2Y/dt^2 = AB^2C^2*(\exp^{(-At)})^2*\exp(-C*\exp^{(-At)}) - ABC^2*\exp(-C*\exp^{(-At)})$$

The times of maximum degradation rate (TMDR) were determined by setting the second derivative of the Gompertz function equal to zero (0) and solving for "t". The maximum degradation rates (MDR) were determined by calculating the first derivative of the Gompertz function with respect to TMDR. In the case of negative TMDR values it was assumed that the MDR occurred at the start of incubation (t=0).

The amount of organic matter and nitrogen instantaneously released into the rumen was calculated by multiplying the first derivative of the Gompertz equation for dry matter and nitrogen by their respective proportions present in each forage. It was assumed that the rate of degradation for organic matter was similar to that of dry matter. The ratio of the two release rates was plotted against time (0 to 72 h) for 2 forages (Fig. 3).

Results and discussion

The sigmoidal shaped model fitted the degradability data well, with high r^2 and low residual standard error (rse) values (Table 1).

The MDR (Table 2 and Figs 1 and 2) represents the highest value of degradation rate observed for a substrate and it depends on the type of substrate and its structural arrangement in the plant cell. Nitrogen often had the highest values, indicating a higher susceptibility to degradation in the rumen. Most of the nitrogen is present in the cell content (van Soest, 1983) and it is likely that the breakdown of the cell wall will release nitrogen into the rumen fluid, leading to a high estimate of its degradation rate.

The TMDR (Table 2 and Figs 1 and 2) represents the time that the MDR occurs and so gives complementary information about the time-course of rumen degradation. In both plant families, the TMDR of DM and N were mostly considerably less than 4 h of incubation and were thus substantially shorter that the TMDR values for the NDF (data not shown), which generally occurred at least 4 to 6 hours later.

Table 2. Maximum degradation rate (MDR, %/h) and time of maximum degradation rate (TMDR, h) for dry matter and nitrogen in the forages

Forage and harvest†	Dry matter MDR	Nitrogen MDR	Dry matter TMDR	Nitrogen TMDR
TFE-III	2.95	3.58	3.7	0 (-0.4)
TFE-V	1.69	2.06	3.3	0 (-4.6)
IRG-III	4.39	5.36	0 (-1.9)	0.7
IRG-V	3.70	6.75	0 (-0.3)	4.2
LUC-III	4.57	5.24	1.2	0 (-1.1)
LUC-V	2.79	3.94	1.4	0.3
RCL-III	4.43	5.26	0.5	0 (-0.6)
RCL-IV	4.28	4.26	1.3	1.3

†Harvest date: III, end of March; IV, end of April; V, beginning of May

The type of study undertaken in this paper permits an examination of the degree of synchrony of the release of nutrients from feeds into the rumen environment. Sinclair *et al.* (1993) used a similar approach but their study was limited by the use of an exponential model to fit the degradability data, which only allows decreasing degradation rates from the beginning of incubation. Figure 3 shows how the first derivative of the Gompertz equation accommodates both increasing and decreasing rates of degradation (IRG sample) while the LUC sample had a more regular decreasing trend. The difference between these two experimental plots and the value of 25 g of nitrogen per kg of degraded organic mater chosen as the optimal ratio for synchronization (Sinclair *et al.*, 1993) gives an indication of the type of feed which would need to be offered with the forages to optimize microbial growth - feeds rich in readily degradable carbohydrate for the LUC and feeds with both fermentable nitrogen and carbohydrate for the IRG. However, practical value of introducing this type of data into a ruminant nutrition model still needs to be demonstrated.

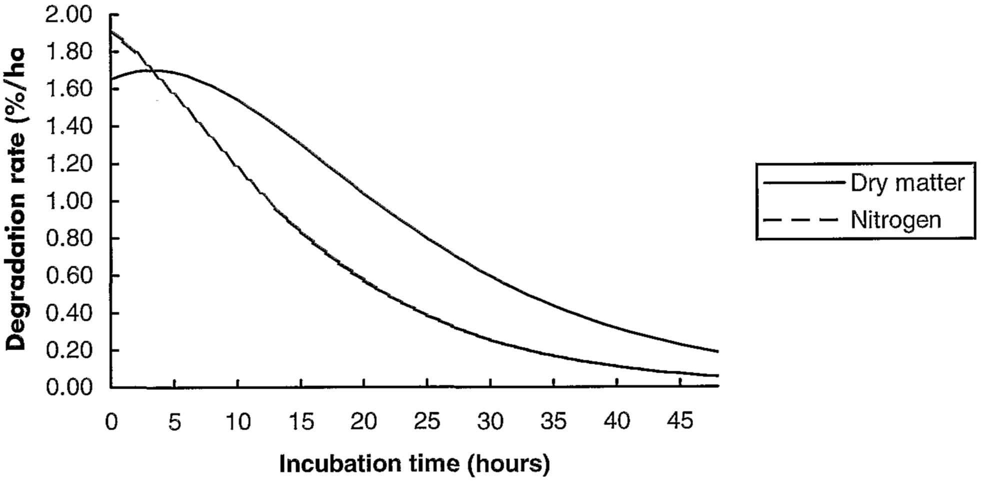

Fig. 1. Degradation rates of TFE-V dry matter and chemical components.

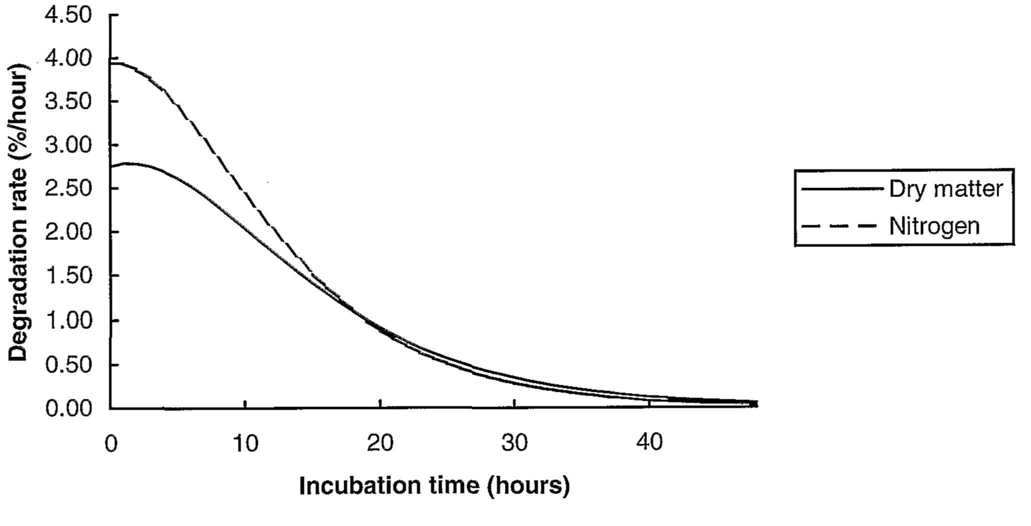

Fig. 2. Degradation rates of LUC-V dry matter and chemical components.

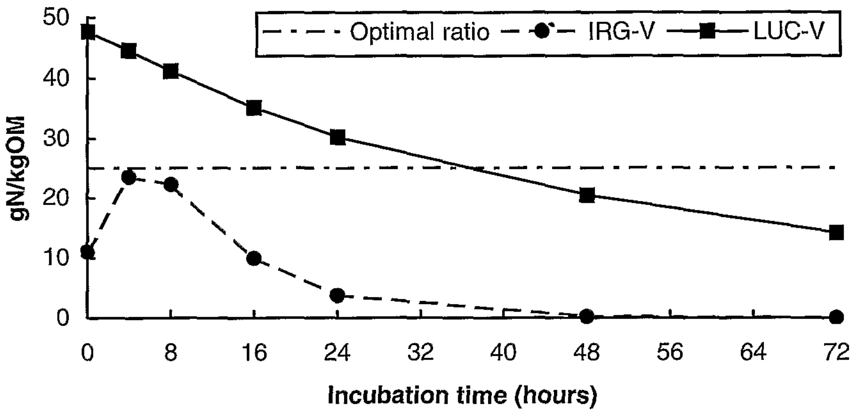

Fig. 3. Changes in the nitrogen-to-organic matter ratio during the rumen incubation of two forages.

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