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**Review article**

# Relation between nutrition, performances and nitrogen excretion in dairy cows

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**Abstract** — Reducing N excretion from individual cows is one way among others to better cope with the problem of the negative contribution of the dairy herd to the "Nitrogen cycle" on the farm. The objectives of this paper are first to quantify the effects of the main forage systems and protein feeding level on the amount of N excreted in relationship to their simultaneous effects on animal performances and efficiencies and then to examine the particularities of the grazing situation. N excretion depends primarily on the level of N intake i.e. on forage species, fertilisation, growth stage and protein supplementation and therefore varies between the main usual forage systems from 90 to 150 kg N per cow per year (i.e. 12 to 20 kg N per ton of milk). A simple method is proposed to calculate the load of excreta N from a dairy herd according to the specific pattern of feeding practices over the year. The effects of the level of metabolic protein supply over a wide range of dietary concentrations (80–125 g PDI per UFL) were analysed from a set of 5 feeding trials. Through that range, excreta N were largely increased and productive responses were also important (but without any residual effect), not only for milk yield (+15 to +30%) but also for milk protein concentration (+2 $g \cdot kg^{-1}$) and feed efficiency (+10%). The simultaneous increase observed in feed intake (+1 to +3 kg DM) accounted for half of the productive responses and could explain why the nutritive balance was hardly affected by protein levels, even in early lactation. Most of the productive parameters responded to increasing PDI levels according to laws of decreasing return that are given in the text. On the contrary, the relative N losses (excreta N per milk N) decreased curvilinearly with decreasing PDI levels reaching a minimal plateau. The concentration of 100 g PDI per UFL appears as a common key value for both phenomena: higher PDI levels results only in small increases in productive performances whereas N losses increase sharply, and the reverse occurs with lower PDI levels. At grazing, the level of N fertilisation, through the increase in sward yield and N content, is the main determinant of productive performances and losses of excreta N per ha. The other factors of sward valorisation such as stocking rate only have a moderate effect whereas the effect of concentrate supply could be low or high according to protein content. Total grazing days per ha is an integrative parameter that accounts quite well for all these factors since it reflects both sward yield and herd valorisation conditions. Roughly, each extra 100 grazing days induced by higher fertilisation increases N flows by 10–15 $kg \cdot ha^{-1}$ as milk and by 70–80 $kg \cdot ha^{-1}$ as excreta.

**dairy cows / nitrogen / excretion / nutrition / milk yield**

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**Résumé — Conduite alimentaire et rejets azotés chez la vache laitière. Interrelations avec les performances.** Réduire la quantité d'azote excrétée par les vaches est un moyen parmi d'autres qui contribue à faciliter la gestion des déjections du troupeau laitier dans leurs incidences sur le cycle de l'azote. L'objectif de cette synthèse est d'abord de quantifier l'effet de la nature et de la conduite 1/ du système fourrager et 2/ de l'alimentation azotée sur les rejets N et leurs relations avec les performances puis 3/ d'examiner ces problèmes dans le cas particulier du pâturage. L'azote des déjections dépend d'abord des quantités de N ingérées et varie de 90 à 150 kg par vache par an (ou de 12 à 20 kg par tonne de lait produit) avec la nature du fourrage, l'intensité de son exploitation (fertilisation, stade) et la supplémentation azotée. Une méthode simple est proposée pour estimer les rejets N annuels en fonction des séquences alimentaires du troupeau. Les effets du niveau d'apports azotés ont été examinés au cours de 5 essais dans des situations nutritionnelles variées et pour une large gamme de teneurs en PDIE par UFL des rations (80 à 125 g). Entre les niveaux extrêmes, les écarts de réponses sont importants, mais sans aucune rémanence ultérieure, non seulement pour le lait (+15 à 30 %) et les rejets N mais aussi sur le taux protéique (+2 g·kg$^{-1}$) et l'efficacité alimentaire (+10 %). Les différences d'ingestion (1 à 3 kg MS) induites par le niveau d'apports PDI sont la cause de la moitié de ces écarts de production et expliquent pourquoi le bilan énergétique est peu modifié par la variations des apports PDI (sauf déficit important) même en début de lactation. Avec l'augmentation des apports, ces paramètres suivent pour la plupart des lois de rendements marginaux décroissants précisées dans le texte. À l'opposé, les pertes relatives d'azote dans les déjections rapportées par kg de lait produit diminuent de façon curvilinéaire avec la teneur en PDIE de la ration pour atteindre un seuil bas incompressible. La teneur de 100 g PDIE par UF serait bien une valeur clé commune à ces 2 phénomènes : au-dessus le gain de performances est minime en regard de l'accroissement des pertes N alors que c'est l'inverse au dessous. Au pâturage, la fertilisation azotée, de par son effet important sur les quantités d'azote exportées par la plante, est un facteur déterminant des performances et restitutions d'azote par hectare. Les conditions de valorisation de la prairie telles que le chargement jouent ensuite un rôle modulateur tandis que l'effet de la complémentation dépend de la teneur en MAT du concentré. Le nombre de jours de pâturage réalisé par hectare (JP·ha$^{-1}$) qui caractérise à la fois la production d'herbe et sa valorisation par le troupeau, représente le critère de synthèse qui intégre bien ces facteurs de variation. Globalement, pour 100 JP·ha$^{-1}$ en plus grâce à la fertilisation, l'azote exportée par le lait s'accroît de 10 à 15 kg par ha selon le potentiel des animaux tandis que les rejets totaux augmentent d'environ 70 à 80 kg N par hectare.

**vache laitière / azote / excrétion / nutrition / production laitière**

## 1. INTRODUCTION

For a long time, protein nutrition of ruminants has been a major challenge in feeding management. Much work has been done on the topic in order to improve animal performances and feed efficiency. Recommendations are now functioning well for this purpose, though they differ slightly between countries since there are differences both in the main feeding systems existing on farms and in the proposed evaluation systems. Inversely, studies concerning nitrogen excretions, their varying factors and their consequences are much more recent. These new preoccupations are to be associated with, on the one hand, the important recognised role of excess nitrogen in certain environmental attacks and, on the other hand, to new EC Directives that make the management of animal excreta on farms more difficult. In intensive production areas, the development of off-soil animal productions and the high density of animals generate considerable amounts of excreta nitrogen that enter the overall N cycle and may induce its disequilibrium. Ruminants, even though they are associated with agricultural surfaces upon which they feed, help contribute to this vast problem of exceeding amounts of nitrogen.

Reducing excreta N flow has today been unanimously accepted. The consequences of this choice should, however, be analysed and integrated on the animal and performance levels as well as on the plot and farm levels. After a brief review of nitrogen flow in dairy cows and its principal factors of variation, the objective of this article is to analyse the relation between performances and nitrogen waste under the influence of protein feeding in order to promote balanced solutions. For the specific case of grazing, the role of nitrogen under its different inputs is then examined on the plot and herd scale.

## 2. QUANTIFICATION OF NITROGEN EXCRETION IN THE DAIRY COW

### 2.1. Main factors of variations

In dairy cows, the quantities of nitrogen in the excreta ($N_{excr}$) can be calculated from the balance between ingested nitrogen ($N_i$) and nitrogen that is exported by milk ($N_m$): $N_{excr}$ ($g \cdot d^{-1}$) = $N_i - N_m$. These N excreta are emitted in the faeces and urine under two distinct forms with very different compositions and chemical transformations. The quantity of nitrogen excreted in the faeces ($N_f$ $g \cdot d^{-1}$), varying only a little with the different compositions of the diet, is directly related to total DM intake (7.2 $N \cdot kg^{-1}$ DMi). The nitrogen present in faeces is essentially organic, originating from food proteins, undigested microbial nitrogen and endogenous nitrogen. Urinary nitrogen ($N_u$), which varies essentially with an excess or a disequilibrium in ingested protein, can be estimated by the difference between total excreted nitrogen and faecal nitrogen: $N_u$ ($g \cdot d^{-1}$) = $N_i - N_m - N_f$. In ruminants, increased excreta N may originate from excess of degradable N supply vs. microbial requirements or from excess or unbalanced amino acid supply vs. animal requirements. In both cases, this excess or disequilibrium is catabolised and leads to the production of urea that diffuses in the organism and is excreted in urine where it constitutes from 10 to 80% of urinary nitrogen ([13], Fig. 1).

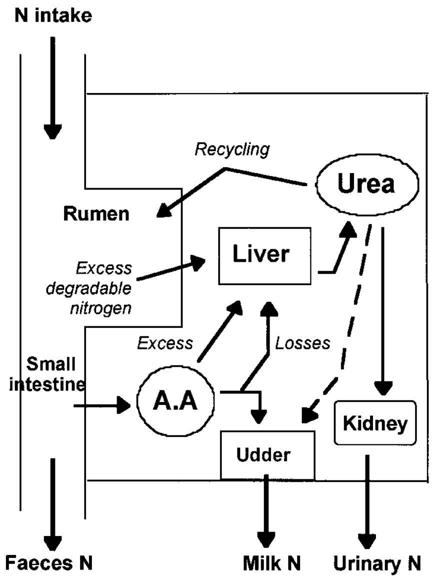


**Figure 1.** Scheme of nitrogen metabolims in the ruminants.

Nitrogen excess, and therefore excreta N, can be assessed using the PDI system used in France. It allows the calculation of the "rumen balance" (PDIN supply – PDIE supply) and the "animal balance" (PDI supply – PDI needs) which both determine the amount of N in excreta. The urea content of milk is another interesting criterion for estimating the amount of daily nitrogen excreted in urine or in the faeces [9].

Delaby et al. [4] described a method for calculating the principal factors of variation of excreted nitrogen in dairy cows, during the second annual meeting, "Rencontres autour des Recherches sur les Ruminants". When a dairy cow (7500 kg of milk) receives a diet composed of maize silage supplemented in UFL and PDI according to the INRAtion [12] program, it annually ingests 131 kg of nitrogen, 50% of which come from concentrates. With these conditions, 40 kg of nitrogen are exported to the milk and practically 70% of ingested nitrogen are restored in the excreta (that is 42 kg and

49 kg respectively in the faeces and urine). Therefore, there is 12.1 kg of excreted nitrogen per tonne of milk produced. With this type of balanced diet, a 1000 kg increase in milk yield per lactation results in an increase in the annual amounts of nitrogen waste (+3.3 kg of faecal N and +4.0 kg of urinary N); however, a decrease in excreted nitrogen per tonne of milk produced is observed due to a dilution of maintenance needs. With feeding that follows recommendations, excreted nitrogen therefore varies from 13.3 to 11.2 kg per tonne of milk between 6000 and 9000 kg of milk.

Nitrogen excretion depends largely on the amounts of nitrogen in the ration and therefore on the amounts in the following two constituents: forage and concentrates. These components vary with the forage system and its level of intensification, on the one hand, and with the supplementation strategy, on the other hand. For example, a diet based on grass silage (15% CP) for a milk production of 7500 kg per year corresponds annually to 153 kg of ingested nitrogen from which 38 and 75 kg are excreted in the faeces and urine respectively.

### 2.2. Practical assessment of annual N excretion

To easily estimate the total amount of N annually excreted by a cow according to various feeding systems a simple method was developed by Delaby et al. [4]. This method integrates the major types of diets given to dairy cows in France, and accounts for various durations over the year. It is based on a simulation of optimised protein supplementation, from which monthly excreted nitrogen is calculated either for indoor or grazing situations (Tab. I).

According to the length of each feeding period, nitrogen waste emitted indoors or directly in the paddock is determined by associating the three above forages. The annual results are presented in Table II. Increasing maize silage in the diet instead of medium or high-N grass silage decreases the total indoor restitution. The introduction of grazing causes an increase in total excreted nitrogen but with an important reduction in indoor excreta N.

It is possible, using a linear combination, to quantify the total annual restitution of a dairy herd as a function of time according to the different monthly feeding sequences of the year and by using different combinations of forages. The effect of the production level of a herd may be integrated assuming a variation in N excreta of 5% per 1000 kg of milk. In addition, in cases when feeding is composed of a mixed ration including grazing, the distribution of the excreta between indoor and the paddock may be fixed at 85/15 as long as the conserved forages represent less than 50% of the ration. They then become 65/35 with more than

**Table I.** Average excreted nitrogen of a dairy cow (6000 kg of milk) according to diet.

| Restitution | Forage CP ($g \cdot kg^{-1}$ DM) | Excretion / tons of milk (2) | Monthly excretion (2) | |
|---|---|---|---|---|
| | | | Indoor | Pasture |
| Diet | | | | |
| Maïze silage | 80 | 13.3 | 6.7 | |
| Grass silage | 120 | 15.0 | 7.5 | |
| | 150 | 18.2 | 9.1 | |
| Grazing (1) | 140 | 16.2 | 1.2 | 6.9 |
| | 180 | 22.4 | 1.7 | 9.5 |
| | 220 | 29.2 | 2.2 | 12.4 |

(1) Admitting 15% restitution during the indoor period (milking, ...); (2) kg N.

**Table II.** Effect of the forage system and its use on annual excreted nitrogen (kg) of a dairy cow (6 000 kg of milk).

| Restitution | Indoor | | | | | Pasture |
|---|---|---|---|---|---|---|
| Maïze silage (month) (1) | 0 | 3 | 6 | 9 | 12 | |
| Grazing (18% CP) | | | | | | |
| 0 (month) | 109 | 102 | 95 | 88 | 80 | 0 |
| 3 | 87 | 80 | 73 | 65 | | 29 |
| 6 | 65 | 58 | 50 | | | 57 |
| 9 | 43 | 35 | | | | 86 |

(1) The 12 month complement is composed of a diet of conserved grass (15% CP).

50% conserved forages, considering the time spent indoors.

Besides the differences due to forage systems and species, the level of N fertilisation and the physiological stage of the grass also influence CP content of the forage, and as a consequence, the daily amount of N excreted. At grazing, an increase of CP content from 18 to 22% will lead to a 30% increase in daily excreted nitrogen, of which most will be eliminated in the urine. An excess of degradable nitrogen (PDIN > PDIE) of 200 $g \cdot d^{-1}$ will lead to an increase of about 18 kg in annual excretion whereas an amino acid excess of 10% (PDI > needs) will increase excretion by 13 $kg \cdot g^{-1}$ [13], considering a moderate response for milk proteins [19].

## 3. PROTEIN FEEDING AND CONTROL OF PRODUCTIVE RESPONSES AND EXCRETION

Nitrogen excretion is therefore directly and principally related to the nitrogen intake that can be controlled via the forage used (nature and level of intensification: fertilisation rate and growth stage of the grass) and by protein supplementation. This last aspect is the easiest to technically control. However in practice the trend is often to increase the CP content of the diet sometimes far beyond the recommended allowances while expecting some positive effects on performances and dietary security and not accounting for extra cost and extra N waste.

For protein nutrition, in order to develop a balanced strategy between the favourable effects on performances and feeding efficiency and the unfavourable effects on nitrogen excretion, it is important to better understand the quantitative relations between nitrogen intake and its different effects. It is therefore useful to enrich the notion of needs and of nitrogen recommendations with their marginal response curves. In addition, this approach can be expanded to excretion and their relations to dairy performances.

### 3.1. Effect of degradable protein supply

Most generally, degradable nitrogen supplementation is entirely recovered in the urine and does not improve performances. This is true not only when degradable N supply is at or above requirements but also when it is slightly below requirements; the only exception is with a large PDIN deficit [19] but such an experimental situation rarely occurs in usual dairy farming. Our recent experiments confirmed that an 8% deficit in PDIN remains tolerable even for cows at peak yield. Other factors devoted to improving rumen activity, such as the ‘quality’ of the degraded nitrogen part (urea vs. totally degraded proteins), synchronisation of ruminally available energy and nitrogen and supplementation with particular additives, should sometimes improve animal performances at least in some particular experimental situations. They do not seem, however, to have a sensitive practical importance on N excretion with customary French dairy diets characterised by medium concentrate proportions.

### 3.2. Supply of metabolic protein (PDI) and changes in performances

On the contrary, the level of metabolisable protein supply (i.e. the PDI supply) has important effects on production, especially when the PDI supply is below the recommendations. It was previously shown [20, 21] that the level of milk production increases with PDI supply according to the laws of decreasing yield: in an iso-energetic situation, the marginal yield of an extra 100 g of PDI is on the average +0.5 kg of milk around the recommendations; it is twice this amount if the initial PDI supply is 15% deficient but it is almost null when there is an excess of 15%. In order to enlarge these response laws over a wider range of nutritional and productive situations and over a larger set of productive parameters, 5 experiments were recently performed at INRA-SRVL Rennes (Vérité, Faverdin and Delaby, unpublished). Different protein/energy ratios varying from 80 to 125 g PDI per UFL were tested on a total of 250 high producing cows ad libitum fed with maize silage and concentrate. Successive tests differed because of lactating stages (early vs. mid lactation), method of rationing (individual vs. complete diet) or extra feed and feed additives. The synthesis of the results obtained in mid-lactation presented below illustrates the response curves. The phenomena are globally similar at the beginning of lactation and were illustrated by Faverdin et al. [10]. During grazing, the same laws are obtained but the effects of protein supplementation are only really important for grass with low CP contents [5].

In all these trials, increases in the PDI/UFL ratio cause differences between the extreme levels which are often important not only for milk production (+4 to +7 kg) but also for the content (+1.5 to 2.2 $g \cdot kg^{-1}$) and quantity (+15% to +30%) of true milk proteins; fat secretion increases proportionately less since fat content tends to decrease (0 to –4 $g \cdot kg^{-1}$). An important positive effect on intake also exists (+1.0 to +3.0 kg DM); its role is central for the interpretation of other responses. The global feeding efficiency (kg $milk \cdot kg^{-1}$ DM) also results in an improvement (8 to 12%). On the contrary, energy balance is practically un-modified (neither positively, nor negatively), and the real bodyweight is not changed (except with the lowest PDI level). Of course, daily excreted nitrogen per animal is increased in the faeces (+6 to 15%) and especially in the urine (+60 to 85%).

In addition, the negative effects of the low nitrogen level tend to increase regularly over 3 months especially for milk production (Fig. 2) and intake. Classically in iso-energetic feeding, these effects stabilise after 2 to 4 weeks [18]. This cumulative phenomenon originates from the sustained evolution of intake probably directed by the sustained low nitrogen/energy ratio. However, despite the importance of the final differences (up to 12 kg of milk daily), there is no residual effect three weeks later.

### 3.3. Marginal responses curves

The response curves for the variation in PDI/UFL contents are shown in Figure 3 and the marginal effects in Table III. The milk, fat and protein production follow the law of decreasing yield as does the milk protein content and total DM intake. Near the recommendations, (100 g PDI per UFL) the marginal yields for a variation of 5 g in the PDI contents (that is approximately +100 g PDI per UFL per cow per day) are

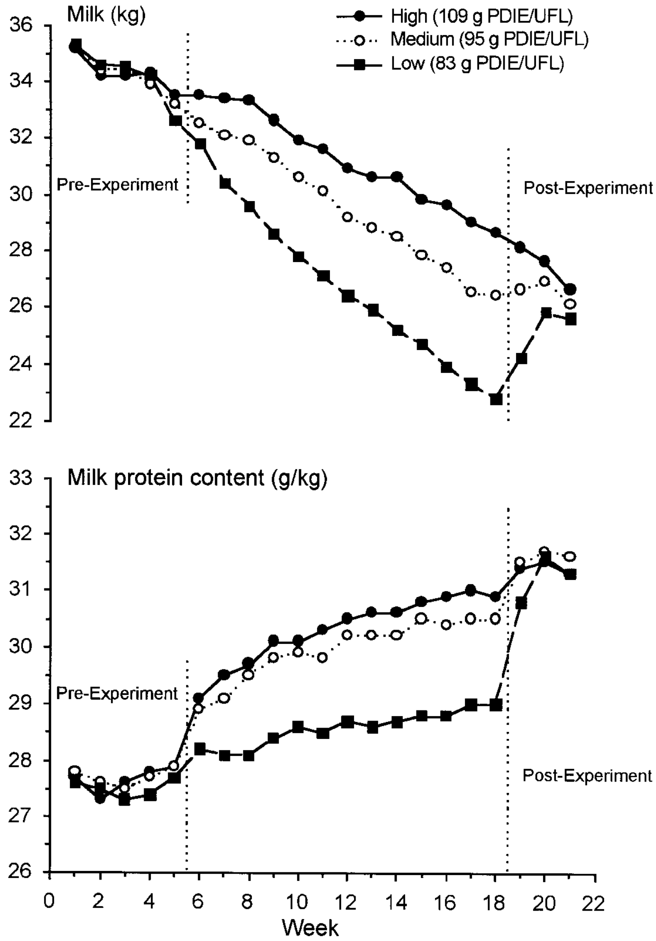


**Figure 2.** Weekly evolution of milk and milk protein content with PDIE/UFL levels in the diet (Average of three experiments – 159 cows).

+0.6 kg of milk, +0.2 points of protein content, +15 g of proteins for +0.25 kg of DM. These values are certainly not negligible but are moderate and close to those noted previously in a different context (iso-energetic ratio and animals with lower genetic merit). Above the recommendations, the effects become small. However, if one wants to feed a cow with rations below the recommendations in order to reduce N excretion, then the negative effects become rapidly important for most of these parameters: the marginal yield is doubled for a 10% PDI deficit and tripled for a 15% PDI deficit (Tab. III).

Curiously, the responses of production and ingestion with a same deficient PDI supply do not vary significantly with the milk potential of the animals (the decrease is only a little more important in high genetic merit cows when there is a strong deficit), nor with their intrinsic intake capacity. However, at the same milk potential, these responses will be more pronounced with diets rich in concentrates (40%) [10].

The responses of the different parameters to PDI level are interrelated. The responses of milk, fat, protein yields and protein content are linearly and positively

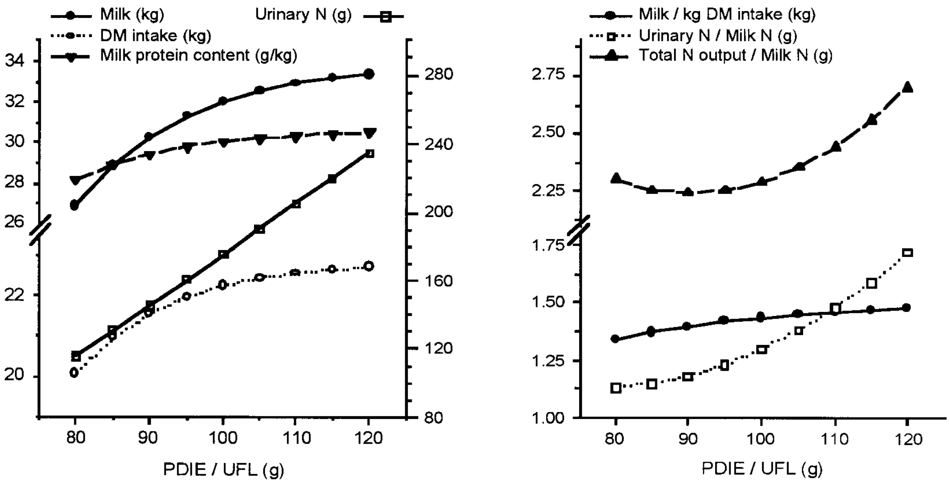


**Figure 3.** Responses to variations in PDIE/UFL ratio in the diet.

**Table III.** Marginal responses to a 5 g increase of PDIE/UFL ratio of the diet (Maïze silage/Concentrate 75/25 – 3 months).

| | Mean | | | | | | |
|---|---|---|---|---|---|---|---|
| PDIE/UFL | 100 | 85 → 90 | → 95 | → 100 | → 105 | → 110 | → 120 |
| PDIE/DM | 94 | 81 → 85 | → 89 | → 94 | → 99 | → 103 | → 107 |
| Total diet (kg DM) | 21.9 | 0.6 | 0.4 | 0.3 | 0.2 | 0.1 | 0.0 |
| Milk (kg) | 30.2 | 1.45 | 1.00 | 0.70 | 0.50 | 0.35 | 0.20 |
| Milk protein content (g·kg$^{-1}$) | 30.2 | 0.50 | 0.35 | 0.25 | 0.20 | 0.10 | 0.00 |
| Proteins (g) | 909 | 66 | 46 | 20 | 11 | 6 | 3 |
| Urinary N (g) | 170 | 15 | 15 | 15 | 15 | 15 | 15 |
| Global efficiency (kg milk·kg$^{-1}$ DM) | 1.43 | 0.030 | 0.020 | 0.015 | 0.010 | 0.009 | 0.008 |
| Urinary N / Milk N (g) | 1.15 | 0.02 | 0.03 | 0.05 | 0.07 | 0.08 | 0.10 |
| N output / Milk N (g) | 2.22 | – | – | 0.04 | 0.06 | 0.09 | 0.12 |

correlated amongst themselves as well as with the ingestion responses ($R^2$ between 0.6 and 0.8). Due to change in PDI concentration, a 1 kg DM intake variation corresponds to the variation, in the same trend, of 1.0 kg milk, 45 g fat, 41 g protein and 0.4 g·kg$^{-1}$ protein content. The change in energy intake may explain approximately half of these responses; the other half is directly explained by the intrinsic effect of protein nutrition.

The global feed efficiency, expressed in kg of milk produced per kg DM (or by UFL), increases linearly with the PDI contents of the rations until 100–105 g PDI per UFL but does not increase any more for greater ratios. This improvement arises totally from the dilution of the maintenance need within an increased production requirement.

### 3.4. Relationship between productive responses and N excretion

The efficiency of N utilisation (extra milk N per extra N intake) of supplementary PDI ranges between 30 and 60% at low PDI levels and between 15 and 25% at the recommended level and was almost null at 105–110 g PDI per UF. Nevertheless, over that range of the PDI/UFL ratio, the daily excretion of urinary N increases linearly with the PDI/UFL ratio at a rate of 30 g urinary N per cow per day for an increase of 10 g of the PDI/UFL ratio.

With increasing PDI supply, the responses in N excretion and in production performances are curvilinearly related as indicated by the urine N/milk N ratio (Fig. 3). Urinary N loss relative to milk N increases from 1.15 to 1.30 and 1.60 when PDIN supply covered respectively 85%, 100% and 115% of the recommended level (100 g PDI per UFL), with a degradable N supply at the 'rumen requirement'. Of course, this 'relative urinary N loss ratio' also depends on the level of milk production and on any PDIN excess: there is a 0.1 point increase when production decreases by 5 kg or when the rumen balance increases by 3 g (PDIN-PDI)/UFL. The same phenomena are even more clear when considering total nitrogen excretion. Further, it appears that relative N loss stays at a minimum plateau (2.3 in our situation) as long as the PDI/UFL ratio is below recommendation but increases rapidly for higher inputs.

The level of PDI supply is therefore an important way to control not only milk yield and composition but also ingestion and feed efficiency. It allows the modulation of the evolution of lactation in a flexible and reversible manner, that is without any residual effects. Someone proposed to reduce the PDI/UFL ratio in early lactation while expecting it would alleviate the problem of a negative energy balance by slowing the rise in milk yield; in fact the reverse would occur since ingestion is reduced proportionately. The average value of 100 g PDI per UFL or 94 g PDI·kg$^{-1}$ DM determined by the 1988 recommendations [19] really represents a critical threshold. This threshold could, however, be slightly higher for high concentrate diets. The reduction of nitrogen intake below this threshold rapidly brings about an important drop in performance whereas relative nitrogen losses do not practically decrease any more. On the contrary, an excess of PDI supply rapidly brings about an excess in N excretion that does not justify the low responses of production.

## 4. RESTITUTIONS OF NITROGEN ON THE GRAZING AREA

During grazing, the excreta are for the most part emitted directly on the paddock, separately between the dung and urine, on an active biomass. Their spatial distribution is very heterogeneous, which creates locally elevated contributions of nitrogen per m$^2$. The valorisation of this nitrogen by the biomass is a function of the growth potential of the plant but also of the temporal restitution dynamics with respect to the climatic and seasonal conditions.

The quantities of nitrogen that are returned directly on the pasture may be considered as the product of the daily N excretion per cow by the number of grazing days realised per hectare (GDha). The principal factors that contribute to the first parameter are identical to those mentioned previously: the level of milk yield, quantities of grass consumed and CP content and supplementation strategy (quantity, nature). The second parameter depends on pedoclimatic conditions (mineralisation, rainfall), production factors (fertilisation, legumes) and conditions of the use of produced biomass (stocking rate, harvest, supplementation).

Nitrogenous fertilisation is of major importance since it acts on both parameters through changes in yield and CP contents of grass.

### 4.1. Effect of level of N fertilisation

During the 1990s, many experiments led to the description of the effects of nitrogenous fertilisation on milk performances per cow or hectare [3]. Unfortunately, very few authors have been interested in the nitrogen excreta of the herd. The precise quantification of nitrogen excretion on the paddock over the grazing period is still very difficult since the values of nitrogen content and herbage intake are not available. Nevertheless, the estimation method proposed by Delaby et al. [6] including the animals annual performances and the chemical composition of the grass offered, allows the description of the effect of production factors such as fertilisation. Increased nitrogenous fertilisation leads to a systematic but variable increase in milk yield per hectare (Fig. 4) due to a linear increase in the number of grazing days realised (+0.8 to +0.9 d·kg$^{-1}$ N, [3]).

Indeed, in order to maintain the individual performances and to valorise the grass produced, it is imperative to control the daily herbage allowance. In these conditions, the amplitude of the response of milk yield per hectare under the influence of nitrogenous fertilisation will also depend on the milk potential of the particular herd. Experiments comparing 3 levels of nitrogenous fertilisation were performed on a permanent pasture at the Le Pin au Haras in Normandy for 5 consecutive years [3]. Increasing fertilisation from 0 to 120 and 300 kg N·ha$^{-1}$·y$^{-1}$ provides 456, 550 and 689 grazing days per hectare and 10 700, 12 600 and 16 050 kg of milk (FCM) respectively.

The effect of nitrogenous fertilisation on the total dairy cow excreta during grazing was quantified by Deenen [2] and Bussink [1] in the Netherlands and by our studies in Normandy [6]. The nitrogen excretion per hectare increases with the level of annual nitrogenous fertilisation applied (Fig. 5). In reference to the lowest level of fertilisation for each experiment, this increase reaches an average +58 kg of nitrogen per 100 kg of nitrogenous mineral applied on the pasture, 87% of which is associated to urinary

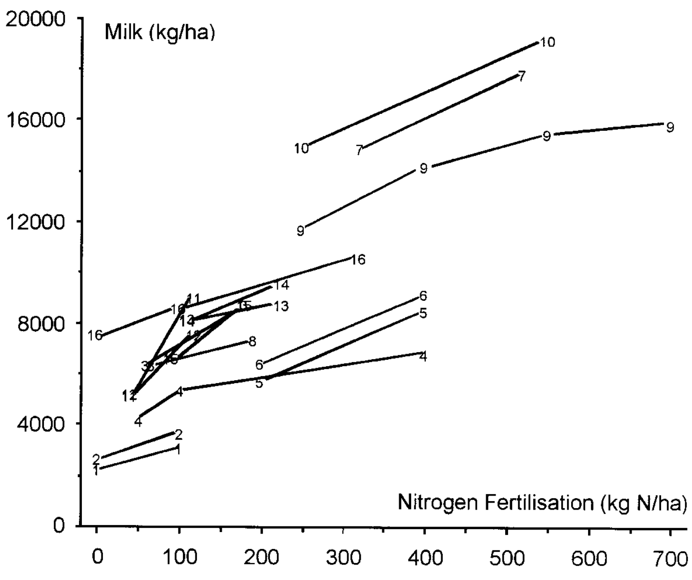


**Figure 4.** Annual nitrogen fertilisation and milk production per hectare (from Delaby and Peyraud [3]).

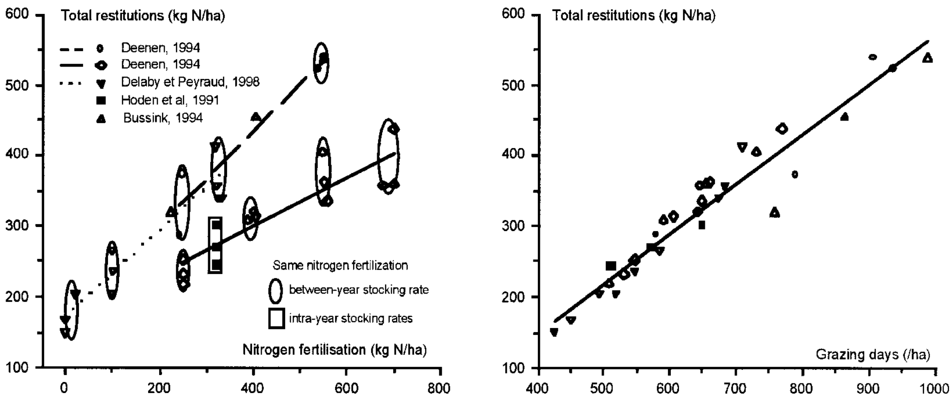


**Figure 5.** Effects of nitrogen fertilisation or grazing days on total nitrogen restitutions.

nitrogen. Expressed as a marginal yield, this increase of excretion seems to decrease with higher level of nitrogenous fertilisation notably in one experiment led by Deenen [2] This translates the lower efficiency of nitrogen on the grass growth for very high levels of fertilisation. For the same nitrogenous fertilisation level, many non-negligible variations exist for the different experimental sites and years due to pedoclimatic differences.

Indeed, the number of days of grazing is an excellent synthetic criterion to assess N excretion on the paddock, when the stocking rate varies with nitrogenous fertilisation while the individual performances and daily herbage intake are maintained (Fig. 5).

In other terms, when considering the paddock area on an annual basis, any increase in N fertilisation induces increases both in milk yield·ha$^{-1}$ and in excreta N·ha$^{-1}$ that are linearly related: +33 kg N excreted per 1 000 kg of milk per ha. Variations in N excretion with N fertilisation are also closely related to the number of grazing days (between 400 and 1 000 Gdha):

N urine (kg·ha$^{-1}$) = –136 + 0.585 × Gdha
($n$ = 28 – Syx = 31.5 – $R^2$ = 0.88)

N faeces (kg·ha$^{-1}$) = 5.4 + 0.116 × Gdha
($n$ = 28 – Syx = 6.7 – $R^2$ = 0.87).

In these conditions, the urinary nitrogen excretions increase five times faster than those of faecal origin. This more rapid increase probably originates from an increased CP content of grass and increased protein degradability.

### 4.2. Effect of stocking rate

Grazing and animal feeding managements are other factors that modify the level of N excretion per ha. The influence of stocking rate on milk production per hectare has been well described in the literature, notably for high levels of fertilisation. With a voluntary increase in stocking rate, the individual performances only decrease a little whereas the performances per hectare are generally increased [11]. From a recent bibliographic review, Delaby and Peyaud (unpublished) showed that there is an approximately 1500 kg milk production increase per hectare when there is a stocking rate increase of one cow per hectare; the response is lower if the reference stocking rate is high. The nitrogen excreta also vary with voluntary changes in the stocking rate and are directly associated with the number of grazing days realised. But the amplitude of the variations is then less important than

**Table IV.** Effect of annual stocking rate on nitrogen restitutions at grazing (from Hoden et al. [11]).

| Stocking rate (cow·ha$^{-1}$) | 4.7 | 5.3 | 6.0 |
|---|---|---|---|
| Grazing days (ha$^{-1}$) | 512 | 572 | 648 |
| Faecal N (kg N·ha$^{-1}$) | 67 | 74 | 82 |
| Urinary N (kg N·ha$^{-1}$) | 178 | 196 | 220 |
| Balance (kg N·ha$^{-1}$) | + 232 | + 225 | + 216 |

that described previously when the stocking rate was regulated by fertilisation. Data from Hoden et al. [11] comparing three stocking rates at a similar fertilisation level (300 kg N·ha$^{-1}$·y$^{-1}$) provide evidence for this (Tab. IV) .

For 100 extra days of grazing, urinary and faecal nitrogen excretion increase respectively from +30 and +10 kg·ha$^{-1}$. With the increase in stocking rate, stricto sensu, a better valorisation of grass is obtained and the nitrogen balance of the paddock [8] does not vary or improves only a little. Indeed, more N is exported outside of the paddock as milk and excreta whereas N input on the paddock remains constant or increases very slightly with some extra feed supplement. On the contrary, the internal flow increases since the herbage intake and the excreta per hectare increases with stocking rate.

Finally, in a given pedoclimatic context, the level of nitrogenous fertilisation determines the biomass and the amount of plant protein produced and therefore the number of grazing days and the level of nitrogen excretion per hectare. Management through voluntary changes in stocking rate has a modulating role. Total nitrogen excretion per hectare can be cut in half (141 against 287 kg N·ha$^{-1}$) when a reduction in nitrogenous fertilisation is enhanced by a further reduction in stocking rate [7]; although individual cows yield slightly more milk, the lower fertilised pasture produces much less milk per hectare (11300 against 17250 kg of milk).

### 4.3. Effect of feed supplementation

Feed supplementation (forages or concentrates) and its CP content change the number of grazing days, the performances and the excreta per hectare. The quantities of concentrate distributed during grazing are generally moderate and their consequences on nitrogen balance per hectare are minimal. With a concentrate efficiency of 0.8 kg of milk and a substitution rate of 0.5 kg of DM, the use of a concentrate based on cereals poor in CP (120 g·kg$^{-1}$ DM) has no consequence on the daily nitrogen excreta. If the total ingestion increases under the influence of supplementation, then, despite a high efficiency (+1.2 kg of milk·kg$^{-1}$ of concentrate), nitrogen excretion per cow increases but does not vary per kg of milk produced [14]. Finally only a substantial increase in the number of grazing days allowed by concentrate supplementation could significantly modify the restitutions per hectare.

On the contrary, the use of a concentrate rich in proteins increases the total quantities of ingested nitrogen of a herd and per hectare. Inevitably, with the same number of grazing days, nitrogen excretion is then increased by this intake of concentrate, as found by Soegaard and Aaes [15]. These authors observed during a complete grazing season (165 days), a 145 kg nitrogen per hectare increase in the restitutions by modifying the CP content of the concentrate from 143 to 315 g·kg$^{-1}$ CP (Tab. V). According to Delaby et al. [5], the use of protected meal compared to a concentrate based on cereals causes a +27 and +46 kg increase in nitrogen excretion respectively on graminae pasture fertilised with 20 or 60 kg N per hectare and per spring cycle (63 days). The importance of this increase depends very little on the marginal yield in terms of milk proteins, even if on low fertilised pastures, the zootechnical response is better. Most of the variation is due to the stocking rate difference induced by nitrogenous fertilisation (respectively 206 and

**Table V.** Effect of concentrate on annual nitrogen fluxes at grazing (from Soegaard and Aaes [15]).

| Type of grass | Rye Grass (300 kg N·ha$^{-1}$) | | Rye Grass + White Clover (0 kg N·ha$^{-1}$) | |
|---|---|---|---|---|
| Concentrate (kg N·ha$^{-1}$) | 117 | 250 | 117 | 250 |
| Grazing days (ha$^{-1}$) | 833 | 816 | 777 | 794 |
| Milk N (kg·ha$^{-1}$) | 117 | 121 | 111 | 116 |
| Faecal N (kg·ha$^{-1}$) | 100 | 99 | 92 | 95 |
| Urinary N (kg·ha$^{-1}$) | 199 | 354 | 231 | 366 |

312 days of grazing per hectare) which modifies the nitrogen associated with the concentrate consumed per hectare.

Supplementation with maize silage is an efficient way to reduce nitrogen excretion per day [17]. Supplemented cows always have lower total nitrogen intake and excreta N than cows fed grass alone [16], especially if the herbage allowance is limited. The variation between the two diets depends on the proportion of maize silage introduced in the ration. But the advantage is less obvious when considering the paddock instead of the individual cow. Indeed, use of maize silage at grazing transfers nitrogen from the maize area to the grass area via the animal excreta and furthermore it induces a higher stocking rate or a longer grazing season. As a consequence, the number of grazing days realised per hectare of grass area increases and the favourable effect of maize silage on the restitution per grazed hectare is thus highly lost. According to the results of Valk [16] and of Van Vuuren and Meijs [17], who reported a decrease in daily excretion respectively of 219 g N (594 g against 375 g) and 143 g (519 against 379 g) with a 50% maize silage, it seems that the interest of mixed rations is null if the number of grazing days increases by +58 and +38%. This important difference between the authors is essentially due to the variation in nitrogen intake by the cows fed grass alone (100 g·d$^{-1}$).

During grazing, the performances as well as nitrogen excretion per hectare will vary with the number of GDha, which are also under the necessary influence of nitrogenous fertilisation but also under the presence of legumes. The grazing management via stocking rate or energy supplementation, which also changes the number of grazing days realised per hectare, have more limited consequences on nitrogen restitution.

## 5. CONCLUSION

The quantities of nitrogen ingested by dairy cows simultaneously influence the performances and nitrogen restitutions in the excreta. But the importance of the observed variations, integrated as response laws, depends on the state of protein nutrition of the animal and of its rumen. Around the critical value of 100 g of PDI per UFL, the zootechnical consequences evolve differently. On the contrary, any excess in PDIN intake compared to PDIE systematically increases the excretions without modifying their performances. During grazing, N availability in the soil determines not only grass production level and grass CP content but also the number of grazing days. A significant reduction of nitrogen restitutions during grazing depends above all on the level of N fertilisation, on the proportion of legumes as well as on supplementation.

Finally, the control of protein nutrition allows to avoid excess situations which are biologically inefficient and can be harmful to the environment. However, the analysis of the agronomic utilisation of these dairy farm nitrogen masses is necessary in order to quantify the real risk of pollution by volatilisation or lixiviation.

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