CHAPTER 6

GRASSLAND MANAGEMENT WITH EMPHASIS ON NITROGEN FLOWS

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Abstract. This chapter deals with the challenge to reduce nitrogen (N) excretion and the amount of N able to leach under pasture. N inputs need to be adjusted while limiting adverse effects on animal nutrition and milk production per cow and per hectare. The chapter starts with discussing the origin and variation of N flow in dairy cows. N intake is divided into N exported in milk and N excreted in faeces and urine. Variation in N excretion is mainly due to urinary N and can be influenced by fertilization and nutrition management. At the animal level, lowering N fertilization improves the N utilization and N balance without greatly affecting the nutritive value of grasses. Only when the grass crude-protein content falls below 120 g kg^{-1} dry matter (DM), dry-matter intake and consequently animal performance may be reduced. The negative effects of lowering N fertilization on animal performance can be compensated by the inclusion of (white) clover in the sward, due to its higher intake and digestibility. Because of higher ruminal N losses, white clover may again increase the amount of N excreted, despite of higher milk yields per cow on mixed swards. At the paddock level, decreasing N fertilizer always reduces N surplus and the risk of nitrate leaching, because N input is reduced to a far greater extent than the N exported to milk. Replacing high N fertilization by grass–clover mixtures also has the potential to reduce N surplus and nitrate leaching, but to avoid high levels of N_2 fixation, the clover content should not exceed 0.3 to 0.4 of sward DM. Increasing the stocking rate for a given level of N fertilization only marginally reduces N surplus per ha. Supplementation with either cereal-based concentrates or maize silage reduces the N excretion per cow, but because it enables an increased stocking rate it may increase the N surplus per ha.

Keywords: dairy cows; grazing; N fertilization; N excretion; supplementation; clover; nitrate leaching

INTRODUCTION

In the last decades, intensive animal production systems have been encouraged. However, such systems generate a considerable excess of nitrogen (N), of which it is now well established that it causes environmental risks, notably effects on the nitrate content of water resources and on the emission of nitrogenous gases into the atmosphere. This increased concern about the effects of intensive animal production systems on the natural environment is likely to lead to the development of new grazing systems. This trend is also supported by recent changes in agricultural policy and the changing economic conditions of dairy production within the

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European Union, through the attempts to achieve low-input – lower-output systems.

Reducing the N excretion from individual cows is today unanimously recognized as one way to cope better with the problem of the negative contribution of the dairy herd to the N cycle on a farm. However, the consequences of the choice to reduce harmful emissions should be analysed and integrated on the animal performance level as well as on the paddock and farm levels. In intensive dairy farming there is a high use of N fertilizer, or/and large amounts of N_2 can be fixed when clover/grass pastures are grazed. Moreover, during grazing the excreta are for the greatest part emitted directly on an active sward biomass. The quantities of N that are returned directly to the pasture depend on the daily excretion per cow, but also on the stocking rate and the length of the grazing season.

From the animal production point of view, the challenge will be to reduce N excretion by adjusting N inputs while limiting the adverse effects on animal nutrition and milk production per cow and per hectare. Nitrogen fertilization is of major importance, as it contributes significantly to grassland productivity in temperate regions (Journet and Demarquilly 1979; Leaver 1985). The supply of concentrate feeds has also important effects on production and may further increase N excretion per cow. After reviewing flows and excretion of N in dairy cows, the objective of this paper is to examine the role of N in its major inputs (i.e. fertilizer and supplements) on dairy cow nutrition, milk yield and N restitution per cow and per hectare, resulting from adjustments of grazing management or alternative strategies such as the utilization of legumes.

N FLOW IN DAIRY COWS: ORIGIN AND RANGE OF VARIATION

In dairy cows, the quantities of N excreted (g d^{-1}) can be calculated from the difference between N intake (N_i) and N exported in milk (N_m), because N retained in the body is negligible. N excreted in faeces (g d^{-1}) originates from truly indigestible food protein, undigested microbial N and endogenous N. Apparently indigestible N is only weakly dependent on the N content of forage (Demarquilly et al. 1981). For most diets fed to dairy cows, faecal N is directly related to the total dry-matter intake (DMI) and averages 7.2 g N kg^{-1} DMI (Peyraud et al. 1995). Indeed the slope slightly increases (up to 8.0) when cows are fed grass having a very high N content. Moreover, faecal N is predominantly in a slowly soluble organic form of which only a small proportion is able to leach or can be volatilized (Decau et al. 1997). On the contrary, N excreted in urine (N_u, g d^{-1}) is directly affected by the level and composition of the ingested protein. Increases in urinary N may originate from an excess of rumen-degradable N vs. rumen microbial requirements or from an excess or unbalanced amino-acid supply vs. cow requirements. Both lead to the production of urea that diffuses in the organism and is ultimately excreted in the urine, where it constitutes 10 to 80 % of urinary N (Peyraud et al. 1995). Urea-N is rapidly converted to ammonia (NH_3) and easily volatilized or leached. N_u (g d^{-1}) can be estimated as g N intake – g N in milk – 7.2 kg d^{-1} DMI.

Using the French feeding systems (Jarrige 1989) and the previous formula, Delaby et al. (1995) and Peyraud et al. (1995) have calculated the variation in annual

N excretion (Table 1). A cow (7500 kg milk yr^{-1}) fed a well balanced maize-silage-based diet ingests annually 131 kg of N, 50 % of which comes from concentrates. The same cow excretes 42 kg of N in faeces and 49 kg in urine. The amount of N excreted in faeces and urine equals 70 % of N intake, the equivalent of 12.2 kg of N/ton of milk. With the same diet, the N excretion per ton of milk decreases from 13.2 to 11.2 kg when the milk yield increases from 6000 to 9000 kg, due to a dilution of the maintenance requirements. However, the consequences at farm level are difficult to extrapolate because the total N excretion per cow increases (from 80 to 101 kg) with the milk yield, as does the N excretion per ha of forage grown on the farm, because the extra milk is mainly produced with purchased concentrate. Moreover, as Table 1 shows, the effect of changing the potential of the cow is rather limited compared to the effect of changes in the forage system.

***Table 1**. Effect of type of forage on N balance of a cow producing 7500 kg of milk and fed a constant diet throughout the year, based either on maize silage or on grass. The cow is fed according to the French systems (Jarrige 1989)*

	Maize silage	Grass	Grass highly fertilized
Forage crude protein content (% DM)	8	15	22
N inputs: total (kg N)	131	153	215
as forage	65	104	208
as concentrate	66	49	7
N outputs : Milk	40	40	40
Faeces	42	38	43
Urine	49	75	132
Faeces + urine (kg t^{-1} milk)	12.2	15.1	23.3

The amount of N excreted increases when cows are fed a grass-silage-based diet (15 % CP) compared to a maize-silage-based diet. This higher N excretion cannot directly be translated to a higher level of N losses at the farm scale because N exported per ha is higher for grass than for maize (Peyraud et al. 1995) and the grass-based diet requires less N from purchased feed. However, N excretion increases dramatically with the level of CP in grass and this can lead to huge losses at the farm scale, as stocking rate will also increase.

The effect of the type of supplementation on N excretion depends on the difference between the CP content in forage and concentrate. This is illustrated in Table 2 for a cow fed fresh grass (CP=180 g kg^{-1} DM; 18 kg DMI, 20 kg milk d^{-1}) that is supplemented with either 4 kg of a cereals-based concentrate (CP=120 g kg^{-1} DM) or a mixture of cereals and soybean meal (CP=250 g kg^{-1} DM). Under these conditions, the substitution rate (kg forage DM kg^{-1} concentrate) and milk response to concentrate (kg milk kg^{-1} of concentrate) do not vary significantly (Peyraud and Delaby 2001). The substitution rate averages 0.5, the milk response is 0.9 and the protein content of milk increases by 0.2 g kg^{-1} per kg concentrate. The use of a cereal-based concentrate has no consequence for the daily N excretion but reduces the N excretion per unit of milk produced, since the milk response is high. The use of a protein-rich concentrate inevitably increases N excretion per cow and per kg of milk produced, despite the milk response.

The N excretion also depends of the feeding practice. Using safety margins will sharply increase the amount of N excreted. For example, a 10-% increase of the protein supply as PDIE above the cow's PDI requirements will increase the amount of N excreted by 13 kg yr^{-1} whereas a 10-% excess of rumen-degradable N (PDIN) will lead to an 18 kg yr^{-1} increase in N excreted (Peyraud et al. 1995).

Table 2. *Simulation of the effect of amounts of concentrate fed on the N balance of a cow producing 20 kg milk d^{-1} before being supplemented.*

Concentrate CP content (g kg^{-1} DM)	No concentrate	Concentrate 120	Concentrate 250
Grass intake (kg d^{-1})	18.0	16.0	16.0
Milk (kg d^{-1})	20	23.5	23.5
N intake (g d^{-1})	518	538	621
Milk N	102	123	123
N excreted (g d^{-1})	416	415	498
(g kg^{-1} milk)	20.8	17.6	21.2

EFFECTS OF N FERTILIZATION LEVEL AND SUBSTITUTION OF INORGANIC FERTILIZER-N BY FORAGE LEGUMES ON DAIRY-COW PERFORMANCE

Nowadays, the increased concern about effects of intensive grazing systems on the natural environment may lead to a reduction in the level of N fertilization on grassland. Owing to its major effects on the N content of grass and on stocking rate, it is remarkable that only few studies have so far addressed the impact of N fertilization of herbage on ruminant nutrition and grazing management. Increased use of forage legumes also offers some potential to alleviate the environmental problems.

Lowering N fertilization hardly affects the nutritive value of grasses

For grass species harvested at the same age, a reduction in N fertilization has little effect on the measured OM digestibility. On average, the OM digestibility decreased from 0.74 to 0.72 when reducing N fertilization between 300 and 400 kg N ha^{-1} per yr to less than 100 kg N ha^{-1} per yr, as summarized by Peyraud and Astigarraga (1998). This variation was seen under grazing on perennial-ryegrass swards (Peyraud 1993; Delagarde et al. 1997) as well as on permanent grass pastures (Peyraud and Delaby 1992). Reducing N fertilization results in a sharp decrease in grass CP content (Blaser 1964; Demarquilly 1977), but at the same time increases the content of water-soluble carbohydrates (WSC) (Reid 1966; Reid and Strachan 1974; Wilman and Wright 1978; Valk et al. 1996; Astigarraga et al. 2002), which are totally digestible. A decline in CP content of 10 g kg^{-1} DM is accompanied by a rise of 8 to 10 g kg^{-1} DM in the WSC. The increase in WSC is attributed to a decrease in the utilization of carbon chains for protein synthesis and for the production of the energy required for nitrate reduction prior to protein synthesis.

The true protein value of forage (metabolizable protein, MP) diminishes slightly with the level of fertilization. The studies published so far (Hagemeister et al. 1976; Van Vuuren et al. 1992; Peyraud et al. 1997; Delagarde et al. 1997; Réarte et al. 2003, see also Figure 1) show that reduced levels of N fertilization cause a small (i.e. 5 % on average) decrease in the amount of non-ammonia N entering the intestine, despite a much lower CP content in less fertilized grass. Indeed, the efficiency of microbial protein synthesis and the microbial N flow to the intestine vary little as a function of N fertilization. The soluble carbohydrates, which are present in larger amounts in less fertilized forage, may represent a favourable energy substrate for microbial protein synthesis. Furthermore, a reduction in N fertilization causes only a moderate decrease in the N flow to the duodenum. This can be explained by the fact that the CP of fresh forage is readily and extensively degraded in the rumen (Beever et al. 1986; Peyraud 1993), so the duodenal N flow as proportion of N intake is always low in animals fed on fresh grass. Moreover, a reduction in N fertilization from high levels (i.e. 400 kg N ha^{-1} per year or even more) to less than 100 kg N ha^{-1} per year decreases the theoretical rumen-degradability of plant protein from 0.75 to 0.70 (Peyraud and Astigarraga 1998). Therefore the MP supply, calculated according to the French PDI system (Vérité and Peyraud 1989), decreased by only 5 g kg^{-1} DM for a decrease of 50 g kg^{-1} DM in CP content in the fresh grass.

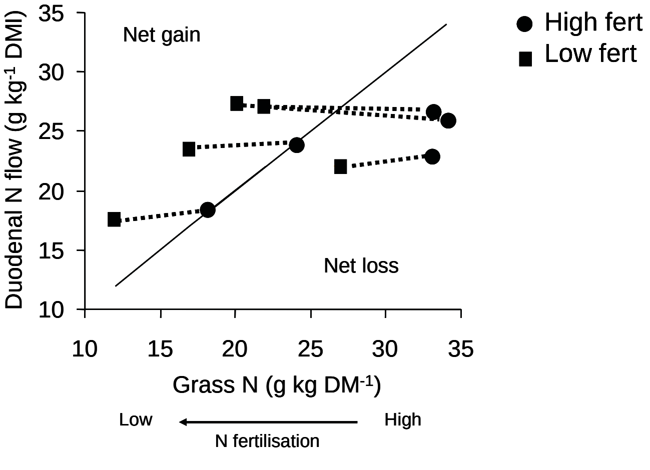

***Figure 1**. Effect of lowering N fertilization on ruminal N metabolism in dairy cows fed fresh forages (adapted from Hagemeister et al. 1976; Van Vuuren et al. 1992; Peyraud et al. 1997; Delagarde et al. 1997; Réarte et al. 2003)*

Lowering N fertilization reduces dry-matter intake and milk yield only when severe grazing conditions are imposed

On average, a reduced N fertilization has no effect on the quantity of dry matter voluntarily ingested by stall-fed sheep, as long as the forage is collected at the same age of regrowth (Peyraud and Astigarraga 1998). Similar data have been obtained in dairy cows fed perennial ryegrass indoors (Van Vuuren et al. 1992; Peyraud et al. 1997). However, under extreme conditions, N fertilization can affect the amount of forage that is voluntarily ingested. Voluntary intake of less fertilized forage could be depressed when low levels of fertilization lead to a drastic decrease in the protein content of grass. This is well illustrated by Minson (1973), who reported a decrease in both forage intake and forage digestibility with unfertilized tropical forages having a CP content below 80 g kg^{-1} DM. At the opposite end of the scale, a very high level of N fertilization led to a decrease of 20 to 50 g DM kg^{-1} fresh forage (Demarquilly 1977) and this may also decrease voluntary intake, since a low DM content reduces intake (Cabrera Estrada et al. 2004) of fresh forage. This is illustrated in the study of Van Vuuren et al. (1992), showing a 3.5 kg d^{-1} decrease in DM intake with highly fertilized grass (500 vs 250 kg of N ha^{-1}) as the DM content dropped from 218 to 138 g kg^{-1} in response to the increased N fertilization.

At grazing, lowering the N fertilization can also reduce daily intake when severe grazing conditions are imposed. This was recently studied at Rennes with dairy cows producing more than 25 kg of milk (Table 3). Herbage allowances were similar at both levels of fertilization. This was achieved by increasing the offered area to compensate for a lower sward mass on the lower-fertilized sward. Despite this precaution, contrasting results were observed. In trial 1, herbage DM intake was not affected by reducing N fertilization whereas it was reduced by 2.6 kg d^{-1} in trial 2. In trial 1, herbage allowance was high and cows were able to graze upper horizons having a higher CP content than the deeper horizons (Delagarde et al. 2000). Upper horizons are more easily harvestable than deep horizons. In this case the cows selected grass with a CP content higher than 150 g kg^{-1} DM, even on unfertilized swards. In contrast, in trial 2, with a lower herbage allowance, the cows were forced to graze deeper horizons and selected grass with quite a low CP content on the

Table 3*. Effect of the level of N fertilization on herbage intake at grazing; adapted from Astigarraga et al. (2002) – trial 1 and Delagarde et al. (1997) – trial 2*

	Trial 1		Trial 2	
N fertilization (kg ha^{-1} per cycle)	0	60	0	60
Herbage mass (t DM ha^{-1})*	3.9	4.8	1.9	2.6
CP content of offered grass (g kg^{-1} DM)*	113	151	106	173
Herbage allowance (kg OM d^{-1})*	26.6		20.7	
Offered green-leaf mass (kg OM d^{-1})	19.2	21.0	18.0	20.5
Herbage intake (kg OM d^{-1})	16.2	16.2	13.0	15.6
CP content of ingested grass (g kg^{-1} DM)	151	180	130	205

* Herbage cut with motor scythe at 5 cm

unfertilized sward. The detrimental effect of a low CP content on intake was further confirmed in trial 2 by showing that herbage DM intake increased by 1.8 kg d^{-1} in dairy cows grazing on low-fertilized swards and supplemented with 2 kg of rumen-protected soybean meal.

Milk yield should not be affected when reducing the N fertilization level, as the nutritive value of grass is not greatly reduced. Delaby et al. (1998) summarized thirteen long-term grazing experiments conducted in western-European countries, where both N fertilization and stocking rate were reduced in such a way that the amount of grass offered to the cows and the age of regrowth were similar at both fertilization levels. The results clearly showed that on low-fertilized swards the milk yield per cow did not decrease during the experiments. However, for the same reduction in N fertilization, the effects may vary according to the local agro-climatic conditions. Studies conducted in France (Table 4) have shown that on deep and rich soils (8 % OM, Normandy), reducing N fertilization from 320 kg ha^{-1} yr^{-1} to almost nil did not affect milk yield, provided the CP content of the unfertilized swards remained higher than 15 % in the DM (Delaby et al. 1998).

***Table 4**. Effect of level of N fertilization on milk yield in dairy cows grazing on swards with the same age of regrowth; adapted from Delaby et al. (1996) – trials 1 and 2 and Delaby et al. (1998) – trial 3*

	Trial 1		Trial 2		Trial 3	
N fertilization (kg ha^{-1} per cycle)	0	60	0	60	0	60
Soil OM (%)	2		2		8	
Herbage allowance (kg OM d^{-1})	17.2		26.8	20.0	18.0	
Grass CP content (g kg^{-1} DM)	105	172	121	187	152	220
Milk yield (kg d^{-1})	23.1	25.7	26.0	26.4	27.3	27.5
Allowance (kg CP d^{-1})	1.9	2.8	3.2	3.8	3.3	4.7

On the contrary, with soils having a low N-supplying capacity (2 % OM, Rennes, Britanny), the same reduction in N fertilization led to a decline in milk yield (2.5 kg d^{-1}) and in herbage intake (2 kg OM d^{-1}) while the CP content in the grass fell below 120 g kg^{-1} DM (Delaby et al. 1996). Reduced herbage intake is then mostly mediated through a reduction in DM intake as a consequence of a low CP content (see Table 2). Taking all data together, to maintain individual milk yield, it appears to be necessary to offer at least 3 kg d^{-1} of CP (herbage allowance x CP content) from grass. For lower allowances, individual milk yield can be maintained by feeding protein-rich concentrates.

Lowering N fertilization always improves the N balance at the animal level

N balance measurements indicate a marked reduction of the amount of N excreted via urine and only a slight reduction of N excreted in faeces, in the case of lowering the levels of grass fertilization. This has been observed in studies with stall-fed sheep (Demarquilly 1977) and dairy cows fed indoors or at grazing (Table 5).

***Table 5**. Effect of the level of N fertilization on the N balance in stall-fed and grazing dairy cows; adapted from Peyraud et al. (1997) – trial 1, Astigarraga et al. (2002) – trial 2 and Delagarde et al. (1997) – trial 3*

	Trial 1		Trial 2		Trial 3	
N fertilization (kg ha^{-1} per yr)	60	300	60	300	0	250
N in grass (g kg^{-1} DM intake)	17.0	24.0	23.8	28.3	21.6	33.8
N in milk (g kg^{-1} DM intake)	6.0	6.0	6.1	6.1	7.0	6.9
N in faeces (g kg^{-1} DM intake)	6.0	6.1	6.1	6.3	6.7	6.9
N in urine (g kg^{-1} DM intake)	5.0	11.9	11.6	15.9	7.9	20.1

The difference in N excretion via urine is fully explained by the variation in urea-N excretion (Peyraud et al. 1997; Réarte et al. 2003). The digestion of CP in highly fertilized grass (more general in N-rich grass) is characterized by substantial losses of N between mouth and duodenum (Beever et al. 1986; Peyraud 1993). This leads to high rumen ammonia losses, and thus to increasing urinary urea N loss. On low-fertilized swards, the reduced excretion of urinary-N is primarily attributable to a decrease of N losses in the rumen. The intestinal N flow can become much greater than the total N ingested, thus reflecting that a considerable reflux of N to the rumen is possible. The amount of recycled N can represent a gain of up to 5-6 g N kg^{-1} DM, that is 30 to 40 % of the total N ingested (Peyraud et al. 1997; Réarte et al. 2003) (see also Figure 1).

White clover has potential to increase animal performance but may increase the amount of N excreted compared to fertilized grass

In temperate grasslands, white clover is by far the predominant forage legume. The nutritional advantage of white clover over grasses is well established (Thomson 1984; Jarrige 1989). A series of experiments conducted in Rennes with fistulated dairy cows (Peyraud 1993, and unpublished) has shown that white clover increases OM digestibility (0.80 vs 0.78) and the amount of non-ammonia N entering the intestine (28.9 vs 24.3 g kg^{-1} DM intake) compared to ryegrass. With white clover, both the efficiency of microbial protein synthesis in the rumen and the duodenal N flow are increased. Indeed, digestibility and N flow entering the intestine in cows fed ryegrass can reach values as high as those reported when cows eat white clover (Peyraud 1993), but one of the advantages of white clover in a mixed sward is that it maintains its high quality throughout the plant-ageing process. The digestibility of pure white clover and that of a mixed sward decrease very slowly with advancing age. Peyraud (1993) and Delaby and Peccatte (2003) reported a digestibility higher than 0.75 after 7 weeks of regrowth or at flowering stage during the first growing cycle.

The voluntary intake of legumes is greater than that of grasses of similar digestibility (Jarrige 1989), mainly because legumes have a lower resistance to chewing and a higher rate of particles breakdown and digestion in the rumen (Steg et al. 1994). In a grazing situation, herbage intake is markedly higher with pure legumes relative to pure grass swards (Alder and Minson 1963), and the beneficial effects of legumes on animal intake and performance with a mixed ryegrass / white-clover sward have been demonstrated by Wilkins et al. (1994), the difference increasing with the clover content. In studies conducted in Rennes (Ribeiro-Filho et al. 2003; 2005) on mixed swards, the DM intake and milk yield (on average 1.5 kg d^{-1}) steadily increased irrespective of the level of herbage allowance. The differences were even larger when the regrowth interval was increased from 29 to 35 days. Therefore, from a nutritional point of view, ryegrass / white clover swards should seriously be considered as an alternative to pure grass swards, with the expected concomitant reduction in the use of N fertilizer.

However, white clover increased the N excretion relative to ryegrass from 20.1 to 29.8 g kg^{-1} DM intake (Peyraud unpublished), mainly because ruminal N losses are much higher with white clover than with grass, due to its high N content compared to ryegrass (38.7 vs 26.1 g kg^{-1} DM). The duodenal N flow averaged 75 % of the N intake when feeding white clover, while it averaged 93 % when feeding ryegrass. From the data of Ribeiro-Filho et al. (2005) it could be calculated that at grazing on mixed swards compared to ryegrass swards, the N excretion increased from 17.0 to 20.7 g kg^{-1} milk, despite the higher N output in milk.

FACTORS AFFECTING PERFORMANCES AND N SURPLUS PER HECTARE

Milk yield and the quantities of N excreted per grazed hectare can be expressed as the product of daily milk yield or daily N excretion per cow and the number of grazing days per hectare (GD), where GD represents the number of daily rations realized per hectare over the grazing season. The N surplus at the paddock level (Figure 2) can be calculated as proposed by Farrugia et al. (1997). This surplus takes account of total N inputs on the field (i.e. fertilizer, concentrate, symbiotic fixation, atmospheric deposition), and total N outputs (i.e. milk, harvested forages and transfer of N from the paddock to the lanes and milking shed via excreta).

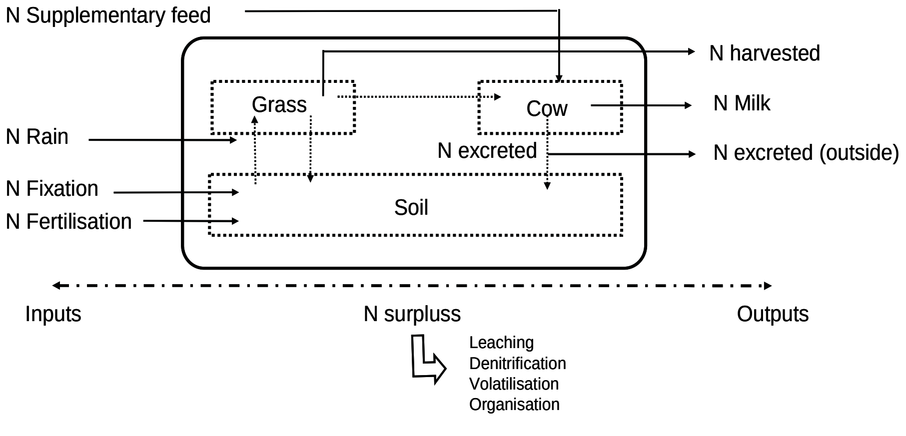

***Figure 2**. Inside and outside N flows at the paddock scale*

The transfer of N from the paddock to the lanes and milking shed via cow excreta corresponds to a removal from the pasture of 15 % (Ledgard et al. 1999) to 20 % (Delaby et al. 1997) of the N excreted. The internal N flows are not taken into account in the calculation of the N surplus at paddock level. These internal flows correspond to N produced in grass and grazed by the cows, N excreted on the field and N disappearing from herbage to litter. The overall N efficiency at the paddock level is largely driven by N inputs (mainly N fertilizer and symbiotic N fixation), and is only moderately affected by the efficiency of feed N utilization by the herd. This is presented in this section.

Lowering N fertilization reduces N surplus at the expense of milk yield

N fertilization is of major importance as it affects both animal performance (see above) and grass yield. Grass swards show average responses ranging from 5 (Peel and Matkin 1984) to 15 (Reid 1978) kg DM kg^{-1} N applied. This large range of responses can partly be explained by local agro-climatic conditions, grass species and level of N applied. In our own studies, the response fell from 25 to 10 kg DM kg^{-1} N when N fertilization was increased from 100 kg N ha^{-1} to 300 kg ha^{-1}. From their comprehensive review of the literature, Delaby et al. (1998) have reported that decreased N fertilization leads to a systematic decrease in milk yield per hectare, mostly due to a linear decrease in the number of grazing days (GD), since milk yield per cow was hardly affected. The mean slope is 87 GD ha^{-1} per 100 kg N ha^{-1} applied per yr, corresponding to 1375 kg milk per 100 kg N ha^{-1} per yr. This equals 1580 kg milk for a shift of 100 GD in response to N fertilization, at a mean milk yield of 15.8 kg d^{-1} in the data base (Figure 3). This milk response may be higher with high-producing cows, because in our study, milk yield increased by 2290 kg ha^{-1} per 100 GD for cows producing 30 kg milk at turnout.

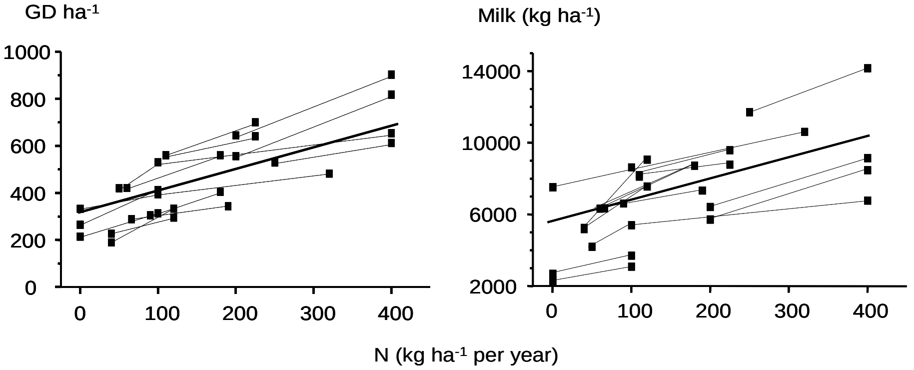

***Figure 3**. Effect of annual N fertilization on the number of grazing days (GD) and milk yield par hectare; adapted from Delaby et al. (1998)*

The effect of N fertilization on the total N excretion during grazing was quantified by Deenen (1994) and Bussink (1994) in the Netherlands, and by our own study in Normandy (Delaby et al. 1998). The total N excretion per ha increased with the level of N fertilization applied. This increase reached on average 58 kg of N for an extra 100 kg N ha^{-1}. However, for the same N fertilization level, non-negligible variations may exist for the different experimental sites and years due to local agro-climatic conditions. The number of grazing days appears to be an excellent synthetic criterion to assess N excretion, when the stocking rate varies with N fertilization (Figure 4). N excretion increases linearly with GD. The mean slope is 70 kg of N per 100 GD, 85 % of which is associated with urinary N. This response is very high and more rapid than that reported for milk yield. Any decrease in N fertilization induces both a decrease in milk yield and in N excretion, but the relative response is more rapid for N excreted. Therefore the amount of N excreted per unit of milk produced declined sharply (see Table 6, trial 2).

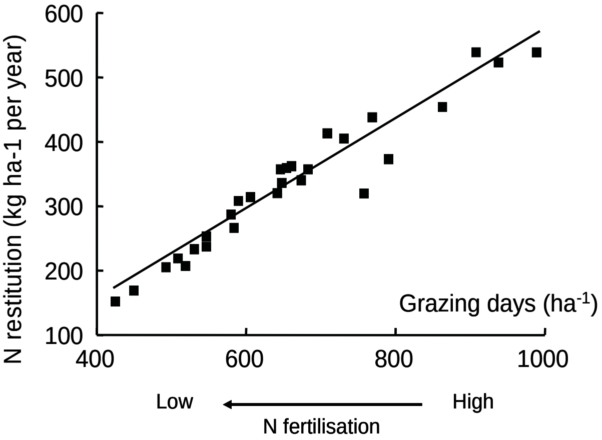

Figure 4. *Relation between the number of grazing days (ha^{-1}) and total N excretion when N fertilization is changed; adapted from Deenen (1994), Bussink (1994) and Delaby et al. (1998)*

The effect of lowering the N fertilization on the N surplus at paddock level has been quantified by Delaby et al. (1998, see trial 2 in Table 2). N surplus is always sharply improved because the N fertilizer input is reduced to a far greater extent than the N exported with milk. Ledgard et al. (1999), in a three-year experiment comparing 0 kg N with 3.3 cow ha^{-1} and 400 kg N with 4.4 cow ha^{-1}, also showed that fertilizer N inputs resulted in only a small increase in N removal in animal products (+ 42 kg ha^{-1}) relative to the amount of N applied. When lowering N fertilization, the internal N flows decrease, since N intake and N excreted decrease in response to a lower stocking rate and to a lower grass N content.

***Table 6**. Effect of stocking rate associated or not with variation in N fertilization level on milk yield, N restitutions and N surplus at the paddock scale; adapted from Hoden et al. (1991) – trial 1 and Delaby and Peyraud (1998) – trial 2*

	Trial 1			Trial 2		
Stocking rate	3.7	4.1	4.6	3.3	4.0	5.1
Grazing days (ha^{-1})	512	572	648	456	550	689
N fertilization (kg ha^{-1})	300	300	300	7	100	320
Milk N (kg ha^{-1})	56	61	67	56	66	83
N excreted: Faecal N (kg ha^{-1}) (1)	67	74	82	62	74	92
Urinary N (kg ha^{-1}) (1)	178	196	220	113	161	277
Total (kg t^{-1} milk) (1)	22.5	22.6	23.1	16.3	18.6	23.0
Paddock N surplus (kg ha^{-1}) (2)	242	235	226	7	93	272

(1) From which 20% are excreted outside the paddock

(2): calculated as N fertilization + N concentrate + N deposition + N fixation – N milk – N transferred form the paddock to the lanes and milking shed - N harvested in grass

Increasing stocking rate increases milk yield and marginally reduces N surplus

For a fixed level of N fertilization, grazing management is another factor that may affect milk yield and level of N restitution per hectare. The influence of stocking rate on milk production per hectare has been well described in the literature, notably for high levels of fertilization. To quantify the role of stocking rate on milk yield, Delaby and Peyraud (unpublished) reviewed 30 responses covering a large range of variations in stocking rates (from + 0.3 to + 2.5 cow ha^{-1} within experiments), with stocking rates varying from 1.1 to 5.5 cow ha^{-1}. The addition of one unit in the stocking rate (i.e.: add one cow ha^{-1}) marginally decreased the milk yield per cow by only 1 kg d^{-1} (i.e. 7 %), but increased the milk yield by approximately 1500 kg ha^{-1}. This response tended to decrease with higher reference stocking rates.

The total N excretion increases with a higher stocking rate. Variation is directly associated with the number of GD, as N excretion per cow does not vary to a large extent as long as the N content of the forage is not modified. It should be stressed that the amplitude of the variation of total N excreted is less important than that described previously, when the stocking rate was regulated by N fertilization. Data from Hoden et al. (1991), comparing three stocking rates at a similar fertilization level (300 kg N ha^{-1} per yr), and data from Delaby et al. (1998), comparing three stocking rates with different levels of fertilization in the same experimental farm, provide evidence for this (Table 6). For 100 extra GD, the total N excretion increased from + 42 kg N ha^{-1} (74 % of which was associated with urinary N) in trial 1 to + 83 kg N ha^{-1} (85 % of which was associated with urinary N) in trial 2.

With the increase in stocking rate (trial 1), a better valorization of grass is obtained as more N is exported in milk (+ 11 kg N ha^{-1}). However the N surplus at the paddock level does not vary or is only slightly improved. The extra amount of N exported in milk and excreta remains small relative to the level of N input on the paddock, which remains high and even increases slightly because some extra feed supplement (same amount per cow but higher stocking rate) per ha is needed.

Grass–clover pastures have potential to lower N surplus

Forage legumes have been suggested as an important component of low-input sustainable systems for livestock production (Thomas 1992; Pflimlin et al. 2003). Ledgard et al. (1999) measured the N inputs and outputs and N flows over three years in a trial involving three dairy farmlets (i.e. the herd and the experimental area required to feed the herd). Each farmlet was subjected to one level of N fertilization. The grass–clover pastures were grazed throughout the year. As shown in Table 7, N fertilization reduced the white clover content by 70 %. On the 0-kg N farmlet, N_2 fixation by white clover was the sole source of N input and total N inputs were only 40 % of those in the 400-kg N farmlet. N_2 fixation decreased with increasing levels of N fertilization, because the clover proportion in the sward decreased. Milk N represented the major form of N output. Compared to white clover, fertilizer input resulted in a small increase in removal of N with milk. The response was lower than that reported by Delaby et al. (1998), mainly because the stocking rate was kept constant. The results clearly show that intensively managed ryegrass / white-clover pastures are relatively efficient in terms of conversion of N inputs from N_2 fixation into milk and to reduce N surplus at the paddock level. An additional advantage is that these swards also save non-renewable resources required to manufacture and distribute fertilizers.

Table 7. *Annual N inputs and outputs (kg ha^{-1}) for dairy farmlets varying in N fertilizer and white-clover content; adapted from Ledgard et al. (1999); mean of 3 years with 3.3 cows ha^{-1})*

N fertilization	0	200	400
Inputs : N fertilization	0	215	413
N_2 fixation	174	117	40
Purchased feed	3	4	3
Atmospheric deposition	2	2	2
N output			
Milk and meat	80	95	98
Harvested forage	1	15	28
Transferred N excreta (1)	57	78	84
N surplus (2)	41	150	248

(1) 20% of total N excreted

(2): calculated as N fertilization + N feed + N deposition + N fixation – N products – N transferred form the paddock to the lanes and milking shed – N harvested as grass

However, total N inputs in ryegrass / white-clover swards are very dependant on N_2 fixation by white clover as the sole main source of N. In the study of Ledgard et al. (1999), this N entry varied up to 2-fold between years (101 to 235 kg ha^{-1}), mainly due to climatic differences. The challenge of these mixed swards will be to maintain a clover content of around 30-40 %, to allow sufficient grass production and stability of the system from year to year. Indeed, the production of mixed swards is most often lower than that observed on highly fertilized grass swards.

Table 8*. Simulation of the effect of grazing ryegrass / white-clover pasture compared to intensively managed monoculture grass on N excretion and N surplus at the paddock level*

Proportion of white clover	0	25	50
Proportion of white clover (%)	0	25	50
CP content of forage (g kg^{-1} DM)	180	180	200
Grazing days	600	510	600
N intake (kg ha^{-1})	311	264	346
N excreted (kg t^{-1} milk)	20.8	20.8	23.7
Inputs N fertilization (kg ha^{-1})	300	0	0
N_2 fixation (kg ha^{-1}) (1)	0	106	207
Outputs N in Milk (kg ha^{-1})	61	52	61
Transferred N in excreta (kg ha^{-1}) (2)	50	42	57
N surplus (kg ha^{-1})(3)	189	11	89

(1) Calculated as 0.0354 x forage produced x proportion of clover – 0.35 (Decau et al. 1997)

(2) 20% of total N excreted

(3) calculated as N fertilization + N feed + N deposition + N fixation – N products – N transferred form the paddock to the lanes and milking shed – N harvested as grass

We have simulated (Table 8) the effect of the proportion of white clover (25 or 50 %) compared to a pure ryegrass sward receiving 300 kg N ha^{-1}. The simulations assume that stocking rate was adjusted to maintain the same level of intake and milk yield per cow (18 kg DM and 25 kg milk d^{-1}), and take account of the mean response of sward yield observed in Brittany. Compared to a ryegrass sward, a 25 % white-clover sward cannot produce the same number of GD, and N output in milk is reduced. However, this effect remains rather small relative to the reduction in N fertilizer and consequently the N surplus was greatly improved. When the proportion of clover increased, N_2 fixation by white clover was doubled, and the forage yield and finally the number of GD increased. However, N_2 fixation inputs resulted in a relatively small increase in N removal in milk, and N surplus at the paddock level was higher. It should be noted that for the same N removal in milk, N surplus remained lower on the 50-% clover sward than on the highly fertilized ryegrass sward, despite that the total N excretion per unit of milk produced was increased.

Feed supplements always increase milk yield but can increase N surplus

Feeding cereal-based concentrate decreases the N excretion per cow. The quantities of concentrate distributed during grazing are generally moderate and effects on N surplus per hectare are often minimal. According to the expected response to concentrate supply (Peyraud and Delaby 2001, Table 2), the supply of 4 kg of concentrate allows an increase in N removed in milk that is slightly lower than the amount of N supplied with the concentrates (Table 9). Therefore, the N surplus marginally increases. But feeding cereal-based concentrates allows the stocking rate to increase, since herbage intake per cow decreases. This marginally improves N surplus at the paddock level, although total N excretion is increased (282 vs 251 kg ha^{-1}).

***Table 9**. Simulation of the effect of feeding 4 kg of concentrate with or without a further increase in stocking rate and simulation of the effect of the concentrate CP content on N excretion and N surplus at the paddock scale*

		0	4 kg	4 kg + increased SR	4 kg
Grazing days		600	600	675	600
Concentrate CP content (g kg^{-1} DM)		-	120	120	250
Total N intake (kg ha^{-1})		311	323	363	372
Inputs	N fertilization (kg ha^{-1})	300	300	300	300
	N concentrate (kg ha^{-1})	0	46	52	96
Outputs	N in milk (kg ha^{-1})	61	72	81	72
	Transferred N excreta (kg ha^{-1}) (1)	50	50	56	60
N surplus (kg ha^{-1})(2)		189	224	215	274

(1) 20% of total N excreted

(2): calculated as N fertilization + N feed + N deposition + N fixation – N products – N transferred form the paddock to the lanes and milking shed – N harvested as grass

The use of a concentrate high in CP increases the total quantity of N ingested. This will inevitably increase total N excretion (see Table 2) per cow and, with the same number of GD, N excretion per hectare. This was clearly shown by Soegaard and Aaes (1996). During a complete grazing season (165 days), these authors observed a 145-kg ha^{-1} increase in total N excretion by modifying the CP content of the concentrate from 143 to 315 g kg^{-1}. This effect was similar for a herd grazing on a highly fertilized pure ryegrass sward (300 kg N ha^{-1}) and for one an unfertilized ryegrass / white-clover sward. According to Delaby et al. (1996), the use of a rumen-protected high-protein meal (CP = 460 g kg^{-1} DM) compared to a cereal-based concentrate, causes a +27 kg increase in total N excretion on ryegrass swards fertilized with 20 kg N ha^{-1} per regrowth in a 63-day spring grazing season. Despite a high milk N response (+2 kg d^{-1}), this increase in milk N removal is low compared to the extra feed N inputs on the paddock. The increase in total N excretion was even higher (+ 46 kg ha^{-1}) on a sward receiving 60 kg N ha^{-1} per regrowth. Most of the difference in the response was due to the difference in stocking rate, a difference linked to N fertilization that greatly modified the concentrate N supply per ha (+ 46 and + 30 kg N ha^{-1}, respectively, in high- and low-fertilized swards). The simulation (Table 9) also shows a large (22 %) increase in paddock N surplus in response to increased CP content of the concentrate from 120 to 250 g kg^{-1} DM.

Supplementation with maize silage is an efficient way to reduce N excretion per day (see Table 1) by diluting the N content of fresh grass. The range of variation depends on the proportion of maize silage introduced in the ration. But the advantage of maize silage is less obvious when considering the paddock instead of the herd. Indeed, use of maize silage at grazing transfers N from the maize area to the grass area via the animal excreta. Furthermore, the use of maize silage induces a higher number of GD (increased stocking rate or the length of the grazing season), since it sharply reduces grass intake. With good grazing conditions, the supply of conserved forages as a buffer feed may result in a substitution rate over 0.9 and a very low milk response or even a decrease (Leaver 1985). As a consequence, the favourable effect of maize silage on the restitution per grazed hectare is largely lost. This puts the results of Valk (1994) and Van Vuuren and Meijs (1987), who reported a decrease in daily excretion per cow of, respectively, 219 g N (594 g against 375 g) and 143 g N (519 against 379 g) with a 50-% maize silage diet in a different perspective. The large difference between the authors is essentially due to the variation in N intake by the cows fed grass alone (100 g d^{-1}). However, it seems that the advantage of mixed rations is largely nullified if the number of grazing days increases by +58 and +38 %.

N LOSSES AT THE PADDOCK LEVEL

While N surplus at the paddock level is a useful guide to show the potential for N losses to the environment, it gives no indication of the process of N loss. N loss may occur by leaching, denitrification and volatilization, but N can also be organically bound into soil organic matter (see Figure 2). Some comparative studies have been conducted to study these routes of losses, particularly on intensively managed grasslands or ryegrass / white-clover swards. Modelling was also used to circumvent the difficulties associated with field investigation.

Lowering N fertilization reduces nitrate leaching

Decau et al. (1997) have built a relatively simple static model to illustrate the difference in the potential for annual leaching from grazed pastures. The model performs an N balance at the end of the year assuming: 1) N inputs equal N outputs + N losses; 2) the pool of soil mineral N is similar at the beginning and at the end of the year and equals 0; and 3) there is volatilization from this pool. Nitrogen consumed by cows was partitioned as described above and the fate of N from urine and dung was partitioned according to mean coefficients, which were calculated from a review of the literature. From this review it appeared that annually 31 % of urinary N is organically bound, 29 % is recycled in forage growth, 22 % is leached, 16 % is volatilized and 2 % is subject to denitrification. The mean figures for faecal N were 69, 9, 17, 3 and 2 %, respectively. Annual N losses by denitrification were assumed to equate losses from excreta plus 8.5 % of the pool of soil mineral N. N losses by volatilization originate from excreta only. The level of potentially leachable mineral N accumulated in autumn was assumed to equate losses from excreta plus the proportion of soil mineral-N not used for grass growth and not denitrified. This pool is not necessarily leached, therefore the N balance, calculated by difference between N surplus and N losses, could be underestimated.

The model was applied to illustrate the effects of decreasing the levels of N fertilization and stocking rate using the data from Delaby et al. (1998, trial 2 in Table 6). All routes of N losses were reduced (Table 10). In particular, decreasing the level of N fertilization sharply reduced the risk of N leaching, and it should be noted that the effect is very pronounced between 300 and 100 kg N ha^{-1} per year. Scholefield et al. (1993) have also measured proportionally lower leaching losses from lysimeters with decreasing level of N application. Assuming that N mineralization was equal to 160 kg ha^{-1}, soil N available for plant growth averaged 319 and 469 kg ha^{-1} for low and medium level of N application, of which 70 % was recovered in forage produced. At high levels of N application, 815 kg N ha^{-1} was available, of which only 55 % was recovered in the forage produced. When low levels of fertilization were applied, the N balance was negative, indicating a net mineralization from the pool of soil organic N.

***Table 10**. Effects of varying the level of N fertilization and stocking rate or the level of fertilization and clover content on annual N losses (kg N ha^{-1}).*

		from Delaby et al. (1998)			From Ledgard et al. (1999)		
N fertilization		0	100	300	0	200	400
Stocking rate (cow ha^{-1})		3.3	4.0	5.1	3.3	3.3	3.3
Grazing days (ha^{-1})		456	550	689	1204	1204	1204
Paddock N balance (kg ha^{-1}) (1)		7	93	272	41	150	248
N losses	denitrification	16	28	50	5	15	25
	Volatilization	16	22	50	16	38	61
	Leaching (2)	28	44	161	40	79	150
N balance (3)		-55	-2	27	-20	18	12

(1): calculated as N fertilization + N feed + N deposition + N fixation – N products – N transferred form the paddock to the lanes and milking shed – N harvested as grass
(2): in trial 1 it is the level of potentially leachable N. In trial 2 it is the amount of nitrate N leached
(3): calculated as N surplus – N losses

Grass–clover pastures have potential to reduce nitrate leaching, provided the clover content is not too high

In their study, Ledgard et al. (1999) have shown that nitrate-N is the major form of N losses to the environment. Leaching of nitrate-N was minimal for the ryegrass / white-clover system and increased very rapidly with the level of fertilization and a decreased proportion of clover (Table 10). Losses of N by denitrification remained small, but were reduced on ryegrass / white-clover swards. Hooda et al. (1998) also reported lower annual nitrate leaching losses from intensively managed ryegrass / white-clover swards compared to ryegrass swards receiving 250 kg ha^{-1} N fertilization, although both swards annually received more than 150 kg ha^{-1} slurry N.

In the study of Ledgard et al. (1999), the amount of nitrate-N leached varied greatly (20 to 74 kg ha^{-1}) in the ryegrass / white-clover paddocks and this variation was linked to the N_2 fixation by white clover. It might be expected that nitrate leaching rises with an increasing legume content, and thus the level of N_2 fixation per hectare. Loiseau et al. (2001) have reported higher leaching losses from lysimeters when swards were sown with pure white clover (28 to 140 kg ha^{-1}), whereas the losses from ryegrass / white-clover swards were lower than 20 kg ha^{-1} over the 6 years of the experiment.

CONCLUSION

The adoption of intensive dairy systems has contributed to a number of environmental problems, particularly through their reliance on inorganic N fertilizers, on monoculture grasses and on large amounts of supplementary feeds. The N excretion by the herd can be manipulated to a large extent, but this variation is not necessarily linked to the risk of environmental pollution, because of the massive amounts of N inputs through N fertilization and/or N_2 fixation by white clover. Environmental risks must be evaluated from an animal point of view, but also through an overall approach at the forage area required to produce milk. Reducing the amount of N fertilization on grass swards limits the risk of N losses, but inevitably reduces milk production per hectare while milk yield per cow can easily be maintained at a high level. The substitution of inorganic N fertilizer by white clover offers some potential advantages. Animal performance is maintained or even increased and N losses are sharply reduced. However, a target white-clover proportion in the sward must be found (i.e. around 0.3 to 0.4) and maintained. Low proportions of clover will reduce forage production and milk yield per hectare, while a high clover content will lead to a high level of N_2 fixation and increased nitrate leaching. Feeding cereal-based concentrates as supplements is not efficient to reduce N losses, because it allows higher stocking rates. The same is true for maize silage. Although it may decrease the N excretion per cow per day, supplementing grass with maize silage implies a transfer of N from the maize area to the grass area and an increase of the stocking rate.

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