Influence of grassland management in Alpine regions and concentrate level on N excretion and milk yield of dairy cows

L. GRUBER[1], A. STEINWIDDER[1], B. STEFANON[2], B. STEINER[1], R. STEINWENDER[1]

[1]*BAL Gumpenstein, Institute of Animal Production and Nutrition Physiology, A-8952 Irdning, Austria*

[2]*DISPA University of Udine,Department of Animal Production Science, I-33010 Pagnacco, Italy*

Abstract

Permanent grassland of a typical Alpine region in Austria (Styria, 700 m above sea level, 1100 mm precipitation) was cut either 2, 3 or 4 times per year, respectively, conserved as barn-dried hay and fed to dairy cows at 3 concentrate levels (zero, concentrate according to requirements or 25 % of DM intake concentrate). Fertilization levels were 32 m³ slurry with or without 100 kg N ha^{-1} mineral N. Because of lower DM yield (8.65, 8.05, 6.51 t ha^{-1}) and higher forage intake (10.4, 13.2 and 15.3 kg DM) the potential stocking rate decreased with increasing cutting frequency. Milk yield and N excretion per cow increased with increasing cutting frequency. When milk yield and N excretion are related to the forage area there was only a small influence of cutting frequency at the low level of concentrate. When the forage, however, was supplemented with concentrate according to requirements, both milk yield and N excretion per ha decreased with increasing cutting frequency. Additional fertilization of 100 kg mineral N increased the amount of slurry from 37.5 to 41.4 m³ ha^{-1} forage and excretion of N from 149 to 160 kg ha^{-1} forage.

Keywords: N excretion; Dairy cows; Concentrates; Cutting frequency; Fertilizing intensity

1. Introduction and literature

In recent years there is much concern and discussion in public opinion about the role of agriculture in the environmental pollution. In industrial countries intensification of plant and animal production was realized by bringing large external inputs of fuel, fertilizer and feed from elsewhere, leading to losses of nutrients and their accumulation in the soil, water and air (Tamminga 1998). However, there are substantial differences even within these countries. In an experiment (van Horn et al., 1996) about whole-farm budgeting of manure nutrients, of the 1037 kg N excreted by 10.4 cows per ha, only 572 (55 %) kg N were taken up by the forage plants, and from the total of 1492 kg N consumed by the cows, 920 kg (62 %) were purchased. A high N surplus exists also in specialized dairy farms of countries like the Netherlands. Korevaar (1992), summarizing the data of 177 dairy farms, gives figures of 486 kg ha^{-1} N surplus (568 kg N input minus 82 kg N output). The increase in roughage production, mainly by high fertilization rates on grassland, and a high concentrate consumption per cow are predominantly responsible to the increase of stocking rates (Korevaar 1992). Based on model calculations, van Bruchem et al. (1997) conclude, that reducing the external inputs of fertilizer N is the only effective measure to reduce N losses in the Netherlands. Supporting this intervention by improved N recovery from manure, forage yield and milk quota per unit land can be maintained (ca. 15 tons ha^{-1}). In that paper, intensive dairy farming systems are characterized by high external N inputs from concentrates (244 kg ha^{-1}, 40 % of total feed N) and from mineral fertilizer (364 kg ha^{-1}, 49 % of total fertilizer). On the other hand, environmentally balanced dairy farms import only 114 kg N through concentrates (27 % of total feed N) and 158 kg N through mineral fertilizer (35 % of total fertilizer). As a consequence, N losses in the soil by leaching, accumulation, denitrification etc. would be reduced from 46 to 37 % and N utilization efficiency by the cow would by improved from 17 to 25 %. Simon et al. (1994) state, that N fertilization and to a lesser degree concentrate feeding had the most important influence on the N surplus of dairy farms in north west France, where N surpluses ranging from 128 to 225 kg per year have been measured in conventional dairy farms and from 6 to 121 kg N surplus in low-input or organic farms. Peyraud et al. (1995) pointed out, that the forage system (e.g. based on forage maize or grass, level of N fertilization), the level of milk production (dilution of maintenance requirements) and the accurate feeding along with recommendations without safety margins are major factors influencing the N excretion of dairy cows. In this case N excretion per cow increased with milk yield, but decreased per kg milk produced. However, the N excretion per ha forage and total area increased with higher milk yields, which agrees with calculations obtained from the model of Gruber & Steinwidder (1996). A decrease of N required per kg of milk with increasing total milk yields was also emphasized by Kirchgessner et al. (1991) and Flachowsky (1992). However, it should not be overlooked, that the N need per kg milk produced decreases much more at a low milk level than at a high one, when applying current recommendations (e.g. INRA 1989, GfE 1997).

In contrary to such intensive dairy farming systems, the excretion of nutrients per animal and unit area is much lower in countries like Switzerland or Austria. The mean figure for N excretion of a reference cow (600 kg liveweight, 5000 kg milk yield) in Switzerland is 105 kg per year (FAP, RAC, FAC 1994) and 82 kg in Austria (Schechtner 1991). Gruber & Steinwidder (1996) calculated on the basis of a literature review that N excretions of dairy cows under Alpine growing conditions accounted between 90 and 180 kg per ha forage area depending on milk yield and forage quality. In these model calculations the stocking rate, i.e. number of cows per forage area decreased with increasing forage quality due to lower grassland DM yield and higher cow forage intake.

There is no doubt, that the amount of protein intake is the most deciding factor for the level of N excretion per cow (Kirchgessner et al. 1991). Tamminga (1992) described the losses of N ingested in dairy cow at the rumen level, as faecal and as urinary losses. Assuming a balanced N status of the lactating cow, the difference between N intake and N milk yield is excreted in faeces and urine. Furthermore, considering the amount of N excreted in faeces rather constant (about 7.5 g kg^{-1} DMI), all the N ingested in excess will be excreted in the urine (Peyraud et al. 1995). For accurate calculations, the variation of true digestiblity, variation of body composition, ageing of cows and synchronicity of carbohydrate and nitrogen degradation in the rumen have necessarely to be considered in a real situation.

Under conditions of production like in Central Europe, where animal production (at least for ruminants) is almost entirely based on home-grown forage and where animal excretions are not exported from the farm, the N excreted per unit of area is the ecologically critical figure rather than the excretion per animal or per unit of product. It can thus be expected that grassland management factors like level of fertilization and cutting frequency would have an effect on the N circle of a farm through its impact on both the DM yield and the nutrient content of the forage (protein, digestibility). It is well established that the DM yield per unit of area can be increased by N fertilization. Under the Alpine growing conditions of Austria, DM yield increased of 8 - 16 kg per kg mineral N (Jo & Schechtner 1990). This is in agreement with the mean N fertilizing efficiency of 15 kg DM per kg mineral N determined in an European joint research project on mountain pastures (Caputa & Schechtner 1970). In Switzerland, Künzli (1968) found an efficiency of N fertilization of 12.9 kg DM kg^{-1} N (mean of 5 years and 4 sites). At very high fertilization levels (300 - 400 kg mineral N ha^{-1}) Rieder (1973) determined an increase in DM yield of 9.4 kg kg^{-1} N. On 7 sites in Bavaria Rieder (1985) found an efficiency of N fertilization of 10.5 kg DM kg^{-1} N in long-term studies. This will lead to higher stocking rates. On the other hand increasing the cutting frequency will reduce the stocking rate, mainly due to its positive effect on forage intake. Under ad libitum forage feeding systems a given amount of forage means high stocking rates with low forage quality and vice versa. There is clear evidence that the DM yield decreases if cutting exceeds an optimum frequency and level of fertilization is kept constant (Klapp 1951, Mott 1962, Vetter & Kuba 1963, Bommer 1964, Wilman et al. 1976, Rieder 1985, Wilhelmy et al. 1991, Buchgraber & Pötsch 1994, Wachendorf et al. 1995). E.g., at constant fertilization levels, DM yield was 12.82 and 12.08 t ha^{-1} with 3 and 4 cuts $year^{-1}$ (Klapp 1951) and 10.01, 9.35, 7.94 and 6.82 t ha^{-1} with 2, 3, 4 and 6 cuts $year^{-1}$ (Buchgraber & Pötsch 1994). This further decreases the potential stocking rate with increasing cutting frequency.

The objective of the present paper is to describe the influence of cutting frequency and level of N fertilization in permanent grassland as well as concentrate supplementation on N excretion and milk yield of dairy cows under Alpine growing conditions.

2. Material and methods

2.1 Experimental design

A two-factorial design was used to study the effects of cutting frequency and fertilization level on DM yield of grassland and quality of forage (3 x 2):

Cutting frequency: [2] 2 cuts per year (27 06 / 30 09)
[3] 3 cuts per year (30 05 / 27 07 / 30 09)
[4] 4 cuts per year (17 05 / 27 06 / 10 08 / 30 09)

Fertilization level: [S] 32 m³ ha^{-1} slurry (10 % DM), corresponding to 100 kg N
[SN] 32 m³ ha^{-1} slurry plus 100 kg ha^{-1} mineral nitrogen

In the feeding and N balance trial, additionally 3 concentrate levels were used (3 x 2 x 3):

Concentrate level: [Co] feeding forage only, without concentrate
[Cs] supplementation of forage with concentrate according to standards (GEH 1986)
[Cc] constant proportion of concentrate (25 % of DM intake)

2.2 Grassland experimentation

The grassland experiment was conducted on each of two similar meadows (5.2 and 7.3 ha) for 4 years (1994-1997). The experimental fields were cultivated meadows with some typical species of moist meadows (reseeded 3 years before start of the trial). One year before starting the experiment the cuts consisted of 76 and 68 % grasses, 10 and 21 % legumes and 14 and 11 % herbs, respectively (DM basis). Each meadow was divided into 6 plots of differing area to take into account expected differences in yield and forage intake due to experimental treatments. Three plots were fertilized with slurry (32 m^3 ha^{-1}, 10 % DM), and three with the same level of slurry and 100 kg mineral nitrogen. The actual amount of N was 102.6 and 202.3 kg N ha^{-1} in plots S and SN. Fertilizers were applied in equal amounts in spring and after each cut. The forage was harvested by a forage wagon and conserved as barn-dried hay. The yield of each growth was measured by weighing the total amount of a plot after one day of wilting. No further losses during conservation and distribution have been taken into account.

2.3 Animals, feeding and N balance trial

All growths of each cutting frequency level were fed together corresponding to the DM yield to dairy cows in a feeding trial. This trial lasted for 12 weeks from day 100-200 of lactation. The cows were kept in stalls and individual daily intakes were recorded providing a weekly adjustment of the amount offered to obtain an amount of refusals higher than 5-10%. A preliminary period of four weeks before the beginning of the experiment was used. During the first week the animals recieved a ration of an average quality hay, to become ruminally adapted; during the second week the cows were fed according to energy reqirements (GEH 1986) and the milk yield was recorded to obtain covariates for milk yield potential in the statistical analyses. The third week cows recieved a ration consisting of 2/3 hay and 1/3 concentates, in order to obtain covariates for feed intake capacity. Starting from the fourth week the experimental rations were fed, without using these data for the results. Two concentrates were used to supplement energy and protein in the respective concentrate treatments Cs and Cc. In treatment Cc the protein concentrate was fed only in the case to supply the rumen microbes with sufficient degradable N (calculations based on GEH 1986). In treatment Cs the concentrates were mixed in order to cover to N requirements of both the host animal and the rumen microbes (GEH 1986). In case of protein surplus only the energy concentrate was fed. The energy concentrate was composed of 30 % barley, 15 % maize, 15 % wheat, 25 % dried beet pulp and 15 % wheat bran (122 g crude protein kg^{-1} DM, 7.7 MJ NEL kg^{-1} DM, calculated values). The composition of the protein concentrate was 25 % faba beans, 25 % peas, 25 % rapeseed meal and 25 % soyabean meal (365 g crude protein kg^{-1} DM, 8.3 MJ NEL kg^{-1} DM, calculated values).

In the middle of the feeding experiment, cows were equipped with harnesses and the amount of nutrients ingested and excreted in faeces, urine and milk was recorded for 5 days. The faeces and urine were weighed twice daily, sampled and stored (at 4°C). At the end of the collection period, all samples from each cow were mixed and subsequently analysed. The cows were milked twice daily (5.00 a.m. and 4.30 p.m.) and the milk yield recorded. Feeding time was 04.30 - 08.30 a.m. and 03.00 - 07.00 p.m.

Four N balance trials (three in 1997/98) using 12 cows each were carried out every winter feeding period following the harvest year (total N = 180); data of one cow were rejected due to health problems and the final number of animals was 179. Sixty cows belonged to the Simmental, 58 to the Brown Swiss and 61 to the Holstein Friesian breed; 54 cows were used one times during the four year experimentation, 28 were used two times, 11 were used three times and 9 four times (not in the same harvest year and never in the same treatment group); 53 cows were primiparious. After calving the experimental cows were fed according to requirements and their milk yield was recorded once a week for 8 weeks. This yield was the main criterion for alloting them to the treatment groups, besides of breed and parity. The average milk yield in the preexperimental week was 22.3, 23.2 and 27.8 kg ECM for the Simmental, Brown Swiss and Holstein Friesian cows, respectively. The average milk yield and feed intake in the preexperimental weeks was 24.6, 24.5 and 24.2 kg ECM as well as 18.3, 18.3 and 18.1 kg DM in the cutting frequency levels 2, 3 and 4, respectively. In the balance trials the cows were 139, 141 and 137 days in milk.

2.4 Calculations, chemical and statistical analyses

Feeds offered and refusals were recorded at each meal individually and analysed for DM and nutrient contents. The chemical analyses was done by conventional methods as described by ALVA (1983) using devices of Tecator®. The energy content of the forages was calculated according GfE (1995) using the digestibility coefficients elaborated in the balance trials with the cows. In the treatment groups recieving concentrates the proportion of digestible nutrients coming from the concentrates was subtracted using tabulated values (DLG 1997) and assuming no digestive interaction between forage and concentrate. The supply with protein was computed on the basis of the German protein evaluation system (GfE 1997). The milk samples of the morning and evening milking were mixed and analysed for fat, protein and lactose every day throughout the experiment (Milkoscan NIRS instrument). ECM (energy corrected milk) was calculated by taking into account the fat and protein content of the milk and assuming an energy content of 3.1 MJ kg^{-1} milk. The equation is as follows (GEH 1986):

$$ECM = ((0.37 \text{ fat } \% + 0.21 \text{ protein } \% + 0.95) \text{ kg milk}) / 3.1$$

The milk yield per lactation was calculated by the following regression equation using data of a total lactation study (Gruber & Steinwender 1996):

$$ECM_{305} = 275.5\ ECM_{week} + 69.9\ WEEK - 1242\ b + 18.4\ BAL_{NEL} - 175.4\ NEL + 51.4\ ECM{*}b - 23.8\ CONC$$

$R^2 = 99.4$, RSD = 441 kg, N = 1320

ECM_{305}, ECM_{week} = kg ECM in 305 days, in i^{th} week of lactation
WEEK = week of lactation
b = linear slope (kg ECM day^{-1}) of lactation curve (4 weeks before and after the respective week)
BAL_{NEL} = calculated NEL balance (MJ)
NEL = NEL concentration of the total ration (MJ NEL kg^{-1} DM)
CONC = concentrate intake (kg DM)

The data were statistically analyzed using the LSMLMW computer program (Harvey 1987) and Statgraphics® Plus (1996). The model terms were the fixed effects "Cutting frequency", "Fertilization level", "Concentrate level", "Harvest year", "Breed", "Parity" and the interactions of the main effects as well as the covariates "DM intake" and "Milk yield" of the preliminary period and "Day of lactation". The values in the tables of results are least squares-means, RSD is the pooled standard deviation within treatments groups (√ (Mean Squares of Remainder)).

3. Results and discussion

3.1 Effect of cutting frequency and fertilization level upon forage production and composition

The DM yield of grassland significantly decreased with increasing cutting frequency, especially when cutting 4 times per year (table 1). On the average of the two fertilization levels the DM yield was 8648, 8054 and 6509 kg DM ha^{-1}. The mean proportions of the respective growths were 56 and 44 % of total DM yield, 42, 32 and 26 % as well as 27, 27, 27 and 19 % in the cutting regimes 2, 3 and 4 times per year. It is well known that the DM yield decreases if cutting exceeds the optimum frequency without increasing the level of fertilization (Klapp 1951, Mott 1962, Vetter & Kuba 1963, Bommer 1964, Wilman et al. 1976, Wilhelmy et al. 1991, Buchgraber & Pötsch 1994, Wachendorf et al. 1995). According to Vetter & Kuba (1963), the reduction of DM yield of grassland associated with cut frequency is due to many factors. Among these, the main reasons are that the development of the plants is interrupted before the maximum daily growth is reached and that the development of the roots (Klapp 1951) and the storage of nutrient reserves is lower and botanical composition changes. Generally speaking, there are two main reasons for the reduction of DM yield (F. Taube, personal communication): (1) Shortening of the time of growth of the primary growth, which has a higher growth rate than the regrowths; (2) More lag-phases through more cuttings (sigmoidal shape of growth curve). The depressing effect of cutting can be compensated for by higher N fertilization rates (Vetter & Kuba 1963, Bommer 1964, Buchgraber & Pötsch 1994).

The addition of 100 kg of mineral N to the meadows increased the yield from 7384 to 8090 kg DM ha^{-1} (mean of 3 cutting frequency levels), but no interaction was found between cutting frequency and fertilization level. The N fertilization efficiency decreased during the period of the experiments (13.0, 8.7, 4.5 and 2.0 kg DM kg^{-1} N in year 1994, 1995, 1996 and 1997, respectively). The mean N fertilization efficiency of 7.1 kg DM kg^{-1} N is in the lower range of figures reported in literature. Under similar growing conditions Jo & Schechtner (1990) determined N fertilization efficiencies of 8 - 16 kg DM kg^{-1} N and in long running experiments Müller (1985) found out that the N response is negatively correlated with the growth potential of the site (8.7, 9.4, 13.2 and 22.1 kg DM kg^{-1} N on meadows yielding 9780, 8640, 6410 and 4400 kg DM ha^{-1}). In Switzerland, Künzli (1968) found the N fertilization efficiency was 12.9 kg DM kg^{-1} N (mean of 5 years and 4 sites). At very high fertilization levels (300 - 400 kg mineral N ha^{-1}) Rieder (1973) determined an increase in DM yield of 9.4 kg kg^{-1} N. The yield of NEL was highest at the medium cutting frequency, whereas the yield of crude protein was not significantly different between the 3 cutting regimes.

As expected, the cutting regime showed significant influences ($P<0.001$) on the feeding value of the forages. With increasing cutting frequency the crude protein content increased from 11.4 to 15.8 % and energy concentration from 4.5 to 5.7 MJ NEL and this was accompanied by a decrease of crude fibre (31.1 to 24.4 %) and of cell wall constituents (60.4 to 47.2 % NDF, 35.8 to 28.4 % ADF). The range of in vivo OM digestibility was 57.1 to 69.6 %. With cutting frequency the proportion of grasses decreased and the proportion of leaves increased from 47 to 63 % of DM, and those factors might have been an impact on the nutritive value (table1). The fertilization level had no significant influence on the nutritive parameters and there were no interactions between cutting frequency and fertilization level. The slightly lower protein content at the higher fertilization rate is probably due to the higher proportion of grasses, which are of lower protein content and to the harvest date, that was the same for both fertilizing treatments. As a consequence, higher fertilized swards were at a slighty higher stage of growth, resulting in marginal lower protein and higher crude fibre contents. These changes in the nutrient content during vegetation are well documented in literature (Minson 1990, Van Soest 1994).

3.2 Effect of main factors (cutting frequency, fertilization, concentrate) upon animal performances

The LS means for the main effect levels of the animal performance data are presented in table 2, together with the P values for the main effects and their interactions.

3.2.1 Feed intake, ration characteristics and milk yield

With increasing cutting frequency forage intake (10.5, 13.2, 15.3 kg DM) and total feed intake (14.0, 16.4, 18.2 kg DM) increased significantly ($P<0.000$). Minson (1990) pointed out that the fall in voluntary forage intake is caused by three factors: (1) an increase in the proportion of stem which is eaten in smaller quantities than leaf, (2) a fall in voluntary forage intake of both leaf and stem fraction and (3) a nutrient deficiency in the mature forages. All these three factors can be considered with the present results. Mertens (1994) reported that (under conditions of physical feed intake regulation, i.e. energy demand does not limit feed intake) intake capacity corresponds to 12.5 ± 1.0 g NDF intake kg^{-1} body weight. The cows fed with hay harvested with cutting frequencies 2, 3 and 4 consumed on average 12.1, 13.3 and 13.4 g NDF kg^{-1} live weight, what is close to the expected value of 12.5, and feed intake was slightly lower with mineral nitrogen fertilization. On average, concentrate intake was lower with high cutting frequency due to the experimental design in groups Cs (concentrate according to standards). Substitution ratio of forage for concentrate averaged 0.43 kg DM, although it was higher with forage of good quality (0.33, 0.47 and 0.57). In the INRA fill unit system (INRA 1989) the substitution rate also increases with increasing energy density (ratio NEL/Fill units).

Cutting frequency increased protein and energy intake by both the higher intake and the higher concentration. Protein intake however, was increased to a higher extent than energy intake, resulting in an impaired crude protein to energy ratio (CP/ME). N supply and demand in the rumen was almost balanced with low cutting frequency and a considerable N surplus of 45 g day^{-1} was found with the highest cutting frequency. This can also be derived from the diverging figures of crude protein and utilizable protein supply. As expected, cows with low cutting frequency and low concentrate level were in negative calculated energy balance, corresponding to 3 kg ECM (difference ECM actual - ECM computed).

Concerning the protein supply of host cows based on the protein evaluation of GfE (1997), there was a surplus of utilizable crude protein reaching the duodenum, which increased with increasing energy supply (through forage quality or concentrate). The calculated protein supply is not always in agreement with the N balance data, which were slightly negative in some cases (see below), although the discrepancies were not very numerically consistent (from -4 to -12 g, on average 1.8 % of intake) and N balances were often subjected to great variations. E.g., Kreuzer & Kirchgeßner (1985), Kaufmann & Kirchgeßner (1987) and Peyraud et al. (1997) reported variations of similar magnitude (up to 21 g RSD). The other point is the accuracy of the protein evaluation system. Stefanon et al. (1998) compared the ability of different feed evaluation systems to predict rumen microbial nitrogen flow of lactating dairy cows, using purine derivatives excretion as reference value for microbial protein. The correlations between purine derivative excretion and microbial yield estimated by the Italian PDI system, UK MP system, German nXP system and

US CNCPS (Cornell) system were 0.73, 0.75, 0.77 and 0.76, indicating a certain degree of bias. The authors concluded that the 4 systems gave similar predictions although based on different inputs.

Due to the short length of the balance trial, the results of milk yield have to be interpreted with care. Theoretically, the milk yield (computed from the energy supply) was 11.5, 17.4 and 22.4 kg ECM day^{-1} for cutting frequencies 2, 3 and 4, and the actual milk yields were 14.7, 18.4 and 21.8 kg ECM. Considerable mobilisation of body reserves probably will have taken place, particularly for low forage quality and low concentrate level rations. This can also be seen in the milk contents of protein and lactose, which increased with increasing energy supply (through forage quality or concentrate). The cows that received concentrate according to requirement (Cs) showed lower energy intakes and milk yields when fed forage of low quality (cutting frequency). Therefore low forage quality can only be compensated with high concentrate levels to a limited extent.

3.2.2 Excretions and N balance

The excretion of faeces was nearly the same in the 3 cutting frequency levels (∅ 5.55 kg DM), the increase of feed intake and improvement of digestibility being therefore balanced. Although significantly, the excretion of faeces was only slightly increased through concentrate feeding (5.4, 5.7 and 5.6 kg DM in concentrate levels Co, Cs and Cc). On the other hand the excretion of urine increased significantly from 11.0 to 15.4 and 22.7 kg with increasing cutting frequency, whereas there was only a small but significant influence of concentrate level. The excretion of faeces and urine (slurry, corrected to a DM content of 10 %) was increased from 61.7 to 66.9 and 71.0 kg animal^{-1} day^{-1} and it was significantly higher with concentrate feeding. The DM content of slurry decreased with increasing cutting frequency from 11.3 to 10.6 and 10.3 %, which was caused particularly by the increasing proportion of urine in the slurry (18, 23 and 32 % of slurry fresh weight (10 % DM)). The slurry DM content increased when feeding concentrates.

There were also great differences between faeces and urine regarding their changes in N content with cutting frequency. The faecal N content increased markedly with cutting frequency (22, 27 and 32 g N kg^{-1} DM), whereas the N content of urine was not affected (∅ 6.87 g kg^{-1}). As a consequence, the N content of slurry significantly increased with cutting frequency (3.14, 3.86 and 4.71 g kg^{-1} slurry). The excretion of excess N by dairy cows was therefore managed by two mechanisms, (1) increasing the concentration of N in faeces at constant amount of faeces excretion and (2) increasing the amount of urine at constant N concentration of the urine.

N intake was equal to 265, 344 and 440 g day^{-1} for cutting frequencies 2, 3 and 4. With increasing cutting frequency N excretion increased in both faeces (121, 153 and 179 g) and to a higher degree in urine (72, 104 and 155 g). Of the N ingested 46, 45 and 41 % were excreted via faeces and 28, 31 and 36 % via urine. This corresponds well to the calculated N surplus in the rumen in the respective treatment groups. Excessive protein in high-protein diets is turned into ammonia, which is absorbed from to rumen and wasted as urea in urine (Van Soest 1994). As a consequence, urine contributed more to the total N excretion the higher the cutting frequency was. The contribution of urinary N to total N excretion increased from 38 to 41 and 46 % with cutting frequencies 2, 3 and 4. According to Kirchgeßner et al. (1991) NPN in slurry is on average 46 % of total N. Nitrogen bound in urine is more critical from an ecological point of view than faecal N which is only slowly mineralized (Amberger et al. 1982). By feeding concentrates, relatively less N is excreted via the urine (42.3, 40.6 and 41.7 % of total N excretion in Co, Cs and Cc) and - in addition - less N is excreted when related to consumed N (79.9, 73.8 and 73.0 % of N intake). This clearly indicates the importance of providing rumen microbes with fermentable matter to capture degraded N and to synthesize microbial protein. From the above mentioned principles of ruminal N metabolism it is clear, that the present effect of concentrate feeding on N excretion is to a high degree due to its low protein content, providing fermentable matter at a low N content.

Milk N yield increased from 72 to 93 and 112 g day^{-1} with increasing cutting frequency and from 78 to 103 g day^{-1} by concentrate supply. However, the efficiency of N utilisation decreased with inceasing cutting frequency due to wastage of N through urinary excretion. Of the N ingested 26.9, 26.6 and 25.3 % ($P=0.020$) were found as milk N and, in terms of N excretion, 13.9, 14.7 and 15.7 g N kg^{-1} ECM ($P<0.000$) were excreted through faeces and urine. On the other hand, N efficiency was significantly improved through feeding additional grain-based concentrate (24.7, 27.5 and 26.6 milk N in % of N intake in Co, Cs and Cc). The N excretion kg^{-1} ECM was also reduced (16.2, 13.9 and 14.1 g N). Two main factors are responsible for the higher N efficiency, (1) increased microbial protein synthesis (less N surplus in rumen, higher supply of fermentable matter) and (2) dilution of maintenance requirements through higher milk yield). The second aspect was also stressed by Kirchgeßner et al. (1991), Flachowsky (1992), and Peyraud et al. (1995), who calculated N excretions of 13.3, 12.1 and 11.2 kg^{-1} ECM for milk yields of 6000, 7500 and 9000 kg year^{-1}. These excretion data for dairy cows are in line with the results of Flückiger et al. (1989), Windisch et al. (1991), Kirchgeßner et al. (1991) as well as Peyraud et al. (1995), and show the great influence of the ration composition and milk yield on N excretion.

3.3 Main factor interactions and animal performances

From table 2 it can be seen, that both cutting frequency and concentrate level had a significant influence on nearly all of the animal performance traits (feed intake, ration criteria, milk yield, N excretion and N balance), whereas the fertilizing level seldom showed significance. At the animal performance level, almost no significant interaction were detected between cutting frequency and fertilization as well as between fertilization and concentrate level. However, significant interactions became apparent between cutting frequency and concentrate level in most of the animal performance parameters, meaning that the effect of cutting frequency was not independent of concentrate feeding. Therefore the animal performance data of the cutting frequency x concentrate interactions are presented in table 3.

Comparison between groups Co and Cs is most interesting, because concentrate intake differed in the cutting frequency levels due to the experimental design. Forage intake was 11.6, 15.0 and 17.3 kg DM in cutting frequencies 2, 3 and 4 at zero concentrate level and 9.4, 12.0 and 14.6 kg DM at concentrate supply according to standards. With low forage quality a higher concentrate intake is necessary than with high forage quality. Nevertheless, cows consumed only 90 MJ NEL with low forage quality and 110 MJ NEL with high forage quality, although supplemented with concentrate according to their requirements. The effect of cutting frequency on digestibility and energy intake was more distinct at the low level of concentrate.

As a consequence of the different energy supply, the influence of cutting frequency on milk yield depended on the concentrate level. Although on a higher level, the effect of forage quality on milk yield was more pronounced at a low concenrate feeding than a at higher one. This can be seen especially in the socalled milk yield "computed", i.e. milk computed from the energy supply. The energy supply corresponded to a milk yield of 5.5, 14.0 and 19.4 kg ECM in cutting frequencies 2, 3 and 4 with zero concentrate and 16.9, 19.2 and 22.9 kg ECM when concentrate was fed according to requirements. From these figures it can be concluded that low forage quality can only be compensated for with high concentrate levels to a limited extent. From the difference between "computed" and "actual" ECM as well as the from calculated energy balance the high degree of body reserve mobilization can be derived, which presumably has taken place especially in treatment Co x cutting frequency 2. As mentioned above, the actual milk yields are therefore not only the results of nutrient intake by feed, but also the result of mobilisation.

Significant interactions were also apparent in several parameters of excretion (faeces, urine, nitrogen). The data show, that there were only minor differences in excretion between the concentrate levels at high cutting frequency. On the other hand, the level of excretion was much lower with zero concentrate than with normal concentrate levels at low cutting frequency. Of course, this reflects the N and fermentable matter intake in the respective groups. This interaction was more significant with faecal N (102, 146 and 176 g in Co; 141, 158 and 179 g in Cc; P=0.001) than with urinary N (63, 103 and 158 g in Co; 77, 104 and 158 g in Cc; P=0.088).

3.4 Effect of main factors and interactions expressed per unit of landscape used to feed the herd

From the present experiment it is also possible to calculate the output of milk and excretions per hectare forage. The figures of milk yield and excretion per year are also shown, to facilitate the comparison between the data expressed per animal and per hectare (tables 4 and 5).

3.4.1 Milk production

The actual milk yield per year (computed from the milk yield of the balance trial by additionally taking into account stage of lactation, persistency and nutrient supply of the cow, see section Material and methods) was calculated to be 4515, 5478 and 6405 kg ECM in cutting frequencies 2, 3 and 4. From the figure "milk computed" it can be concluded, that the mobilization in cutting frequency 2 corresponds to 1000 kg ECM per lactation (mean of all concentrate levels). The same difference of 1000 kg ECM between milk "actual" and "computed" was found in the zero concentrate (Co) cows (mean of all cutting frequency levels). Gruber & Steinwender (1996) found similar effects of forage quality and concentrate level on milk yield in a long-term total lactation study. As mentioned above, a highly significant interaction existed between forage quality and concentrate level regarding milk yield (table 5). The energy supply of the cows fed with low quality forage and without concentrate corresponded to a milk yield of 1676 kg ECM per lactation, i.e. they would have to mobilize body reserves for 2000 kg ECM. This shows, that forage of such a low quality is not suited for milk production in the long run. On the other hand, the cows in cutting frequency 4 without concentrate consumed energy corresponding to 5917 kg ECM, which was close to the actual milk yield of 6033 kg ECM. Applying linear regression, the milk yield per lactation (kg ECM "computed") will increase by 3160 kg MJ^{-1} NEL content of forage without concentrate feeding (Co) and 1012 kg MJ^{-1} NEL in Cs as well as 2836 kg MJ^{-1}

NEL in Cc on a long-term basis.

To calculate the milk production (and nutrient excretion) per unit forage area (hectare, ha) the stocking rate has to be taken into account. It is calculated as: DM yield ha^{-1} / (forage DM intake day^{-1} x 365). All three main factors considered in the present experiment played an important role in affecting the stocking rate: (1) cutting frequency decreased DM yield of grassland and increased forage DM intake, (2) N fertilization increased DM yield of grassland and, (3) concentrate decreased forage DM intake. As a consequence, for the levels of the main effects this resulted in stocking rates of 2.25, 1.66 and 1.16 cows ha^{-1} in cutting frequencies 2, 3 and 4, 1.53 and 1.72 cows ha^{-1} in fertilizing levels S and SN as well as 1.44, 1.76 and 1.71 cows ha^{-1} in concentrate levels Co, Cs and Cc, respectively. Again, an interaction appeared between cutting frequency and concentrate level (P=0.076). With Co (zero concentrate) stocking rates were 2.03, 1.46 and 1.03 in cutting frequencies 2, 3 and 4, whereas 2.51, 1.82 and 1.23 cows ha^{-1} could be fed with Cs (concentrates to cover the energy requirements).

These stocking rates are the cardinal point for the further discussion and are used to calculate the milk production (and nutrient excretion) per unit forage area (table 4 and 5). Milk yield (actual) was 10150, 9120 and 7440 kg ECM ha^{-1} in cutting frequency 2, 3 and 4. However the parameter milk (computed), which indicates more about the effective energy supply due to presumably high mobilization with low forage quality, was highest at the medium forage quality (7890, 8850 and 7930 kg ECM ha^{-1} in cutting frequency 2, 3 and 4. Fertilizing 100 kg ha^{-1} mineral N increased milk production by 928 kg ECM ha^{-1} . There was a great influence of feeding concentrates on milk production per unit forage area (5690, 10570 and 9730 kg ECM ha^{-1} in Co, Cs and Cc.

Because of the significant interaction ($P<0.000$) the influence of cutting frequency on milk production per ha should not be looked upon without considering the concentrate level. Actual milk yield ha^{-1} was quite similar in the 3 cutting frequencies, with Co rations. However, milk ha^{-1} "computed" increased from cutting frequency 2 to 3 and was similar in 4 (3400, 6220 and 6090 kg ECM ha^{-1}). Supplementing deficient energy rations with concentrates according to standards (Cs), decreased milk ha^{-1} "computed" with increasing cutting frequency (12960, 10690, 8570 kg ECM ha^{-1}) at cutting frequencies 2, 3 and 4. Regarding milk production from the present results it can be concluded, that (1) importance of forage quality depended on concentrate level, (2) too a high cutting frequency led to a lower milk production per hectare forage area and, (3) despite the highest milk yield per hectare with low cutting frequency, forage of such a low energy concentration is not suited in dairy cow nutrition, especially with cows of high milk yield potential and in that stage of lactation with high milk yields.

3.4.2 Excretion of slurry and nitrogen

The excretion of slurry and nitrogen $year^{-1}$ increased with increasing cutting frequency and concentrate level (table 4). Concerning the main effects, the excretion of slurry ha^{-1} considerably decreased with increasing cutting frequency (50.6, 40.6 and 30.1 t ha^{-1}). The excretion of nitrogen ha^{-1} did not decrease to the same extent (158, 156, 142 kg ha^{-1}), since the concentration of N increased significantly with cutting frequency (table 2). Fertilizing 100 kg ha^{-1} mineral N increased N excretion by 11 kg ha^{-1}. There was a significant influence of feeding concentrates on N excretion per unit forage area (131, 175 and 164 kg ha^{-1} in Co, Cs and Cc). At the zero concentrate level (Co) the excretion of slurry decreased to a lower extent with increasing cutting frequency (42.6, 35.1 and 26.8 t ha^{-1}) than in the case of feeding concentrates (Cs) according to standards (60.6, 45.0 and 31.6 t ha^{-1}). Due to the increase of N content in the slurry the results of N excretion per forage area were quite different from that of the slurry excretion. At the zero concentrate level (Co) the excretion of N was similar at all 3 cutting frequency levels (123, 133, 125 kg ha^{-1}), the increase of excretion per animal (amount and concentration) equalizing the decrease of stocking rate. On the other hand the N excretion per unit forage area decreased with increasing cutting frequencies (199, 174, 151 kg ha^{-1}), when supplementing the forage ration with concentrates according to standards (Cs).

The "N balance in the soil" can be calculated as the difference between N input (fertilization with slurry and mineral N, N fixation by legumes (3 kg N ha^{-1} per % of legumes), N mineralization (60 kg N ha^{-1})) and N output (N yield of forage). Although this soil N balance is incomplete (deposition, leaching, accumulation, denitrification etc.), the figures are interesting as relative comparison. With increasing cutting frequency the surplus of N in the soil tended to inrease (64, 74 and 97 kg ha^{-1}). The concentrate level revealed no influence on the soil N balance (76 kg ha^{-1}). From the low effect of N fertilization on DM yield in the present grassland experiment it is clear, that mineral N fertilization increased the N balance in the soil (39 and 113 kg ha^{-1} in S and SN). Additionally the N balance in the soil was calculated, taking into account not only the amount of slurry applicated due to the experimental design (32 m³ ha^{-1}, corresponding to 100 kg "field falling N", N balance in soil "fert(ilized)", but also considering the effective amount of N excretion by the cows depending on experimental treatment (N balance in soil "excr(eted)"). Despite the fact, that this different N excretion would have an effect on DM yield and consequently stocking rate and therefore N excretion per unit forage area, a significant influence of all three main effects on N balance in soil (excr.) would take place. The N balance in soil (excr.) would increase with cutting frequency (85, 86 and 98 kg N ha^{-1}), with fertilizing level (48 and 131 kg ha^{-1}) and concentrate level (73, 104 and 95 kg ha^{-1}). A significant interaction appeared, increasing the N balance in soil (excr.) with cutting frequency at zero concentrate (Co) to a high degree and resulting in a constant soil N balance (excr.) in the case of feeding concentrates according to standards (Cc).

From an ecological point of view it can be concluded, that (1) the amount of excretions per unit forage area will be higher with low cutting frequency, (2) the feeding of concentrates increases the excretions per unit forage area through higher stocking rates due to substitution of forage, (3) that a significant interaction exists between forage quality and concentrate level regarding N excretion ha^{-1} forage (constant at low concentrate and decrease at concentrate level necessarry to cover energy requirements) and, (4) that the N balance in the soil increases with cutting frequency.

3.5 Prediction of manure and N excretion

Regression equations were developed from the data which are characterized by a large variation of those factors having an essential impact on the manure and N excretion per dairy cow and per unit forage area. Three different data sets were used. In the first set (a) all possible parameters of energy and protein supply were available (forage and concentrate intake and their protein and energy content); this information is usually not given on farms. The second data set (b), applicable for the situation of the total mixed ration, contained the protein and energy content of the forage and total ration as well as the concentrate proportion, but not the respective intakes. The third data set (c) provided the protein and energy content of the forage and concentrate and the concentrate intake. This information is known on many farms in Austria. All data sets included liveweight and milk yield as well as the DM yield of grassland.

Excretion per cow:

(1a) $Ec_S = 53.09 + 0.007\ LW + 0.028\ (IF*XP_F) + 0.025\ (IC*XP_C) + 0.336\ (IC*NEL_C) - 0.011\ (IC*XP_F) - 0.232\ (IC*NEL_F) - 0.067\ (XP_T*NEL_T)$

RSD = 2.3, RSD = 3.4 %, R^2 = 94.7 %

(1b) $Ec_S = 53.75 + 0.035\ LW + 1.813\ ECM - 7.685\ NEL_T$

RSD = 5.2, RSD = 7.9 %, R^2 = 71.4 %

(1c) $Ec_S = 39.22 + 0.035\ LW + 1.846\ ECM – 4.998\ NEL_F – 0.159\ (IC*NEL_C)$

RSD = 5.4, RSD = 8.1 %, R^2 = 69.5 %

(2a) $Ec_N = -0.6 + 0.106\ (IF*XP_F) + 1.153\ (IC*NEL_C) + 0.0605\ (XP_T*NEL_T)$

RSD = 27, RSD = 10.4 %, R^2 = 85.8 %

(2b) $Ec_N = -259.8 + 0.137\ LW + 6.747\ ECM + 2.749\ P_{Conc} + 2.380\ XP_F - 0.02536\ (P_{Conc}*XP_F)$

RSD = 31, RSD = 12.0 %, R^2 = 81.1 %

(2c) $Ec_N = 10.5 + 0.144\ LW + 6.704\ ECM – 41.608\ NEL_F – 0.021\ (IC*XP_F) + 0.3709\ (XP_F*NEL_F)$

RSD = 31, RSD = 12.0, %, R^2 = 81.0 %

Excretion per hectare forage area:

(3a) $Ef_S = 4163 + 5.5\ DMYIELD + 2.5\ (IF*XP_F) – 156.5\ (IF*NEL_F) + 10.3\ (IC*XP_C) + 665.2\ (IC*NEL_C) – 1006.2\ (IC*NEL_F) – 5.865\ (XP_T*NEL_T)$

RSD = 1814, RSD = 4.3 %, R^2 = 97.8 %

(3b) $Ef_S = 54867 + 5.8\ DMYIELD + 6349.9\ NEL_F – 326.5\ XP_T – 19160.0\ NEL_T + 1674.0\ P_{Conc} – 225.2\ (P_{Conc}*NEL_F) + 65.7\ (XP_T*NEL_T)$

RSD = 1387, RSD = 3.3 %, R^2 = 98.7 %

(3c) $Ef_S = 43547 + 5.7\ DMYIELD – 192.9\ ECM – 215.2\ XP_F – 9837.2\ NEL_F + 9.2\ (IC*XP_C) + 513.9\ (IC*NEL_C) - 693.4\ (IC*NEL_F) + 44.5\ (XP_F*NEL_F)$

RSD = 1713, RSD = 4.1 %, R^2 = 98.0 %

(4a) $Ef_N = -156.25 + 0.024\ DMYIELD – 0.486\ (IF*NEL_F) + 1.615\ (IC*NEL_C) – 1.840\ (IC*NEL_F) + 0.196\ (XP_T*NEL_T)$

RSD = 18.4, RSD = 11.6 %, R^2 = 79.2 %

(4b) $Ef_N = -282.51 + 0.026\ DMYIELD + 13.823\ P_{Conc} + 1.167\ XP_F + 138.629\ NEL_F - 127.565\ NEL_T – 1.829\ (P_{Conc}*NEL_F)$

RSD = 17.0, RSD = 10.6 %, R^2 = 82.3 %

(4c) $Ef_N = -167.11 + 0.026\ DMYIELD – 1.484\ ECM + 3.822\ (IC*NEL_C) + 0.174\ (XP_F*NEL_F) – 4.035\ (IC*NEL_F)$

RSD = 18.9, RSD = 11.9 %, R^2 = 78.1 %

Ec_S, Ec_N = Excretion of slurry, nitrogen per cow (kg d^{-1}, g d^{-1})
Ef_S, Ef_N = Excretion of slurry, nitrogen per hectare forage area (kg $year^{-1}$)
DMYIELD = Yield of grassland (kg DM ha^{-1})
LW = Liveweight (kg)
ECM = Energy corrected milk yield (kg)
IF, IC, IT = Intake of forage, concentrate, total ration (kg DM)
XP_F, XP_C, XP_T, NEL_F, NEL_C, NEL_T = Crude protein and energy concentration (NEL) of the forage, concentrate and total ration (g and MJ^{-1}kg DM)
P_{Conc} = Proportion of concentrate (percent of DM intake)

Regarding the excretion per cow, the estimation of manure and N is most accurate if feed intake as well as the ration's energy and protein content are known, i.e. the nutrient intake (RSD = 3.4 and 10.4 %, R^2 = 95 and 86 %). But even under practical situations, where these parameters are not available, an estimation is possible by means of liveweight, milk yield as well as energy and protein content of the ration (RSD = 7.9 and 12.0 %, R^2 = 71 and 81 %). Estimating the excretion per forage area, the same variables proved to have a significant impact, together with the DM yield of grassland.

It can be concluded that the N excretion per cow particularly depends on the N balance in the rumen and the level of feed intake. The N excretion per forage area, however, is additionally determined by the level of concentrates and of N fertilization. There are significant interactions between nutritional and grassland management factors.

Acknowledgements

The authors thank all the co-workers of the institute of animal production and nutrition physiology for their engaged cooperation. Thanks also goes to the referee for helpful comments.

References

ALVA (Arbeitsgemeinschaft landwirtschaftlicher Versuchsanstalten), 1983. Österreichisches Methodenbuch für die Untersuchung von Futtermitteln, Futterzusatzstoffen und Schadstoffen. Selbstverlag ALVA.

Amberger, A., K. Vilsmeier and R. Gutzer, 1982. Stickstoffraktionen verschiedener Güllen and deren Wirkung im Pflanzenversuch. Z. Pflanzenernährg., Bodenkde. 145, 325-336.

Bommer, D., 1964. Zur Frage von Stickstoffdüngung und Schnitthäufigkeit auf der Wiese. Landw. Forschung 17, 252-259.

Buchgraber, K. and E.M. Pötsch, 1994. Grundlagen der Grünlandnutzung - Auswirkungen auf Ertrag, Pflanzenbestand und Futterqualität. Abschlußbericht, Bundesanstalt für alpenländische Landwirtschaft Gumpenstein, 8952 Irdning.

Caputa, J. and G. Schechtner, 1970: Wachstumsrhythmus und Stickstoffwirkung auf natürlichen Beständen der Bergweiden. Das wirtschaftseig. Futter 16, 165-182.

DLG (Deutsche Landwirtschaftsgesellschaft), 1997. DLG-Futterwerttabellen Wiederkäuer. Hrsg. Universität Hohenheim - Dokumentationsstelle, 7. Auflage, DLG - Verlag Frankfurt, 212 pp.

FAP, RAC, FAC (Eidgenössische Forschungsanstalt für landwirtschaftlichen Pflanzenbau Reckenholz, Station federale recherche de agronomiques de Changins, Eidgenössische Forschungsanstalt für Agrikulturchemie und Umwelthygiene Liebefeld), 1994. Grundlagen für die Düngung im Acker- und Futterbau. Landwirtschaftliche Beratungszentrale (LBL), CH-8315 Lindau, 39 pp.

Flachowsky, G., 1992. Animal nutrition - ecology versus economics. Anim. Res. Dev. 35, 7-22.

Flückiger, E., J.-M. Besson and F. Jans, 1989. Anfall an Kot and Harn von Hochleistungskühen. Schweiz. Landw. Forsch. 28, 175-189.

GEH (Gesellschaft für Ernährungsphysiologie der Haustiere - Ausschuß für Bedarfsnormen), 1986. Energie- and Nährstoffbedarf landwirtschaftlicher Nutztiere, Nr. 3: Milchkühe and Aufzuchtrinder. DLG-Verlag, Frankfurt (Main), 92 p.

GfE (Gesellschaft für Ernährungsphysiologie - Ausschuß für Bedarfsnormen), 1995. Zur Energiebewertung beim Wiederkäuer. Proc. Soc. Nutr. Physiol. 4, 121-123.

GfE (Gesellschaft für Ernährungsphysiologie - Ausschuß für Bedarfsnormen), 1997. Zum Proteinbedarf von Milchkühen and Aufzuchtrindern. Proc. Soc. Nutr. Physiol. 6, 217-236.

Gruber, L. and R. Steinwender, 1996. Influence of forage quality on digestibility, feed intake and yield of dairy cows. 16th EGF Meeting 1996. Grassland and Land Use systems. Grado, Italy, 437-440.

Gruber, L. and A. Steinwidder, 1996. Einfluß der Fütterung auf die Stickstoff- und Phosphorausscheidung landwirtschaftlicher Nutztiere - Modellkalkulationen auf Basis einer Literaturübersicht. Die Bodenkultur 47, 255-277.

Harvey, W.R., 1987. User's Guide for LSMLMW PC-1 Version. Mixed model least-sqares and maximum likelihood computer program, Ohio State University, 59 pp.

INRA (Institut National de la Recherche Agronomique), 1989. Ruminant Nutrition. Recommended allowances and feed tables (ed. R. Jarrige), John Libbey Eurotext, London, Paris, 389 pp.

Jo, I.H. and G. Schechtner, 1990: Efficiency of mineral nitrogen fertilization on yield and botanical composition of grassland. I. Dry matter yield and economical mineral nitrogen application of grassland. J. Korean Grassl. Sci. 10, 102-109.

Kaufmann, T.E.G. and M. Kirchgeßner, 1987. Zum Einfluß überhöhter Energiezufuhr bei laktierenden Kühen und dadurch bedingte Folgewirkungen. 2. Mitteilung: Stickstoffbilanz und Stickstoffverwertung bei der Milchkuh während und nach energetischer Überversorgung. J. Anim. Physiol. a. Anim. Nutr. 57, 251-261.

Klapp, E., 1951. Leistung, Bewurzelung und Nachwuchs einer Grasnarbe unter verschieden häufiger Mahd und Beweidung. Z. f. Acker- und Pflanzenbau 93, 269-286.

Kirchgeßner, M., W. Windisch and M. Kreuzer, 1991: Stickstoffemission laktierender Milchkühe über die Gülle in Abhängigkeit von der Leistungsintensität. Agribiol. Res. 44, 1-13.

Korevaar, H., 1992. The nitrogen balance on intensive Dutch dairy farms: a review. Livest. Pro. Sci. 31, 17-27.

Kreuzer, M. and M. Kirchgeßner, 1985. Zum Einfluß von Proteinfehlernährung bei laktierenden Kühen und daraus entstehenden Nachwirkungen. 2. Mitteilung: N-Ansatz und N-Verwertung bei Kühen während und nach überhöhter Proteinversorgung. Z. Tierphysiol., Tierernährg. u. Futtermittelkde. 53, 270-279.

Künzli, W., 1968. Pflanzenbestand und Ertrag der Fromentalwiese in Abhängigkeit von Standort und Düngung. Arbeiten aus dem Gebiete des Futterbaues 10. Juni 1968, 9-27.

Mertens, D.R., 1994. Regulation of forage intake. In: Forage quality, evaluation, and utilization. National Conference on Forage Quality, Evaluation, and Utilization (Eds. G.C. Fahey et al.), 450-493.

Minson, D.J., 1990. Forage in Ruminant Nutrition. Academic Press, 483 pp.

Müller, A., 1985. Auswirkungen langjähriger PK- und NPK-Düngung auf Pflanzenbestand und Ertrag in Abhängigkeit vom Standort. Das wirtschaftseig. Futter 31, 150-164.

Mott, N., 1962. Der Einfluß der Schnitthäufigkeit auf Ertrag und Pflanzenbestand der Fuchsschwanzwiese bei unterschiedlicher N- und PK-Düngung. Bayer. Landw. Jahrb. 39, 311-336.

Peyraud, J.L., R. Vérité and L. Delaby, 1995. Rejets azotés chez la vache laitière: effets du type d'alimentation et du niveau de production des animaux. Fourrages 142, 131-144.

Peyraud, J.L., L. Astigarraga and P. Faverdin, 1997. Digestion of fresh perennial ryegrass fertilized at two levels of nitrogen by lactating dairy cows. Anim. Feed Sci. a. Technol. 64, 155-171.

Rieder, J.B., 1973. Einfluß der Steigerung mineralischer Stickstoffdüngung auf Bestandesentwicklung, Ertrag und Qualität des Dauergrünlandes. Bayer. Land. Jahrbuch 50, 606-612.

Rieder, J.B., 1985. Der Einfluß steigender Düngung und steigender Nutzungshäufigkeit auf Ertrag und Qualität unterschiedlicher Grünlandbestände in Bayern. Versuchsergebnisse der Bayerischen Landesanstalt für Bodenkultur und Pflanzenbau Freising-München, 67 pp.

Schechtner, G., 1991. Wirtschaftsdünger - Richtige Gewinnung und Anwendung. Sonderausgabe der Zeitschrift "Förderungsdienst". BMLF, Fachbeirat für Bodenfruchtbarkeit und Bodenschutz, 118 pp.

Simon, J.-C., L. Le Corre and F. Vertès, 1994. Nitrogen balances on a farm scale: results from dairy farms in north west France. Proc. 15th Gen. Meeting EGF, 6-9 June 1994, Wageningen, NL, 429-433.

Statgraphics® Plus for Windows®, 1996. Manugistics® Working as one. User Manual and Advanced Regression.

Stefanon, B., L. Gruber, S. Moscardini, V. Volpe and P. Susmel, 1998. The ability of different feed evaluation systems to predict rumen microbial nitrogen flow of lactating dairy cows. Proc. Annual Meeting of British Soc. Animal Sci., Scarborough, March 1998, 22.

Tamminga, S., 1992. Nutrition management of dairy cows as a contribution to pollution control. J. Dairy Sci. 75, 345-357.

Tamminga, S., 1998. The role of nutrition management in the control of environmental pollution. Proc. Conferrence "Agriculture and Environment", Bled, Slovenia, 12-13 March 1998, 423-432.

Van Bruchem, J., M. van Os and H. van Keulen, 1997. Towards environmentally balanced grassland-based dairy farming - New perspectives using an integrated approach. Book of Abstracts No. 3, 48th Annual Meeting of EAAP, Vienna, Austria, 25-28 August 1997, Paper CNMS1.3, 189.

Van Horn, H.H., G.L. Newton and W.E. Kunkle, 1996. Ruminant nutrition from an environmental perspective: Factors affecting whole-farm nutrient balance. J. Anim. Sci. 74, 3082-3102.

Van Soest, P.J., 1994. Nutritional Ecology of the Ruminant. 2. ed., Cornell University Press, Ithaca, New York, 476 pp.

Vetter, H. and F. Kuba, 1963. Trockensubstanz- und Nährstofferträge bei gesteigerter Nutzungshäufigkeit und Stickstoffdüngung in Weiden und Wiesenversuchen in Hohenschulen. Z. f. Acker- und Pflanzenbau 116, 372-394.

Wachendorf, M., A. Kornher, F. Taube and J.-H. Teten, 1995. Ertragsbildung und Qualitätsentwicklung von Rotklee und Rotklee-Gras-Gemengen, simuliert mit witterungs-basierten Modellen. Schriftenreihe der Agrarwissenschaftlichen Fakultät der Universität Kiel No. 78, Vorträge zur Hochschultagung 1995, 55-61.

Wilhelmy, B., A. Kornher and F. Taube, 1991. Leistungsfähigkeit weißkleebasierter Produktionssysteme auf dem Dauergrünland in Abhängigkeit von der Nutzungshäufigkeit und der Stickstoffdüngung. Jahrestagung der Arbeitsgemeinschaft Grünland und Futterbau, Bad Hersfeld.

Wilman, D., A. Koocheki and A.B. Lwoga, 1976. The effect of interval between harvests and nitrogen application on the proportion and yield of crop fractions and on the digestibility and digestible yield and nitrogen content and yield of two perennial ryegrass varieties in the second harvest year. J. agric. Sci., Camb. 87, 59-74.

Windisch, W., M. Kirchgeßner and M. Kreuzer, 1991. Güllemenge bei laktierenden Milchkühen in Abhängigkeit von der Leistungsintensität. Agribiol. Res. 44, 170-181.

Table 1: Effect of cutting frequency and fertilization level upon forage production and composition (N=24)

Fertilization	ha^{-1} $year^{-1}$	32 m³ slurry			32 m³ slurry + 100 kg N			RSD	P values		
Cuts per year		2	3	4	2	3	4		Cut	Fert	C x F
Grassland yield											
Dry matter	kg ha^{-1}	8296	7650	6207	9000	8458	6812	4.69	0.000	0.002	0.910
Energy (NEL)	GJ ha^{-1}	36.53	40.89	35.56	41.40	44.49	38.16	2.52	0.001	0.003	0.673
Protein	kg ha^{-1}	928	1025	1022	1054	1061	1041	62	0.250	0.031	0.217
Nutrient content											
Crude protein	g kg^{-1} DM	112	134	164	117	125	153	6	0.000	0.076	0.048
Crude fat	g kg^{-1} DM	23	21	23	20	22	23	4	0.625	0.725	0.387
Crude fibre	g kg^{-1} DM	312	285	242	310	285	247	17	0.000	0.896	0.923
Crude ash	g kg^{-1} DM	78	87	100	89	85	101	7	0.001	0.261	0.191
NDF	g kg^{-1} DM	613	539	474	594	548	470	15	0.000	0.453	0.236
ADF	g kg^{-1} DM	362	318	284	354	323	284	9	0.000	0.783	0.421
ADL	g kg^{-1} DM	45	35	31	44	34	30	2	0.000	0.557	0.912
Digestibility (OM)	%	55.7	65.8	70.0	58.4	65.0	69.1	2.0	0.000	0.668	0.135
ME	MJ kg^{-1}DM	7.81	9.16	9.70	8.07	9.06	9.52	0.27	0.000	0.959	0.271
NEL	MJ kg^{-1}DM	4.42	5.34	5.73	4.61	5.28	5.61	0.18	0.000	0.982	0.231
Calcium	g kg^{-1} DM	4.4	5.8	7.1	5.5	5.8	7.1	0.7	0.000	0.192	0.160
Phosphorus	g kg^{-1} DM	2.0	2.4	2.6	2.0	2.3	2.7	0.1	0.000	0.382	0.006
Potassium	g kg^{-1} DM	21.3	23.1	25.4	20.6	22.2	25.5	0.8	0.000	0.169	0.477
Botanical and plant composition											
Grasses	g kg^{-1} DM	87.3	68.8	60.2	85.4	77.2	69.1	3.2	0.000	0.001	0.006
Legumes	g kg^{-1} DM	4.7	12.2	17.9	5.5	5.9	11.1	2.3	0.000	0.001	0.007
Herbs	g kg^{-1} DM	8.0	18.9	21.9	9.1	16.9	19.9	2.6	0.000	0.375	0.408
Stems	g kg^{-1} DM	51.3	43.8	36.4	53.7	42.8	37.0	3.1	0.000	0.590	0.576
Leaves	g kg^{-1} DM	48.7	56.2	63.6	46.3	57.2	63.0	3.1	0.000	0.590	0.576

Table 2: Effect of cutting frequency, fertilization and concentrate level upon animal performances (Main effects)

Main effects		Cutting frequency			Fertilization		Concentrate level			RSD	P values					
Levels		2	3	4	S	SN	Co	Cs	Cc		Cut. frequ	Fert. level	Conc level	Cut.* Fert.	Cut.* Conc	Fert* Conc
Number of cows	n	61	59	59	89	90	57	61	61	-						
Live weight	kg	599	629	626	617	619	599	632	623	40	0.000	0.662	0.000	0.490	0.847	0.094
Feed and nutrient intake (cow^{-1} day^{-1})																
Forage	kg DM	10.45	13.15	15.32	13.13	12.82	14.61	11.98	12.33	1.44	0.000	0.156	0.000	0.912	0.031	0.192
Energy concentrate	kg DM	3.40	3.13	2.83	3.05	3.19	0.00	5.17	4.28	0.98	0.009	0.339	0.000	0.528	0.000	0.144
Protein concentrate	kg DM	0.05	0.04	0.00	0.03	0.03	0.00	0.03	0.05	0.10	0.049	0.656	0.049	0.635	0.190	0.542
Total feed	kg DM	13.98	16.39	18.22	16.28	16.11	14.62	17.25	16.72	1.57	0.000	0.498	0.000	0.940	0.000	0.063
Crude protein	g	1656	2148	2749	2212	2156	1970	2318	2264	258	0.000	0.164	0.000	0.122	0.000	0.265
Utilizable protein	g	1667	2104	2467	2089	2070	1794	2260	2185	215	0.000	0.576	0.000	0.812	0.000	0.114
Utilizable protein balance	g	111	188	229	176	177	143	184	203	111	0.000	0.971	0.018	0.536	0.019	0.673
Energy	MJ NEL	71.9	92.0	107.6	90.7	90.3	76.5	99.3	95.7	9.5	0.000	0.774	0.000	0.885	0.000	0.100
Energy balance	MJ NEL	-10.1	-3.1	1.8	-4.0	-3.6	-9.2	-1.1	-1.2	6.3	0.000	0.704	0.000	0.997	0.003	0.357
N balance in rumen	g	-2	7	45	20	14	28	9	13	19	0.000	0.039	0.000	0.002	0.400	0.943
Ration characteristics																
Concentrate	% of DMI	22.5	17.9	15.0	17.9	19.1	0.0	30.1	26.0	5.0	0.000	0.096	0.000	0.751	0.000	0.261
Crude protein cont.	g kg^{-1} DM	119	132	151	135	133	134	134	134	7	0.000	0.148	0.887	0.000	0.008	0.633
Digestibility of OM	%	62.1	67.4	71.1	66.6	67.1	63.9	68.6	68.1	1.9	0.000	0.050	0.000	0.083	0.000	0.439
Energy content	MJ NEL	5.08	5.58	5.89	5.50	5.53	5.14	5.74	5.67	0.19	0.000	0.222	0.000	0.363	0.000	0.271
Ratio CP/ME	g MJ^{-1}	13.65	13.90	15.25	14.37	14.16	15.02	13.83	13.95	0.94	0.000	0.147	0.000	0.003	0.330	0.744
Milk yield (cow^{-1} day^{-1})																
Milk (actual)	kg	14.53	18.43	21.60	18.41	17.96	15.92	19.76	18.88	2.46	0.000	0.236	0.000	0.666	0.002	0.135
ECM (actual)	kg	14.71	18.39	21.83	18.45	18.17	15.86	20.03	19.04	2.35	0.000	0.433	0.000	0.918	0.000	0.350
ECM (computed)	kg	11.51	17.43	22.38	17.19	17.02	12.96	19.69	18.67	2.98	0.000	0.715	0.000	0.962	0.000	0.119
Fat content	%	4.17	3.99	4.03	4.05	4.07	4.07	4.08	4.04	0.41	0.044	0.740	0.842	0.187	0.028	0.086
Protein content	%	3.17	3.22	3.33	3.23	3.25	3.12	3.32	3.28	0.22	0.001	0.557	0.000	0.134	0.118	0.931
Lactose content	%	4.74	4.83	4.91	4.83	4.84	4.75	4.89	4.85	0.16	0.000	0.691	0.000	0.596	0.020	0.180
Excretion (cow^{-1} day^{-1})																
Faeces	kg DM	5.41	5.61	5.62	5.61	5.49	5.36	5.72	5.56	0.57	0.094	0.191	0.006	0.522	0.017	0.048
Urine	kg	11.03	15.36	22.70	16.46	16.27	17.72	15.62	15.76	2.30	0.000	0.587	0.000	0.881	0.077	0.697
Slurry (10 % DM)	kg	61.7	66.9	71.0	67.2	65.9	65.0	68.2	66.4	6.4	0.000	0.170	0.036	0.555	0.031	0.122
Nitrogen	g	193	257	334	268	255	250	272	263	30	0.000	0.007	0.001	0.830	0.007	0.617
N content of excretions																
Faeces	g kg^{-1} DM	22.2	27.2	31.8	27.3	26.8	26.2	27.9	27.1	1.8	0.000	0.102	0.000	0.332	0.014	0.752
Urine	g kg^{-1}	6.83	6.90	6.88	7.08	6.67	6.16	7.36	7.09	0.84	0.897	0.002	0.000	0.195	0.105	0.960
Slurry (10 % DM)	g kg^{-1}	3.14	3.86	4.71	3.96	3.85	3.80	3.99	3.92	0.32	0.000	0.022	0.006	0.080	0.216	0.454
DM content of slurry	g kg^{-1}	113	106	103	107	107	103	109	109	7	0.000	0.536	0.000	0.029	0.478	0.773
N balance (cow^{-1} day^{-1})																
N intake	g	265	344	440	354	345	315	371	362	41	0.000	0.164	0.000	0.122	0.000	0.265
N excretion faeces	g	121	153	179	153	148	141	159	152	18	0.000	0.056	0.000	0.828	0.001	0.115
N excretion urine	g	72	104	155	114	107	108	113	111	17	0.000	0.007	0.346	0.272	0.088	0.830
N excretion milk	g	72	93	112	93	92	78	103	97	12	0.000	0.572	0.000	0.947	0.001	0.139
N balance	g	0	-6	-7	-7	-2	-12	-4	3	25	0.245	0.234	0.011	0.013	0.260	0.787

Table 3: Effect of cutting frequency and concentrate level upon animal performances (Interactions)

Concentrate level		No concentrate			Conc. acc. standards			Concentrate constant		
Cutting frequency		2	3	4	2	3	4	2	3	4
Number of cows		19	19	19	20	22	19	22	18	21
Live weight		575	614	608	619	642	636	602	630	635
Feed and nutrient intake (cow^{-1} day^{-1})										
Forage	kg DM	11.56	14.98	17.29	9.38	12.01	14.56	10.40	12.47	14.12
Energy concentrate	kg DM	0.00	0.00	0.00	6.79	5.02	3.69	3.58	4.31	4.94
Protein concentrate	kg DM	0.00	0.00	0.00	0.03	0.05	0.00	0.10	0.05	0.00
Total feed	kg DM	11.56	14.98	17.29	16.29	17.14	18.30	14.18	16.89	19.10
Crude protein	g	1285	1987	2637	1974	2232	2749	1707	2225	2860
Utilizable protein	g	1242	1872	2269	2064	2235	2499	1713	2207	2634
Utilizable protein balance	g	36	171	221	176	171	205	123	222	262
Energy	MJ NEL	51.8	80.4	97.3	90.0	98.4	109.6	74.0	97.2	115.8
Energy balance	MJ NEL	-17.5	-7.4	-2.6	-3.7	-1.0	1.5	-9.2	-0.7	6.3
N balance in rumen	g	7	19	59	-12	-1	40	-1	3	36
Ration characteristics										
Concentrate	% of DMI	0.0	0.0	0.0	42.0	28.4	19.9	26.2	25.8	26.0
Crude protein	g kg^{-1} DM	115	133	154	122	131	151	121	132	149
Digestibility of OM	%	57.3	65.2	69.2	65.7	68.3	71.7	63.3	68.6	72.3
Energy concentration	MJ NEL	4.52	5.28	5.62	5.51	5.71	5.99	5.20	5.74.	6.07
Ratio CP/ME	g MJ^{-1}	14.39	14.59	16.07	12.99	13.49	14.99	13.56	13.60	14.68
Milk yield (cow^{-1} day^{-1})										
Milk (actual)	kg	10.90	16.79	20.06	17.49	19.70	22.11	15.21	18.81	22.62
ECM (actual)	kg	11.02	16.34	20.22	18.10	19.57	22.41	15.01	19.27	22.85
ECM (computed)	kg	5.49	13.99	19.40	16.93	19.24	22.89	12.12	19.05	24.84
Fat content	%	4.25	3.86	4.09	4.28	3.95	4.02	3.98	4.15	3.98
Protein content	%	3.09	3.04	3.23	3.30	3.32	3.35	3.14	3.30	3.41
Lactose content	%	4.60	4.77	4.89	4.89	4.87	4.93	4.75	4.87	4.93
Excretion (cow^{-1} day^{-1})										
Faeces	kg DM	5.01	5.47	5.59	5.85	5.75	5.55	5.37	5.60	5.72
Urine	kg	11.81	16.49	24.87	10.51	14.31	22.03	10.79	15.28	21.21
Slurry (10 % DM)	kg	57.6	66.0	71.4	66.2	67.8	70.5	61.3	66.8	71.3
Nitrogen	g	166	250	334	217	262	336	195	260	332
N content of excretions										
Faeces	g kg^{-1} DM	20.5	26.6	31.5	23.9	27.5	32.2	22.1	27.5	31.8
Urine	g kg^{-1}	5.78	6.29	6.42	7.57	7.35	7.17	7.15	7.08	7.05
Slurry (10 % DM)	g kg^{-1}	2.93	3.78	4.68	3.30	3.90	4.78	3.19	3.91	4.66
DM content of slurry	g kg^{-1}	108	101	99	116	108	103	113	108	105
N balance (cow^{-1} day^{-1})										
N intake	g	206	318	422	316	357	440	273	356	458
N excretion faeces	g	102	146	176	141	158	179	119	154	182
N excretion urine	g	63	103	158	77	104	158	76	106	150
N excretion milk	g	52	80	101	90	102	116	74	97	120
N balance	g	-12	-12	-12	9	-7	-13	4	-1	5

Table 4: Effect of cutting frequency, fertilization and concentrate level upon milk yield and excretion per year and per unit forage area (Main effects)

Main effects		Cutting frequency			Fertilization		Concentrate level			RSD	P values					
Levels		2	3	4	S	SN	Co	Cs	Cc		Cut.	Fert.	Conc.	Cut.*	Cut.*	Fert*
Number of cows	n	61	59	59	89	90	57	61	61	-	frequ.	level	level	Fert.	Conc.	Conc.
Milk yield and excretion per year																
Milk (actual)	kg ECM	4515	5478	6405	5502	5430	4903	5862	5634	605	0.000	0.434	0.000	0.922	0.001	0.220
Milk (computed)	kg ECM	3512	5315	6826	5243	5192	3953	6005	5695	908	0.000	0.715	0.000	0.962	0.000	0.119
Slurry (10 % DM)	kg	22506	24407	25932	24529	24035	23718	24875	24253	2337	0.000	0.170	0.036	0.555	0.031	0.122
Nitrogen	kg	70.4	93.9	121.9	97.7	93.1	91.1	99.2	95.9	10.8	0.000	0.007	0.001	0.830	0.007	0.617
Milk yield and excretion per year and ha forage																
Stocking rate	animals ha^{-1}	2.25	1.66	1.16	1.53	1.72	1.44	1.76	1.71	0.26	0.000	0.000	0.000	0.345	0.076	0.197
Milk (actual)	kg ECM	10148	9119	7439	8402	9345	7057	10319	9620	1228	0.000	0.000	0.000	0.617	0.000	0.245
Milk (computed)	kg ECM	7894	8847	7928	8007	8935	5690	10571	9725	1444	0.003	0.000	0.000	0.956	0.000	0.100
Slurry (10 % DM)	kg	50585	40628	30119	37459	41363	34137	43787	41413	4138	0.000	0.000	0.000	0.702	0.000	0.545
Nitrogen	kg	158.2	156.3	141.6	149.2	160.2	131.1	174.6	163.8	16.7	0.000	0.000	0.000	0.857	0.000	0.482
N balance in soil (fert.)	kg	64	74	97	39	113	77	75	75	12	0.000	0.000	0.501	0.078	0.780	0.980
N balance in soil (excr.)	kg	85	86	98	48	131	73	104	95	15	0.000	0.000	0.000	0.050	0.000	0.609

Table 5: Effect of cutting frequency and concentrate level upon milk yield and excretion per year and per unit forage area (Interactions)

Concentrate level		No concentrate			Conc. acc. standards			Concentrate constant		
Cutting frequency		2	3	4	2	3	4	2	3	4
Number of cows		19	19	19	20	22	19	22	18	21
Milk yield and excretion per year										
Milk (actual)	kg ECM	3668	5007	6033	5305	5761	6519	4572	5666	6663
Milk (computed)	kg ECM	1676	4267	5917	5163	5870	6983	3697	5809	7577
Slurry (10 % DM)	kg	21007	24096	26051	24147	24744	25735	22365	24382	26011
Nitrogen	kg	60.4	91.2	121.7	79.4	95.6	122.7	71.3	95.0	121.3
Milk yield and excretion per year and ha forage area										
Stocking rate	animals ha^{-1}	2.03	1.46	1.03	2.51	1.82	1.23	2.26	1.76	1.25
Milk (actual)	kg ECM	7441	7299	6209	13312	10487	7998	10319	9982	8362
Milk (computed)	kg ECM	3400	6220	6090	12956	10686	8568	8344	10234	9509
Slurry (10 % DM)	kg	42617	35126	26812	60595	45043	31576	50479	42954	32644
Nitrogen	kg	122.5	132.9	125.3	199.2	174.0	150.5	160.9	167.4	152.2
N balance in soil (fert.)	kg	67	73	99	62	75	95	64	72	96
N balance in soil (excr.)	kg	61	68	88	113	101	104	87	93	106