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

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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, conserved as barn-dried hay and fed to dairy cows at three concentrate levels [zero, concentrate according to requirements or 25% of dry matter (DM) intake concentrate]. Fertilisation levels were 32 m^3 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 were related to the forage area there was only a small influence of cutting frequency at the low level of concentrate. When the forage was supplemented with concentrate according to requirements, both milk yield and N excretion per ha decreased with increasing cutting frequency. Additional fertilisation of 100 kg mineral N increased the amount of slurry from 37.5 to 41.4 m^3 ha^{-1} forage and excretion of N from 149 to 160 kg ha^{-1} forage. © 1999 Elsevier Science B.V. All rights reserved.

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

1. Introduction

In recent years there has been much public concern and discussion about the role of agriculture in environmental pollution. In industrial countries intensification of plant and animal production was realised by bringing large external inputs of fuel, fertiliser 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, according to the dairy farm system. In an experiment on whole-farm budgeting of manure nutrients in the USA, only 55% of the 1037 kg nitrogen (N) excreted by 10.4 cows per ha, were taken up by the forage plants, and from the total of 1492 kg N consumed by the cows, 62% were purchased (van Horn et al., 1996). A high N surplus also exists in specialised dairy farms of countries like the Netherlands. Korevaar (1992), summarising 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 from high fertilisation rates on grassland, and a high concentrate consumption per cow, are predominantly responsible for the increase of stocking rates (Korevaar, 1992). Based

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on model calculations, van Bruchem et al. (1997) conclude that reducing the external inputs of fertiliser N is the only effective measure for reducing N losses in the Netherlands. According to these authors, whilst intensive dairy farming systems in the Netherlands are characterised by high external N inputs from concentrates (244 kg ha^{-1}; 40% of total feed N) and from mineral fertiliser (364 kg ha^{-1}; 49% of total fertiliser), environmentally balanced dairy farms importing only 114 kg N through concentrates (27% of total feed N) and 158 kg N through mineral fertiliser (35% of total fertiliser) could reduce N losses in the soil from 46 to 37% and improve N utilisation efficiency by the cow from 17 to 25%. Simon et al. (1994) state, that N fertilisation, 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.

In contrast 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).

Peyraud et al. (1995) pointed out, that the forage system (e.g. based on forage maize or grass), the level of N fertilisation, the level of milk production (dilution of maintenance requirements) and 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 and Steinwidder (1996). A decrease of N required per kg of milk with increasing total milk yields was also emphasised by Kirchgeßner et al. (1991) and Flachowsky (1992). However, it should not be overlooked that the N required 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).

Gruber and Steinwidder (1996) calculated, on the basis of a literature review, that N excretions of dairy cows under Alpine growing conditions accounted for between 90 and 180 kg per ha forage area depending on milk yield and forage quality. In their calculations, the stocking rate (i.e. number of cows per forage area) decreased with increasing forage quality due to lower grassland dry matter (DM) yield and higher cow forage intake.

There is no doubt that the amount of protein intake is the major determining factor for the level of N excretion per cow (Kirchgeßner et al., 1991). Tamminga (1992) described the losses of N ingested in the 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 to be constant (about 7.5 g kg^{-1} DMI), all the N ingested in excess will be excreted in urine (Peyraud et al., 1995). For accurate calculations, the variation of true digestibility, variation of body composition, ageing of cows and synchronicity of carbohydrate and nitrogen degradation in the rumen have necessarily to be considered in a real situation.

Under conditions of production typical 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 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 fertilisation and cutting frequency would have an effect on the N cycle of a farm through its impact on both the DM yield and the nutrient content of the forage (protein, digestibility). Very high fertilisation levels 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 fertilisation is kept constant (Klapp, 1951; Mott, 1962; Vetter and Kuba, 1963; Bommer, 1964; Wilman et al., 1976; Wilhelmy et al., 1991;

Buchgraber and Pötsch, 1994; Wachendorf et al., 1995). 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, level of N fertilisation in permanent grassland and concentrate supplementation on N excretion and milk yield of dairy cows under Alpine growing conditions. Equations for predicting manure and N excretion from information currently available from dairy farms are developed from the results gained.

2. Material and methods

2.1. Experimental design

A three-factorial design was used to study the effects of cutting frequency and fertilisation level on DM yield of grassland, quality of forage and on animal feeding and N balance, according to concentrate distribution ($3 \times 2 \times 3$):

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)
Fertilisation level	[S]	32 m^3 ha^{-1} slurry (10% DM), corresponding to 100 kg N
	[SN]	32 m^3 ha^{-1} slurry plus 100 kg ha^{-1} mineral nitrogen
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 experiment

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 typical species of moist meadows (reseeded 3 years before start of the trial). One year before starting the experiment, the meadows consisted of 76 and 68% grasses, 10 and 21% legumes and 14 and 11% herbs, respectively (DM basis). Each meadow was divided into six plots of differing area to take into account expected differences in yield and forage intake due to experimental treatments. Three plots were fertilised as treatment S and three as treatment SN. The actual amount of N was 102.6 and 202.3 kg N ha^{-1} in plots S and SN. Fertilisers 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 composition of the cuts between grasses, legumes and herbs, and the percentage of leaves were assessed from fresh herbage samples. The yield of each period of 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

Feeding and N balance trials using 12 cows each were carried out every winter feeding period following the harvest year (total $n = 180$); data from one cow were rejected due to health problems and the final number of animals was 179. Sixty of the cows were Simmental, 58 were Brown Swiss and 61 were of the Holstein Friesian breed; 54 cows were used once during the 4-year experiment, 28 were used twice, 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 allocating them to the treatment groups, along with breed and parity. The average milk yield in the pre-experimental week was 22.3, 23.2 and 27.8 kg energy corrected milk (ECM) for the Simmental, Brown Swiss and Holstein Friesian cows, respectively. The average milk yield and feed intake for the cutting frequency levels 2, 3 and 4, was 24.6, 24.5 and 24.2 kg ECM and 18.3, 18.3 and 18.1 kg DM, respectively, during the same period.

The feeding trial lasted for 12 weeks from day 100 to day 200 of lactation. All harvests from each cutting frequency level were fed together corresponding to the DM yield in a feeding trial. 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 of 5–10%. A pre-treatment period of 4 weeks before the beginning of the experiment was used. During the first week the animals received a ration of average quality hay, to become ruminally adapted; during the second week the cows were fed according to energy requirements (GEH, 1986) and the milk yield was recorded to obtain covariates for milk yield potential in the statistical analyses. In the third week, cows received a ration consisting of 2/3 hay and 1/3 concentrates, 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 order 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 the 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 times were 04.30–08.30 a.m. and 03.00–07.00 p.m.

In the N 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 analysis used conventional methods as described by ALVA (1983) using devices of Tecator. The energy content of the forages was calculated according to GfE (1995) using the digestibility coefficients elaborated in the balance trials with the cows. In the treatment groups receiving 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 of protein was computed on the basis of the German protein evaluation system (GfE, 1997). The milk samples from the morning and evening milkings were mixed and analysed for fat, protein and lactose every day throughout the experiment (Milkoscan NIRS instrument). ECM 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):

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

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

$$\mathrm{ECM}_{305} = 275.5\ \mathrm{ECM}_{\mathrm{week}} + 69.9\ \mathrm{WEEK} - 1242\,b + 18.4\ \mathrm{BAL}_{\mathrm{NEL}} - 175.4\ \mathrm{NEL} + 51.4\,b - 23.8\ \mathrm{CONC}$$

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

ECM_{305}, $\mathrm{ECM}_{\mathrm{week}}$ = kg ECM in 305 days, in ith 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)

$\mathrm{BAL}_{\mathrm{NEL}}$ = 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 analysed using the LSMLMW computer program (Harvey, 1987) and Statgraphics® Plus (1996). The model terms were the fixed effects 'Cutting frequency', 'Fertilisation 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 fertilisation level upon forage production and composition

The DM yield of grassland significantly decreased with increasing cutting frequency, especially when cutting four times per year (Table 1). The pooled average DM yields of the two fertilisation levels were 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. The reduction of DM yield of grassland associated with cutting frequency is due to many factors (Klapp, 1951; Vetter and Kuba, 1963). The development of the plants is interrupted before the maximum daily growth is reached, the development of the roots and the storage of nutrient reserves is lower, and changes occur in the botanical composition. The depressing effect of cutting can be compensated for by higher N fertilisation rates (Vetter and Kuba, 1963; Bommer, 1964; Buchgraber and 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 the three cutting frequency levels), but no interaction was found between cutting frequency and fertilisation level. The N fertilisation

Table 1
Effect of cutting frequency and fertilisation level upon forage production and composition ($n = 24$)

Fertilisation (ha^{-1} $year^{-1}$)	32 m^3 slurry			32 m^3 slurry + 100 kg N			RSD	*P* values		
Cuts per year	2	3	4	2	3	4		Cut.	Fert.	C×F
Grassland yield										
Dry matter (kg ha^{-1})	8296	7650	6207	9000	8458	6812	4.7	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 (%)	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

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 resulting mean N fertilisation efficiency of 7.1 kg DM kg^{-1} N is in the lower range of figures reported in literature. Under similar growing conditions Jo and Schechtner (1990) determined N fertilisation efficiencies of 8–16 kg DM kg^{-1} N and in Switzerland, Künzli (1968) found the N fertilisation efficiency was 12.9 kg DM kg^{-1} N (mean of 5 years and four sites). At very high fertilisation levels (300–400 kg mineral N ha^{-1}), Rieder (1973) determined an increase in DM yield of 9.4 kg kg^{-1} N. In long-term experiments Müller (1985) found that 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}).

The yield of NEL was highest at the medium cutting frequency, whereas the yield of crude protein was not significantly different between the three cutting regimes.

As expected, the cutting regime showed significant influences ($P<0.001$) on the feeding value of the forages (Table 1). 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. 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. Those factors might have had an impact on the nutritive value. The fertilisation level had no significant influence on the nutritive parameters and there were no interactions between cutting frequency and fertilisation level. The slightly lower protein content at the higher fertilisation rate is probably due to the higher proportion of grasses, which are of lower protein content and to the harvest date which was the same for both fertiliser treatments. As a consequence, higher fertilised swards were at a slightly higher stage of growth, resulting in marginally lower protein and higher crude fibre contents. These changes in the nutrient content during vegetation are well documented in the literature (Minson, 1990; Van Soest, 1994).

3.2. Effect of the factors (cutting frequency, fertilisation and concentrate) on animal performance

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 ($P<0.001$; Table 2). Minson (1990) pointed out that a 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 three of these factors can be considered with the present results. 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, which is close to the value for intake capacity (12.5) reported by Mertens (1994). Feed intake was slightly lower with mineral nitrogen fertilisation. On average, concentrate intake was lower with high cutting frequency in group Cs (concentrate according to standards). Substitution ratio of forage for concentrate averaged 0.43 kg DM, although it was higher with good quality forage (Table 2). Such results are consistent with the INRA fill unit system (INRA, 1989) which considers that substitution rate increases with increasing energy density.

Cutting frequency increased protein and energy intake with both the higher intake and the higher concentration. However, protein intake 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 were 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 utilisable 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 calculated from energy supply).

Concerning the protein supply of cows based on the protein evaluation of GfE (1997), there was a surplus of utilisable crude protein reaching the

Table 2
Effect of cutting frequency, fertilisation and concentrate level upon animal performances (main effects)

Main effects	Cutting frequency			Fertilisation		Concentrate level			RSD	*P* values					
Levels	2	3	4	S	SN	Co	Cs	Cc		Cut. freq.	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 kg^{-1} DM)	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)	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

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 are often subjected to great variations. Kreuzer and Kirchgeßner (1985), Kaufmann and Kirchgeßner (1987) and Peyraud et al. (1997) reported variations of similar magnitude (up to 21 g RSD).

Due to the short length of the balance trial, the results of milk yield have to be interpreted with care. Theoretical milk yields calculated from the energy supply were 11.5, 17.4 and 22.4 kg ECM day^{-1} for cutting frequencies 2, 3 and 4, whilst the observed 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 (Table 2), 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 quality forage can only be compensated with high concentrate levels to a limited extent.

3.2.2. Excretions and N balance

The excretion of faeces per animal was nearly the same in the three cutting frequency levels (5.55 kg DM), the increase of feed intake and improvement of digestibility being therefore balanced (Table 2). Although significantly different, 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 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%) were increased from 61.7 to 66.9 and 71.0 kg animal^{-1} day^{-1} and they were significantly higher with concentrate feeding. The DM content of slurry decreased with increasing cutting frequency from 11.3 to 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 (Table 2). The faecal N content increased markedly with cutting frequency (22 to 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 (Table 2). The excretion of excess N by dairy cows was therefore controlled 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 in the respective treatment groups. This corresponds well to the calculated N surplus in the rumen. Excessive protein in high-protein diets is turned into ammonia, which is absorbed from the 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. Nitrogen bound in urine is more critical from an ecological point of view than faecal N which is only slowly mineralised (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 synthesise 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 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 increasing 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 ($P<0.001$) 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 (Table 2). 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) and Peyraud et al. (1995), and show the great influence of the ration composition and milk yield on N excretion. According to these authors and to Flachowsky (1992), two main factors are responsible for higher N efficiency when feeding concentrate, (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).

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, whereas the fertiliser level seldom showed significance. At the animal performance level, almost no significant interactions were detected between cutting frequency and fertilisation nor between fertilisation 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. The animal performance data for the cutting frequency × 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 quality forage, a higher concentrate intake is necessary than with high quality forage. 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 lower level, the effect of forage quality on milk yield was more pronounced at a low concentrate feeding than at a higher one. This can be seen especially in the so called milk yield 'computed' (Tables 2–5), i.e. milk calculated 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 from the calculated energy balance, the high degree of body reserve mobilisation can be derived, which presumably has taken place especially in treatment Co × 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 and 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

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 (kg)	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 kg^{-1} DM)	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

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 forage hectare. The figures of milk yield and excretion per animal and 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 animal per year estimated from the observed milk yield of the balance trial was calculated to be 4515, 5478 and

Table 4
Effect of cutting frequency, fertilisation and concentrate level upon annual milk yield and excretion per animal and per unit forage area (main effects)

Main effects	Cutting frequency			Fertilisation		Concentrate level			RSD	*P* value					
Levels	2	3	4	S	SN	Co	Cs	Cc		Cut. freq.	Fert. level	Conc. level	Cut. × Fert.	Cut. × Conc.	Fert. × Conc.
Number of cows (*n*)	61	59	59	89	90	57	61	61	–						
Milk yield and excretion per year and cow															
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)	22 506	24 407	25 932	24 529	24 035	23 718	24 875	24 253	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)	10 148	9119	7439	8402	9345	7057	10 319	9620	1228	0.000	0.000	0.000	0.617	0.000	0.245
Milk (computed) (kg ECM)	7894	8847	7928	8007	8935	5690	10 571	9725	1444	0.003	0.000	0.000	0.956	0.000	0.100
Slurry (10% DM) (kg)	50 585	40 628	30 119	37 459	41 363	34 137	43 787	41 413	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 annual milk yield and excretion per animal 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 (*n*)	19	19	19	20	22	19	22	18	21
Milk yield and excretion per year and cow									
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)	21 007	24 096	26 051	24 147	24 744	25 735	22 365	24 382	26 011
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	13 312	10 487	7998	10 319	9982	8362
Milk (computed) (kg ECM)	3400	6220	6090	12 956	10 686	8568	8344	10 234	9509
Slurry (10% DM) (kg)	42 617	35 126	26 812	60 595	45 043	31 576	50 479	42 954	32 644
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

6405 kg ECM in cutting frequencies 2, 3 and 4. From the figures for 'computed' milk yield from energy supply (Table 4) it can be concluded that the mobilisation in cutting frequency 2 corresponds to 1000 kg ECM per lactation (mean of all concentrate levels). The same difference of 1000 kg ECM between 'actual' milk and 'computed' milk yield was found in the zero concentrate (Co) cows (mean of all cutting frequency levels). Gruber and 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 mobilise 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 forage hectare, the stocking rate has to be taken into account. It is calculated as: DM yield ha^{-1}/(forage DM intake $day^{-1} \times 365$). All three factors considered in the present experiment played an important role in affecting the stocking rate (Table 5): (1) cutting frequency decreased DM yield of grassland and increased forage DM intake (2) N fertilisation increased DM yield of grassland and (3) concentrate decreased forage DM intake. 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 fertiliser levels S and SN, and 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 ($P = 0.076$; Table 5). These stocking rates are used to calculate the milk production (and nutrient excretion) per unit forage area (Tables 4 and 5). They are the cardinal point for further discussion. 'Actual' milk yield was 10 150, 9120 and 7440 kg ECM ha^{-1} in cutting frequency 2, 3 and 4. However the 'computed' milk yield, which indicates more about the effective energy supply due to presumably high mobilisation 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). Fertilising with 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, 10 570 and 9730 kg ECM ha^{-1} in Co, Cs and Cc).

Because of the significant interaction ($P < 0.001$) 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 three cutting frequencies, with Co rations. However, 'computed' milk ha^{-1} increased from cutting frequency 2 to 3 and was similar in 3 and 4 (3400, 6220 and 6090 kg ECM ha^{-1}). Supplementing deficient energy rations with concentrates according to standards (Cs), decreased 'computed' milk ha^{-1} with increasing cutting frequency (12 960, 10 690, 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) the importance of forage quality depended on concentrate level (2) too high a 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 to dairy cow nutrition, especially with cows of high milk yield potential and in that stage of lactation which has high milk yields.

3.4.2. Excretion of manure and nitrogen

The excretion of slurry and nitrogen per animal $year^{-1}$ 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). Fertilising with 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 than in the case of feeding concentrates (Cs) according to standards (Table 5). 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 three cutting frequency levels (123, 133 and 125 kg ha^{-1}), the increase of excretion per animal (amount and concentration) equalising the decrease in stocking rate. On the other hand, it decreased with increasing cutting frequencies when supplementing the forage ration with concentrates according to standards (199, 174 and 151 kg ha^{-1}).

The 'N balance in the soil' can be calculated as the difference between N input (fertilisation with slurry and mineral N, N fixation by legumes (3 kg N ha^{-1} per % of legumes), N mineralisation (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 a relative comparison. With increasing cutting frequency, the surplus of N in the soil tended to increase (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 fertilisation on DM yield in the present grassland experiment it is clear, that mineral N fertilisation 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 applied [32 m^3 ha^{-1}, corresponding to 100 kg 'field falling N', N balance in soil 'fert(ilised)'], but also considering the effective amount of N excretion by the cows depending on the 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 N excretion per unit forage area, a significant influence of all three main effects on N balance in soil (excr.) would take place. The soil N balance (excr.) would increase with cutting frequency (85 to 98 kg N ha^{-1}), with fertiliser 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 balance in the case of feeding concentrates according to standards (Cc).

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) $Ec_S = 53.09 + 0.007\ LW + 0.028\ (IF \cdot XP_F) + 0.025\ (IC \cdot XP_C) + 0.336\ (IC \cdot NEL_C) - 0.011\ (IC \cdot XP_F) - 0.232\ (IC \cdot NEL_F) - 0.067\ (XP_T \cdot NEL_T)$
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) $Ec_S = 39.22 + 0.035\ LW + 1.846\ ECM - 4.998\ NEL_F - 0.159\ (IC \cdot NEL_C)$
RSD = 5.4, RSD = 8.1%, $R^2 = 69.5\%$

(2a) $Ec_N = -0.6 + 0.106\ (IF \cdot XP_F) + 1.153\ (IC \cdot NEL_C) + 0.0605\ (XP_T \cdot NEL_T)$
RSD = 27, RSD = 10.4%, $R^2 = 85.8\%$

(2b) $Ec_N = -259.8 + 0.137\ LW + 6.747\ ECM + 2.749\ P_{Conc} + 2.380\ XP_F - 0.02536\ (P_{Conc} \cdot XP_F)$
RSD = 31, RSD = 12.0%, $R^2 = 81.1\%$

(2c) $Ec_N = 10.5 + 0.144$ LW $+ 6.704$ ECM $- 41.608$ $NEL_F - 0.021$ $(IC \cdot XP_F) + 0.3709$ $(XP_F \cdot NEL_F)$
RSD = 31, RSD = 12.0%, $R^2 = 81.0\%$

Excretion per hectare forage area

(3a) $Ef_S = 4163 + 5.5$ DMYIELD $+ 2.5$ $(IF \cdot XP_F) -$ 156.5 $(IF \cdot NEL_F) + 10.3$ $(IC \cdot XP_C) + 665.2$ $(IC \cdot NEL_C) - 1006.2$ $(IC \cdot NEL_F) - 5.865$ $(XP_T \cdot NEL_T)$
RSD = 1814, RSD = 4.3%, $R^2 = 97.8\%$

(3b) $Ef_S = 54\,867 + 5.8$ DMYIELD $+ 6349.9$ $NEL_F -$ 326.5 $XP_T - 19\,160.0$ $NEL_T + 1674.0$ $P_{Conc} -$ 225.2 $(P_{Conc} \cdot NEL_F) + 65.7$ $(XP_T \cdot NEL_T)$
RSD = 1387, RSD = 3.3%, $R^2 = 98.7\%$

(3c) $Ef_S = 43\,547 + 5.7$ DMYIELD $- 192.9$ ECM $- 215.2$ $XP_F - 9837.2$ $NEL_F + 9.2$ $(IC \cdot XP_C) + 513.9$ $(IC \cdot NEL_C) - 693.4$ $(IC \cdot NEL_F) + 44.5$ $(XP_F \cdot NEL_F)$
RSD = 1713, RSD = 4.1%, $R^2 = 98.0\%$

(4a) $Ef_N = -156.25 + 0.024$ DMYIELD $- 0.486$ $(IF \cdot NEL_F) + 1.615$ $(IC \cdot NEL_C) - 1.840$ $(IC \cdot NEL_F) + 0.196$ $(XP_T \cdot NEL_T)$
RSD = 18.4, RSD = 11.6%, $R^2 = 79.2\%$

(4b) $Ef_N = -282.51 + 0.026$ DMYIELD $+ 13.823$ $P_{Conc} + 1.167$ $XP_F + 138.629$ $NEL_F - 127.565$ $NEL_T - 1.829$ $(P_{Conc} \cdot NEL_F)$
RSD = 17.0, RSD = 10.6%, $R^2 = 82.3\%$

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

4. Conclusion

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 fertilisation. There are significant interactions between nutritional and grassland management factors.

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 decreased at the concentrate level necessary to cover energy requirements) and (4) that the N balance in the soil increases with cutting frequency.

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