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The Effect of Grazing System and Level of Concentrate Protein Feeding on Milk Production and N Use Efficiency of Dairy Cows on Peat Meadows

Nyncke Hoekstra [1,*], Gertjan Holshof [2], Ronald Zom [2], Bert Philipsen [2], René Schils [3] and Nick van Eekeren [1]

[1] Louis Bolk Institute, Kosterijland 3–5, 3981 AJ Bunnik, The Netherlands; n.vaneekeren@louisbolk.nl
[2] Animal Nutrition, Wageningen University and Research, 6708 WD Wageningen, The Netherlands; gertjan.holshof@wur.nl (G.H.); ronald.zom@wur.nl (R.Z.); bert.philipsen@wur.nl (B.P.)
[3] Agrosystems Research, Wageningen Plant Research, 6708 PB Wageningen, The Netherlands; rene.schils@wur.nl
* Correspondence: n.hoekstra@louisbolk.nl; Tel.: +31-343-523-860

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Abstract: The aim of the study was to assess the effect of two contrasting grazing systems, strip-grazing and kurzrasen, at a high stocking rate on herbage intake and milk production and quality on a peat meadow. Additionally, we assessed the effect of the level of crude protein (CP) fed in concentrate on milk production and N use efficiency. Even at the relatively high stocking rates, cows still achieved substantial fresh grass intake (on average >6 kg dry matter cow^{-1} day^{-1}) from both systems. Despite the lower level of gross grass production under kurzrasen management, the difference in milk production between kurzrasen and strip-grazing was small and non-significant. Feeding concentrate with a lower CP level, had no negative impact on milk yield, provided that the CP content of the total ration remained above ~150 g kg^{-1} DM and milk urea content was above ~18 mg 100 g^{-1} milk. Reducing the CP content in the concentrate significantly increased the N use efficiency, and both were strongly related to the milk urea content. Therefore, optimising the use of milk urea as a management tool on dairy farms, also during the grazing season, could reduce N losses to the environment, while maintaining productivity.

Keywords: kurzrasen; strip-grazing; FPCM; fat and protein corrected milk yield; milk urea

1. Introduction

In northwestern Europe, grazed pastures form an important feed source for dairy production and grazing cows are important for the image of the dairy sector [1]. In the Netherlands, in recent decades, herd size has nearly doubled from 55 to 97 dairy cows per farm [2], whereas the available grassland area close to the farm yard remained the same [3]. This results in high(er) stocking rates on the grazed area, often in excess of 7.5 cows per ha, which makes it difficult to maintain a grazing system with access to pasture for more than six hours per day [3]. It is important to assess the effect of grazing system on the ability to convert grazed grass to milk under these high stocking rates [4].

Strip-grazing is a rotational grazing system in which cows are allocated a fresh strip of pasture (with back-fence) each day. The regrowth period between grazings may vary from two to three weeks depending on herbage growth rate and supply. This system generally results in the highest grass production and milk production. However, it is associated with relatively large investments in grazing infrastructure (cow paths and watering points) and labor requirements for moving fences, water supply and grassland planning.

Kurzrasen (KR) is a continuous grazing system that was developed in Switzerland and Germany and is gaining increasing interest. In contrast to conventional continuous grazing systems, which are grazed to approximately 8 cm sward height, for KR the target sward height is between 3 and 5 cm [5]. This combination of a very short rotation length (1 day) and low post-grazing height, results in a very high herbage utilization, but it is likely to have a negative effect on herbage production. In a companion paper, Hoekstra et al. [5] showed that the herbage dry matter production for KR was on average 18% lower compared to SG. Hoekstra et al. [5] found some evidence of a higher nutritional value of the ingested herbage under KR compared to SG. For KR, this consists mainly of protein- and energy-rich young leaf tips, which potentially results in a good conversion into milk. The sward density was higher for KR compared to SG, which had a positive impact on the load bearing capacity [5]. This is a major potential benefit of this system for the Dutch peat meadow region where load bearing capacity is often limited. Additionally, Ernst et al. [6], estimated that continuous grazing resulted in a 50% reduction of labor input and lower costs for infrastructure compared to intensive rotational grazing. In the current paper we assess the effect of two contrasting grazing systems—strip-grazing and kurzrasen—at a high stocking rate on herbage intake, and milk production and quality.

Grass has a high level of rumen degradable protein, which is often in excess of animal requirements and subsequently excreted in urine [7,8]. This N is prone to losses through volatilization, leaching and denitrification. Particularly in the Dutch peat meadow region, the herbage has a relatively high herbage crude protein (CP) content. In addition, there is limited scope to use high-energy roughage feed such as maize in the ration, because growing maize on peat soil is associated with soil degradation and high N losses [9]. Therefore, in the current experiment, we assessed the effect of the level of CP fed in concentrate feed on production and N balance, to adjust this imbalance and reduce losses to the environment.

We hypothesize that the herbage intake of grazed grass is lower for kurzrasen compared to strip-grazing as a result of lower pre-grazing herbage mass, and lower grass production. However, this is partly compensated by the higher quality and higher utilization of kurzrasen herbage, resulting in only a small reduction in milk yield per ha. We hypothesize that reducing the level of concentrate CP will not affect milk production, but will increase N utilization and reduce milk urea N, indicating lower losses to the environment.

2. Materials and Methods

2.1. Experimental Setup

The experiment was conducted at Knowledge Transfer Centre Zegveld (ZV) (52°08′25.8″N 4°50′19.7″E), which is situated on drained peat soil (Terric Histosols; FAO 2015) in the western peat area in the Netherlands (37.5% soil organic matter, 18% sand, 25% clay). The trial ran for two years in 2016 and 2017. The experimental treatments consisted of two grazing systems (strip-grazing = SG, kurzrasen = KR), two (2016, low and high CP) or three (2017, low, medium and high CP) levels of CP in the concentrate feed (high = HP, medium = MP, low = LP), and two cow breeds (Holstein Friesian = HF, Jersey = J) in a factorial design.

In each year, four independent groups were formed, each consisting of 15 cows on 2 ha, representing a stocking rate of 7.5 livestock units (LU) ha^{-1} on the grazing platform. The additional area, only used for silage production, was not taken into account. The swards were permanent, perennial ryegrass dominated grasslands [5]. In 2016, both the grazing system and CP level treatments were applied at the group level, whereas breed was nested within groups. In 2017, the grazing systems were applied at the group level and both the CP level and breed treatments were nested within the groups (Table 1). Sixty cows (36 Holstein Friesian and 24 Jersey) were assigned to 15 blocks based on parity, days in milk, milk yield and body weight (Table 2). Within blocks, cows were randomly allocated to one of four treatment groups.

Table 1. Overview of experimental set-up during 2016 and 2017. Each group or farmlet consisted of 9 Holstein Friesian (HF) and 6 Jersey cows on a 2 ha grazing platform. CP level treatments (LP = low CP; MP = medium CP; and HP = high CP content in concentrate) were applied at group level (2016) or within group level (2017).

	2016				**2017**			
Group/farmlet	KR-LP	KR-HP	SG-LP	SG-HP	KR (Rep 1)	KR (Rep 2)	SG (Rep 1)	SG (Rep 2)
Grazing system	Kurzrasen		Strip-grazing		Kurzrasen		Strip-grazing	
CP level	LP	HP	LP	HP	LP/MP/HP	LP/MP/HP	LP/MP/HP	LP/MP/HP

Table 2. Average parameters (SD in parenthesis) of the Holstein Friesian (n = 36) and Jersey (n = 24) cows at the start of the grazing season in 2016 (20/4) and 2017 (27/3).

	2016				**2017**			
	HF		**Jersey**		**HF**		**Jersey**	
FPCM yield (kg day^{-1})	30.4	(5.2)	25.2	(4.0)	26.4	(4.2)	21.6	(4.2)
Live weight (kg)	579	(65)	395	(31.4)	559	(59)	389	(31)
Parity	2.3	(1.1)	1.8	(0.6)	2.5	(1.5)	2.2	(0.8)
Days in lactation	79	(44)	68	(25)	56	(26)	37	(27)
Body condition score	2.3	(0.4)	2.4	(0.4)	2.4	(0.3)	2.3	(0.2)

2.2. Grazing Management

Grazing time was restricted to night-time grazing only, in order to avoid heat stress during the summer months. For KR, each farmlet consisted of one single grazing block. The aim was to achieve a constant sward height throughout the grazing season of 3 to 5 cm. For SG, cows had access to a fixed area of two strips, consisting of a fresh new strip and the strip from the day before. Strip-size depended on the herbage growth rate and supply and the total grazing area varied from 47 to 267 m^2 per cow. In the strip-grazing system, herbage in excess of animal requirements was harvested for silage production. Cows were supplemented with grass silage in the stable depending on grass production and supply. Silage supplementation was recorded daily at grazing system level, and silage feeding value was determined twice per month. The mean silage nutritional composition in 2016 was 913 g VEM (see Section 2.3) and 147 g CP kg^{-1} DM and in 2017 was 881 VEM and 149 g CP kg^{-1} DM.

In March, 25 m^3 (2016) or 30 m^3 (2017) of cattle slurry was applied to all fields. Additionally, fields were fertilized with 100 (2016) or 80 kg N ha^{-1} (2017) in the form of calcium ammonium nitrate, distributed over 3 to 4 applications over the growing season.

2.3. Crude Protein Level Treatment

In 2016, the concentrate feeding rate was 7 kg DM cow^{-1} day^{-1} for HF and 6.2 kg DM cow^{-1} day^{-1} for J, in 2017 all cows received 7 kg DM concentrate cow^{-1} day^{-1}. The difference in CP level was created by supplementing the cow with concentrates different in rumen-degradable protein balance (OEB = "Onbestendig Eiwit Balans" [10]: −43 vs. + 47 g OEB kg DM^{-1}). The concentrates were equal in intestinal digestible protein (DVE = "Darm Verteerbaar Eiwit" [10]; 91 g kg DM^{-1}) and net energy content (1000 g VEM kg DM^{-1}; VEM = "Voeder Eenheid Melk" = 6.9 kJ NEL (Net Energy for Lactation) [11,12]). The ingredients and chemical composition of the concentrate feeds are presented in Table S1. The medium CP level in 2017 was achieved by combining the low and high CP concentrate in equal parts.

2.4. Weather Conditions and Impact on Grazing

In 2016, wet conditions in early April (See Figure S1 for monthly temperature and rainfall data) resulted in low load bearing capacity of the grazing area. As a result, turnout to pasture was only feasible on the 20th of April, and grazing was commenced for the SG treatment. However, at this time, the sward height was over 10 cm for kurzrasen, which is much higher than the target 5 cm. Therefore, this herbage was cut and harvested, before turning out the cows on the 24th of April. In June and July 2016, the strip-grazing groups were kept indoors for 12 days due low load bearing capacity as a result of high amounts of rainfall (Figure S1). In September and October 2016, rainfall was low, and the SG cows had to remain indoors for 11 days at the start of October due to low grass supply. After 184 days, the grazing season was ended in 2016 at the 22nd of October due to a lack of herbage growth (Table 3).

In 2017, turnout for grazing for KR was the 27th of March and for SG the 4th of April. For SG, cows were kept indoors for one week during June and September because of low grass supply. Additionally, SG cows had to remain indoors for 6 days in September, because of rainfall resulting in low load bearing capacity. The grazing season was ended in 2017 after 191 days on the 5th of October due to high rainfall resulting in a poor load-bearing capacity (Table 3).

Table 3. Average grass and feeding parameters of the kurzrasen (KR) and strip-grazing (SG) systems during 2016 and 2017 (n = 2, SD in parentheses).

	2016				**2017**			
	KR		**SG**		**KR**		**SG**	
Measurement period	20/4–21/10 (184 d)				27/3–4/10 (191 d)			
Days on pasture	180		161		186		177	
Grass on offer (cm)	4.5	(0.4)	10.9	(0.01)	4.4	(0.3)	11.3	(0)
Residual sward height (cm)			6.2	(0.2)			6.0	(0.1)
Concentrates intake (kg DM cow^{-1} day^{-1}) *	6.7	(0.02)	6.7	(0.04)	7.0	(0)	7.0	(0.01)
Grass silage intake (kg DM cow^{-1} day^{-1}) **	3.5		4.3		2.5		2.6	

* For concentrate composition see Table S1. ** Grass silage intake was recorded at the grazing system level, and therefore no SD is available.

2.5. Herbage Production and Quality

The methodology for determining sward height, herbage DM growth in the grazed area and herbage quality is reported in Hoekstra et al. [5]. Additionally, all herbage harvested for silage production was weighed after collection, and a sample was taken for DM analyses.

2.6. Animal Parameters

Milk yield was recorded at each milking for each individual animal. Milk crude fat (CF), CP and urea were determined every three weeks. Cows were weighed monthly on two consecutive days and body conditions score was visually assessed at the same time. Milk yield was corrected for protein and fat content (FPCM) using the following equation:

$$\text{FPCM} = \text{Milk} \times (0.337 + 0.116 \times \%\text{CF} + 0.06 \times \%\text{CP})$$

The total energy requirement (VEM_{Req}) was the sum of the VEM requirement for maintenance and milk production (VEM_{MM}), for grazing (VEM_G), live weight change (VEM_{LWC}), pregnancy (VEM_P) and youth growth (VEM_{YG}) and was calculated as follows:

$$VEM_{MM} = (42.4 \times \text{weight}^{0.75} + 442 \times \text{FPCM}) \times (1 + (\text{FPCM-15}) \times 0.00165) + 42.2 \times \text{weight}^{0.75} \times 0.19505$$

$$VEM_G = (42.4 \times \text{weight}^{0.75}) \times (1 - 15 \times 0.00165) \times 0.2$$

VEM_{LWC} = 4480 VEM per kg live weight loss and 5600 VEM per kg live weight gain.

$$VEM_P = 0.025 \times W_{Calf} \times ((0.0201 \times \text{Exp}(-0.0000576 \times DP) \times (\text{Exp}((151.7 - 151.64 \times \text{Exp}(-0.0000576 \times D_P)))) \times 1000 / 6.9) / 0.15 \times 0.6$$

where W_{Calf} = expected calve weight at birth, which was set at 33 for J and 44 kg for HF, and DP = days pregnant

VEM_{YG} = 660 and 330 VEM day^{-1} for HF in lactation 1 and 2, respectively; 400 and 200 VEM day^{-1} for J in lactation 1 and 2, respectively

The percentage of FPCM derived from grazed grass ($FPCM_{GG}$) was calculated as

$\%FPCM_{GG} = (1 - (VEM_{Sup\_Con} + VEM_{Sup\_silage}) / VEM_{Req}) \times 100\%$

where VEM_{Sup_Con} and VEM_{Sup_silage} is the VEM intake through concentrate and silage.

Silage feeding rate was only recorded at the grazing system level. It was assumed that silage intake rates were not affected by CP level and breed. This assumption must be taken into account when interpreting the effect of CP level and breed on $\%FPCM_{GG}$ and derived parameters.

Herbage DM intake was estimated indirectly from animal performance results as follows:

Herbage DM intake (kg day^{-1}) = FPCM × $\%FPCM_{GG}$ / VEM_{cont_herb}

where VEM_{conc_herb} is the VEM content of the grazed herbage as determined in (bi-) weekly herbage sampling [5].

In 2016, the measured VEM and CP concentration of the kurzrasen herbage was deemed unreliable [5], and therefore, the values of the VEM and CP concentration of strip-grazing grass was used for these calculations.

The mean animal N use efficiency (NUE) for the duration of the experiment was calculated for each cow as follows:

$NUE = (N_{Milk} + N_{LWC}) / N_{Intake}$

where: N_{Milk} is the N content in milk (kg N cow^{-1} day^{-1}), N_{LWC} is the estimated N content in live weight change (kg N cow^{-1} day^{-1}, 0.0302 g N g^{-1} LWC) and N_{Intake} is the calculated N intake rate (kg N cow^{-1} day^{-1}) of grazed grass, forage and concentrate, multiplied by their respective N content (based on weekly averages).

2.7. System Parameters

The total amount of milk produced from grazed grass per ha was calculated by multiplying the mean FPCM (kg milk day^{-1} cow^{-1}) with $\%FPCM_{GG}$, the number of animals (15) and dividing by the area (2 ha). Similarly, the total estimated DM uptake of grazed grass per ha was calculated for each farmlet.

Total available grass for grazing was calculated based on the weekly herbage growth (measured underneath cages [5]), multiplied with the area actually available for grazing (so excluding area set aside for silage production). Total grass production per system was calculated as the sum of the available grass for grazing and the grass harvested for silage production.

The FPCM production at system level was corrected for differences in silage feeding and silage production, assuming 25% conservation losses of silage produced [13] with a VEM of 900, and a conversion into milk of 687 VEM kg^{-1} FPCM produced.

2.8. Statistical Analysis

The effect of System (KR vs. SG), CP level (LP, MP (2017 only), HP), and breed (HF and J), on seasonal milk production and contents for each animal was analysed using a general linear regression model, which included all main effects and interactions and block as random factor.

Additionally, on farmlet level, the effect of grazing system was assessed by ANOVA. Pearson correlations were carried out to assess correlations between diet, production and N efficiency parameters. A linear regression analysis was performed to investigate the relation between dietary N content (N_{Diet}) or milk urea content on the difference in FPCM in LP and HP feeding level ($\delta FPCM_{LP-HP}$).

$\delta FPCM_{LP-HP} = System + N_{Diet} + System \cdot N_{Diet}$

All analyses were performed using R3.6.0 [14].

3. Results

3.1. Silage Intake

Silage intake ranged from 0 at times with ample grass growth, to 12 kg DM cow^{-1} day^{-1} during days when cows were kept fully indoors (See Figure S2). In 2016, the silage feeding rate was on average 3.5 kg DM day^{-1} for KR and 4.2 kg DM day^{-1} for SG (Table 3). In 2017, the level of silage intake was on average 2.6 kg DM cow day^{-1} for both KR and SG. This lower level of supplementation reflected the higher grass production level and thus feed availability during 2017. The effect of CP level and breed on silage uptake is unknown, as silage feeding rate was recorded at the system level.

3.2. Milk Yield and Composition

In 2016, milk yield was on average 20.5 kg cow^{-1} day^{-1} with CP and CF content of 3.7% and 4.9%, resulting in an FPCM yield of on average 22.2 kg cow^{-1} day^{-1} (Table 4). Milk production and FPCM production levels were similar in 2017 compared to 2016 and were on average 21.2 and 22.7 kg cow^{-1} day^{-1}, respectively. Milk production and contents were not significantly affected by grazing system.

In 2016, both milk yield and FPCM yield were significantly ($P < 0.01$) higher for the high CP compared to low CP level. FPCM yield was on average 23.1 and 21.2 kg cow^{-1} day^{-1}, for the high and low CP level, respectively. FPCM yields decreased from on average 29.1 kg cow^{-1} day^{-1} in week 18 to 19.1 kg cow^{-1} day^{-1} during the last two months of the experiment (Figure 1a). The difference between HP and LP was largest for SG during the first half of the season (on average −4.1 kg cow^{-1} day^{-1} until the last week of July) compared to second half (on average −0.6 kg cow^{-1} day^{-1}), whereas the difference tended to be more constant for KR (on average −1.4 kg cow^{-1} day^{-1}). In 2017 there was no significant effect of CP level on milk production, milk CF, CP and FPCM.

In 2016, breed had a strong impact on milk production, which was significantly ($P < 0.001$) higher for HF (23.6 kg cow^{-1} day^{-1}) compared to J (16.0 kg cow^{-1} day^{-1}, Table 4). Milk CP and CF were both significantly higher for J, and as a result the difference in FPCM yield was much less pronounced at 24.0 and 19.5 kg cow^{-1} day^{-1} for HF and J, respectively. In 2017, the effect of breed was comparable to 2016.

In 2016, milk urea was on average 18.7 g 100 g^{-1} and significantly affected by both system and CP level ($P < 0.001$, Table 4). Milk urea was higher for KR compared to SG and for the high compared to the low CP level. In 2016, average live-weight change over the grazing season was 17 kg cow^{-1}, and this was significantly affected by CP level ($P < 0.05$; LP = 10.5, HP = 23.1) and breed ($P < 0.05$; HF = 24.4; J = 5.5, Table 4). In 2017, average milk urea content was higher compared to 2016 (25.1 g 100g^{-1}), but the effects of system (SG < KR, $P < 0.0001$) and CP level (HP > LP, $P < 0.0001$) were similar. There was a significant ($P < 0.001$) interaction between CP level and system, with a larger effect of CP level for KR compared to SG: at the low CP level, the difference between KR and SG was 15%, whereas at the high CP level this difference was 30%. In 2017, live-weight change over the grazing season was on average −54 kg cow^{-1}, and this was only affected by breed ($P < 0.01$; HF = −58; J = −48).

In order to assess the effect of the CP content of the intake on FPCM production, we performed a regression analyses between the CP content of the intake of the LP system and the FPCM difference between the HP and LP feeding level ($\delta FPCM_{LP\text{-}HP}$; Figure 2), based on weekly data on system level. In 2016, there was a significant ($P < 0.01$) positive effect of dietary CP content on $\delta FPCM_{LP\text{-}HP}$ (Table S2), however, this effect was only apparent for the SG system (significant System × CP content interaction, $P < 0.01$, Figure 2a). In 2017, there was a positive effect of CP content on $\delta FPCM_{LP\text{-}HP}$ for both systems (Figure 2b, Table S2).

In a similar analysis in which we replaced CP content of the intake with milk urea, $\delta FPCM_{LP\text{-}HP}$ was positively correlated to milk urea levels in both years. Only in 2016, the slope was different for SG and KR (significant system × milk urea interaction, Figure 2c,d; Table S2).

Table 4. Average milk yield and contents as affected by grazing system, CP level and breed in 2016 and 2017 (SD in parenthesis [1]).

2016		**System**					**CP Level**							**Breed**				
		KR		**SG**		**p** [2]	**Low**				**High**		**p**	**HF**		**J**		**p**
Milk production	(kg cow day^{-1})	20.4	(5.1)	20.6	(5)	ns	19.5	(4.7)			21.5	(5.2)	***	23.5	(3.7)	16.0	(3.1)	***
FPCM	(kg cow day^{-1})	22.1	(4)	22.3	(3.9)	ns	21.2	(3.8)			23.1	(3.9)	**	24.0	(3.2)	19.5	(3.4)	**
Milk CP	(%)	3.7	(0.4)	3.6	(0.3)	ns	3.7	(0.3)			3.7	(0.3)	ns	3.5	(0.2)	4.0	(0.3)	***
Milk CF	(%)	4.9	(0.9)	4.9	(0.8)	ns	4.9	(0.9)			4.8	(0.9)	ns	4.3	(0.4)	5.8	(0.5)	***
Milk urea	(g 100 g^{-1})	21.7	(6.4)	15.7	(5.5)	***	13.3	(3.6)			24.1	(4.3)	***	19.1	(6.2)	18.1	(7.4)	ns
Live weight change	(kg cow^{-1})	12.8	(29.6)	20.9	(27.1)	ns	10.5	(30.9)			23.1	(24.6)	*	24.4	(27.7)	5.5	(26.2)	*
2017		**System**					**CP Level**							**Breed**				
		KR		**SG**		**p**	**Low**		**Medium**		**High**		**p**	**HF**		**J**		**p**
Milk production	(kg cow day^{-1})	20.9	(4.3)	21.5	(4.3)	ns	21.2	(4.3)	21.4	(4.7)	21.0	(4.0)	ns	23.6	(3.6)	17.5	(2.1)	**
FPCM	(kg cow day^{-1})	22.4	(3.4)	22.9	(3.5)	ns	22.5	(3.5)	23.0	(3.8)	22.5	(3.0)	ns	23.6	(3.7)	21.2	(2.4)	*
Milk CP	(%)	3.8	(0.4)	3.7	(0.4)	ns	3.7	(0.4)	3.7	(0.3)	3.8	(0.3)	ns	3.5	(0.2)	4.1	(0.3)	***
Milk CF	(%)	4.6	(0.9)	4.6	(0.8)	ns	4.5	(1)	4.6	(0.8)	4.6	(0.8)	ns	4.0	(0.4)	5.5	(0.5)	***
Milk urea	(g 100 g^{-1})	27.7	(6)	22.6	(4)	***	20.8	(3.5)	24.5	(3.4)	30.0	(5.6)	***	26.0	(5.4)	23.8	(6)	*
Live weight change	(kg cow^{-1})	−50.6	(10.7)	−57.2	(16)	ns	−52.3	(12.5)	−53.8	(11.1)	−55.8	(17.5)	ns	−58.1	(15.3)	−47.7	(8.8)	**

[1] n = 15 for System and CP level in 2016, n = 20 for CP level in 2017, n = 18 for Breed-HF and n = 12 for Breed-J. [2] Significant differences are denoted by *** ($p < 0.001$); ** ($p < 0.01$) or * ($p < 0.05$). [3] Trend for System × CP level interaction (P = 0.058): larger effect of CP level for KR compared to SG: at LP difference between KR and SG = 15%, at HP the difference is 30%.

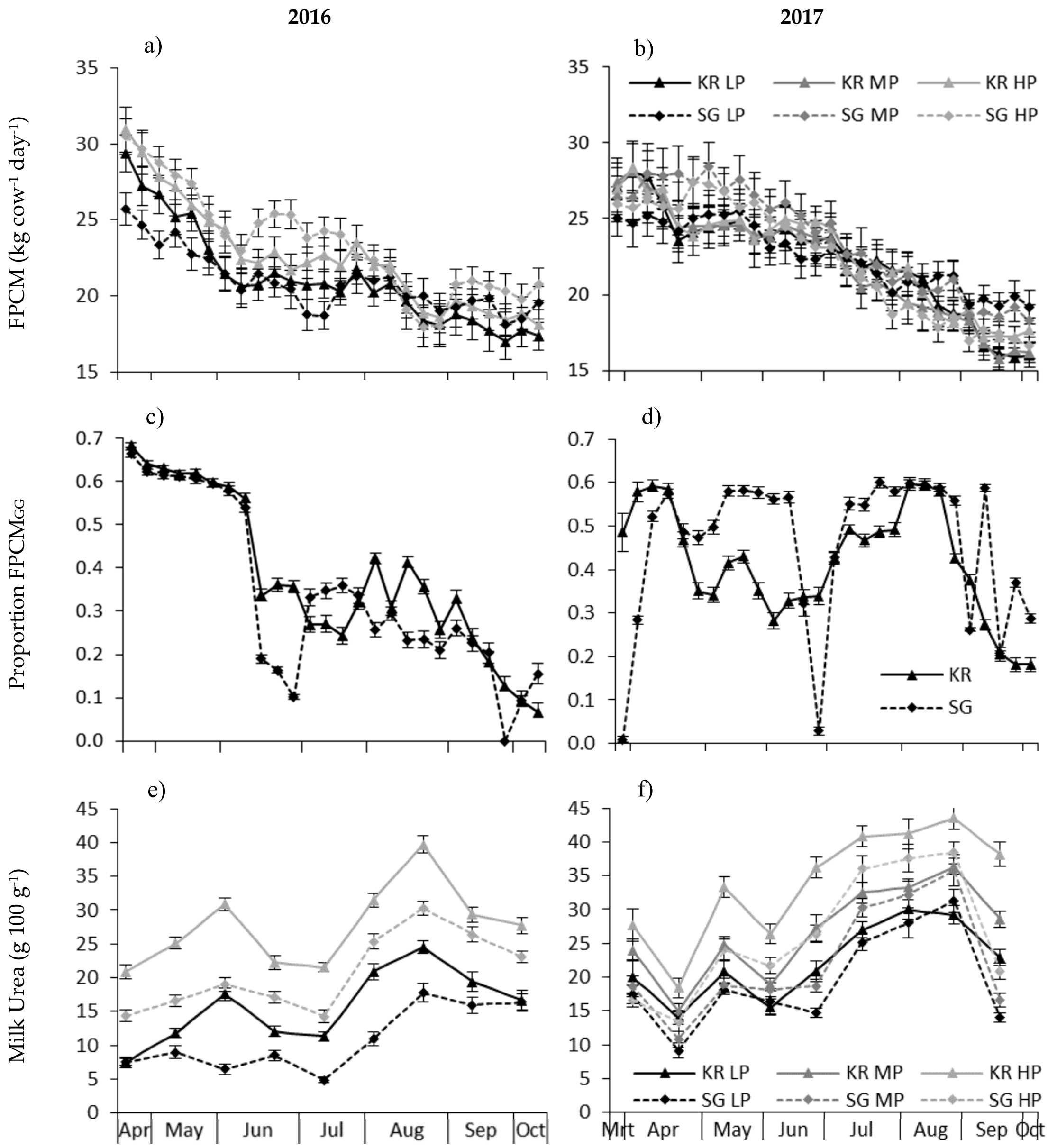

Figure 1. Mean daily fat and protein corrected milk (FPCM) yield (**a**,**b**), Proportion of FPCM derived from grazed grass ($FPCM_{GG}$, **c**,**d**) and milk urea content (**e**,**f**) for the kurzrasen (KR) and strip-grazing (SG) grazing systems at low (LP), medium (MP, 2017 only) and high (HP) CP feeding levels during 2016 and 2017. Error bars = standard error.

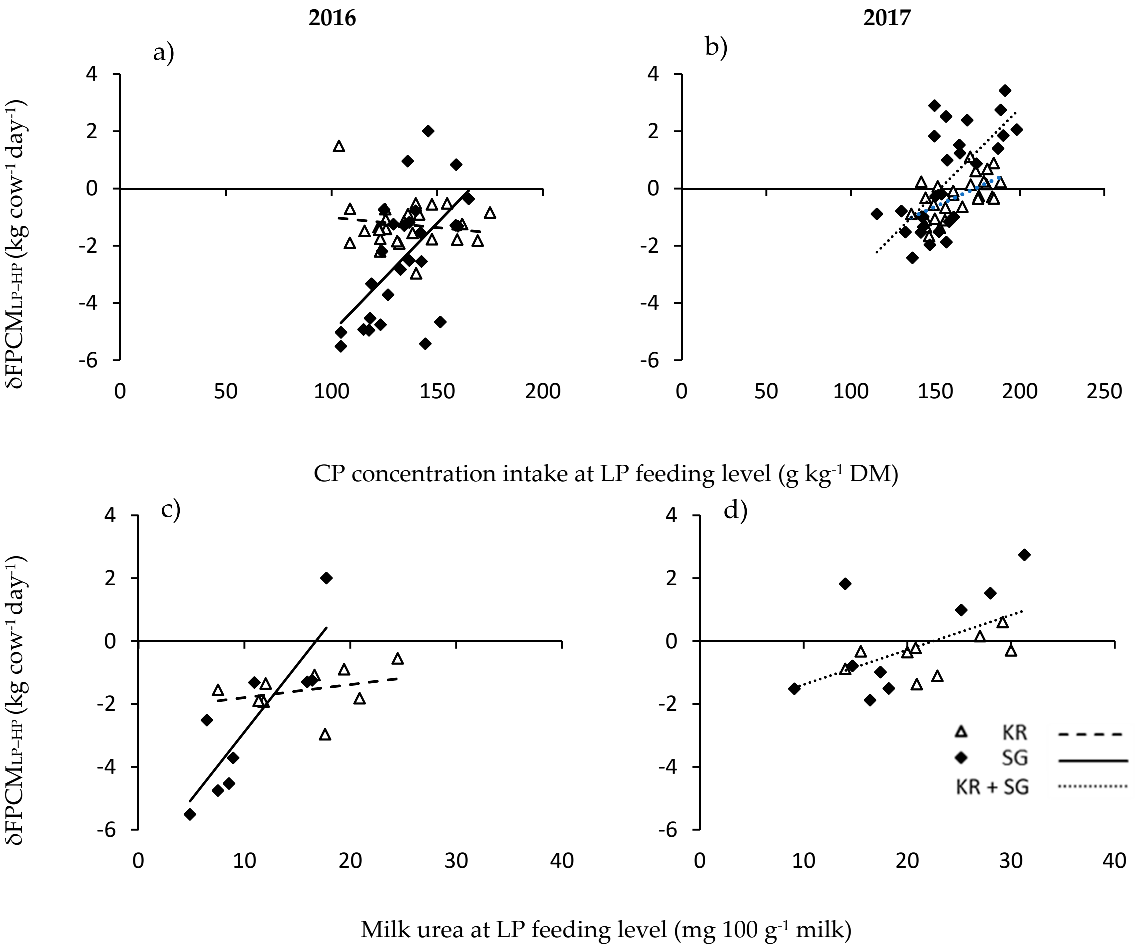

Figure 2. Correlation between the difference in FPCM yield at the and LP minus the HP feeding level ($\delta FPCM_{LP–HP}$; kg cow^{-1} day^{-1}) and the CP concentration of the total ration (g kg^{-1} DM, **a**,**b**) or the milk urea content (mg 100 g^{-1} milk, **c**,**d**) for the LP treatment during 2016 (**a**,**c**) and 2017 (**b**,**d**). Significant ($P < 0.05$) correlations for KR, SG or both are indicated by a line.

3.3. Milk Production from Grazed Grass

3.3.1. Pasture Yield, Intake and Utilization

The grass production on the grazing area (so excluding the area temporarily dedicated to silage production) was on average 7399 kg DM ha^{-1} in 2016 and 10,355 kg DM ha^{-1} in 2017. In both years this grass production was approximately 6% higher for SG compared to KR, but this difference was not statistically significant (Table 5). In 2017 the total grass production (including the area temporarily dedicated to silage production) was significantly higher for SG compared to KR.

The ingestion of grazed grass was estimated based on the VEM requirement (Section 2.6). In 2016, the ingestion of grazed grass was on average 5.7 kg DM cow^{-1} day^{-1} and was higher for KR compared to SG ($P < 0.05$, Table 5). In 2017, the intake of grazed grass tended to be higher for SG compared to KR (7.0 and 6.2 kg DM cow^{-1} day^{-1}, respectively; $P = 0.07$). The total intake of grazed grass during the grazing season ranged from 7600 kg DM ha^{-1} for SG in 2016 to 10,061 kg DM ha^{-1} for SG in 2017.

As a measure of grazing efficiency of grass utilisation, we divided the total intake of grazed grass in kg DM ha^{-1} by the measured grass growth on the grazed area using grass cages (Table 5). In 2016, this % utilisation was 112% for KR (higher than the theoretic maximum of 100%) and 99% for SG. In contrast, in 2017, the utilisation tended to be slightly higher for SG compared to KR (94% and 89%, respectively).

3.3.2. %FPCM from Grazed Grass

The %FPCM from grazed grass ($FPCM_{GG}$) based on the calculated VEM requirement per cow, was on average 36% in 2016 and 40% in 2017 (see 2.6 for calculations). In 2016, $\%FPCM_{GG}$ was significantly higher for KR compared to SG (P < 0.05; KR = 37%; SG = 34%) (Table 5), but no such effect was apparent in 2017. The $\%FPCM_{GG}$ ranged from nearly 70% at the start of the season to 0% for SG in late September, when cows were kept indoors (Figure 1c,d).

Table 5. Grass growth and predicted intake from grazed grass and milk production at system level (n = 2, SD between brackets). Significant differences are denoted by *** ($p < 0.001$); ** ($p < 0.01$); * ($p < 0.05$); ns = not significant.

	2016					2017				
	KR		SG		p	KR		SG		p
Grass growth pasture (kg DM ha^{-1}) [1]	7184	(300)	7614	(112)	ns	10,033	(191)	10,678	(84)	0.09
Grass silage production (kg DM ha^{-1})	839	(316)	1602	(202)	ns	0	(0)	1373	(28)	*
Total grass production (kg DM ha^{-1})	8023	(616)	9216	(90)	ns	10,033	(191)	12,052	(56)	**
Intake grazed grass (kg DM cow^{-1} day^{-1}) [2]	5.9	(1.8)	5.5	(1.6)	*	6.2	(2.1)	7.0	(1.8)	0.07
Intake grazed grass (kg DM ha^{-1}) [2]	8107	(680)	7600	(708)	*	8946	(7)	10,061	(303)	0.07
% utilisation grazed grass [3]	112%	(5%)	99%	(8%)	ns	89%	(2%)	94%	(4%)	ns
%FPCM from grazed grass [2]	38%	(0.1)	35%	(0.1)	ns	39%	(0.1)	40%	(0.1)	ns
FPCM (kg ha^{-1})	30,439	(920)	30,810	(1713)	ns	32,098	(141)	32,800	(490)	ns
$FPCM_{cor}$ (kg ha^{-1}) [4]	25,048	(1283)	24,867	(1458)	ns	27,382	(141)	29,350	(835)	ns

[1] Based on weekly sward height measurements under grass cages, see [5] for more details. [2] Calculated based on VEM requirement (see Section 2.6). [3] Intake grazed grass/grass growth pasture [4] $FPCM_{cor}$ = correction for difference in silage feeding and production between systems, assuming 25% conservation losses of silage produced with a VEM of 900, and a conversion into milk of 687 VEM kg^{-1} FPCM produced (Section 2.7).

3.4. *System Productivity*

For KR the amount of grass silage fed tended to be lower than for SG, particularly in 2016 (Table 4). In contrast, the amount of silage produced was higher for SG compared to KR (Table 5). In order to compare the productivity of the KR and SG grazing system, we corrected the FPCM yield for this silage balance (see Section 2.7). In 2016, the corrected FPCM yield was slightly higher (1%) for KR compared to SG, as opposed to the uncorrected FPCM yield, which was 1% lower (Table 5). In 2017, the difference between KR and SG became slightly more pronounced in the corrected compared to the uncorrected FPCM yield (−2% and −6% lower for KR compared to SG for uncorrected and corrected FPCM yield, respectively), but the difference remained insignificant.

3.5. *N Use Efficiency*

The mean N intake was on average 408 and 467 g cow^{-1} day^{-1} during 2016 and 2017, respectively (Table 6). There was a significant effect of CP level on N-intake, which was 39% and 27% higher for HP compared to LP in 2016 and 2017, respectively. Whereas in 2017 this was only the result of an increased concentrate N intake, in 2016, the estimated N intake through grazed grass was also higher for HP compared to LP (but see limitations, Section 2.6).

N output in terms of milk N was significantly (P < 0.001) higher for HP compared to LP in 2016 (110 and 124 g cow^{-1} day^{-1} for LP and HP, respectively), whereas there was no effect of CP level on milk N output in 2017 (124 g cow^{-1} day^{-1} on average). Additionally, in 2016 there was a small but significant (P < 0.05) effect of CP level on N associated with liveweight change, but no such effect in 2017. As a result, the N use efficiency ($(N_{Milk} + N_{LWC})/N_{Intake}$) was significantly (P < 0.001) higher for LP compared to HP. In 2016, N utilisation decreased from 33% for LP to 27% for HP, whereas in 2017 the N use efficiency was 28% and 22% for LP and HP, respectively.

The weekly data for N use efficiency showed a strong and highly significant (P < 0.001) negative correlation to the N intake, the CP content of the intake and the milk urea content (Table 7).

Table 6. The effect of CP feeding level (LP = low CP, MP = medium CP and HP = high CP) on average N intake and N output (N milk + N LWC) in the form of milk and live weight change (g N cow^{-1} day^{-1}) and the resulting N use efficiency (N output / N intake × 100%) and N loss (N intake – N output). SD in brackets (2016: n = 30; 2017: n = 20).

	2016					2017						
	LP		HP		p [1]	LP		MP		HP		p
N intake	341	(56.7)	473	(69.5)	***	410	(71)	470	(73)	523	(71.6)	***
Grazed grass	152	(48.4)	186	(52.7)	***	245	(71.4)	253	(75.2)	256	(72.2)	ns
Silage [2]	90	(8.1)	90	(8.1)	ns	61	(4.3)	61	(4.3)	61	(4.3)	ns
Concentrate	99	(11.9)	198	(22.6)	***	104	(5.5)	156	(8.7)	205	(11.6)	***
N milk	110	(21.6)	124	(23.9)	***	123	(19)	124	(21.6)	124	(19.2)	ns
N LWC	1.7	(5.1)	3.8	(4)	*	−8.3	(2)	−8.5	(1.8)	−8.8	(2.8)	ns
N use efficiency	33%	(0.032)	27%	(0.021)	***	28%	(0.021)	25%	(0.022)	22%	(0.015)	***
N loss	229	(35.6)	346	(48.1)	***	296	(54.2)	354	(54.2)	407	(55.5)	***

[1] Significant differences are denoted by *** ($p < 0.001$); ** ($p < 0.01$); * ($p < 0.05$); ns = not significant. [2] Silage DM intake was determined at the system level. It was assumed that the level of silage intake was not affected by CP level, see also Section 2.6. This assumption affects the estimation of N intake of both grazed grass and silage.

Table 7. Correlation coefficients of the N use efficiency (NUE), N intake (g N cow day^{-1}), CP content diet (g CP kg^{-1} DM) and milk urea (g 100 g^{-1} milk) during 2016 and 2017. Significant differences are denoted by *** ($p < 0.001$); ** ($p < 0.01$). Correlation is based on weekly means of system × CP level.

2016	NUE		N Intake		CP Content Diet	
N intake	−0.73	***	-			
CP content diet	−0.81	***	0.93	***	-	
Milk urea	−0.80	***	0.61	***	0.77	***
2017						
N intake	−0.51	***	-			
CP content diet	−0.80	***	0.74	***	-	
Milk Urea	−0.74	***	0.35	**	0.78	***

4. Discussion

4.1. No Effect of Grazing System on FPCM Production and Solids

The mean level of FPCM production was 20.8 kg cow day^{-1} in 2016 and 21.2 kg cow day^{-1} in 2017 and was not affected by grazing system. Also, there was no significant effect of grazing system on milk CF and CP content and on liveweight change and BCS (Table 4). This lack of difference in FPCM between grazing systems is in line with results from Pulido and Leaver [15], who compared a rotational and continuous grazing system at two levels of milk production and found no significant effect of grazing system. Similarly, Arriaga-Jordan and Holmes [16], in an experiment with cows milked three times daily and yielding over 30 kg day^{-1}, showed no difference in milk production between the two systems. Pulido and Leaver [15] showed that reducing the sward height from 7–9 to 5–7 cm, had a negative effect on the liveweight gain of cows under continuous grazing. However, in the current study the sward height for KR was 3–5 cm, which is considerably lower than conventional continuous grazing systems, but there was no significant difference in liveweight gain with the SG group.

For both systems, the amount of concentrate fed was the same, but the level of supplementation with silage was higher for SG, compared to KR in 2016 (4.3 and 3.5 kg DM cow^{-1} day^{-1} respectively). This was related to a higher number of days spent inside for the SG groups (24 days in total), due to low load bearing capacity as a result of excessive rainfall in late June and early July 2016, and during a period of low grass growth towards the end of September (see also [5]). In 2017, the SG groups also spent 22 days less in pasture, of which 6 days were due to low load bearing capacity and the remainder in order to build up grass supply to the desired pre-grazing biomass. In 2017, the silage supplementation rate was only slightly higher for SG compared to KR (2.6 and 2.5 kg DM cow^{-1} day^{-1}, respectively). However, the amount of silage produced during the trial, was also higher for SG compared to KR (Table 5). In order to account for these differences and allow for a fair comparison of milk production at the system level, the FPCM was corrected for this silage balance (See Section 2.7 for details). In 2016, the $FPCM_{Cor}$ was slightly but non-significantly higher for KR compared to SG. In contrast, in 2017, the $FPCM_{Cor}$ was 7% lower for KR compared to SG, but again the difference was non-significant. Therefore, in contrast with our hypothesis, there was no significant effect of grazing system on the FPCM yield, despite a significantly higher grass production under SG compared to KR. Furthermore, we found no indication that the two breeds were differentially affected by grazing system.

In this paper we used the calculated energy requirements (VEM_{Req}) and supply in the form of concentrate and silage to calculate the proportion of FPCM derived from grazed grass and the intake of grazed grass. This method is not as reliable as direct measurement of grass intake using alkane techniques; however, it was the best available method. These calculations showed that the intake of grazed grass and the FPCM production from grazed grass was slightly higher for KR compared to SG in 2016, whereas the opposite was true in 2017. On average, the estimated herbage intake during grazing in 2016 and 2017 was 5.5 to 7.0 kg DM cow^{-1} day^{-1}. While these intake rates are much lower than the potential herbage DM intake during grazing, grazed grass contributed substantially (35–40%) to the energy supply for milk production. This shows that even at farms with a relatively low area available for grazing (i.e., 7.5 LU ha^{-1} grazing area), grass can still form an important contribution to milk production.

When the intake of grazed grass using this method was compared to the grass production available for grazing (so excluding silage production), in 2016, the % utilisation (intake GG/production GG) was above the theoretical maximum of 100% for KR and close to 100% for SG, whereas in 2017, the utilisation was slightly higher for SG compare to KR and on average 92%.

The relatively high utilisation of KR compared to SG during 2016 may be related to the low grazing losses due to fouled areas and senescence in KR compared to SG. There is very little standing biomass at KR and the risk of herbage losses are much lower. Additionally, in 2016, the SG cows had to remain indoors for a number of days with high amounts of rainfall, whereas the KR herds could graze throughout the season. This may have been related to the dense sward associated with KR, resulting in a higher load bearing capacity [5]. Additionally, the nutritional value of the KR herbage is generally higher than for SG [5], resulting in a better conversion to milk.

However, the grass utilisation in excess of 100% for KR in 2016, suggests, that there is also a different mechanism at play. The calculation of the amount of grazed grass is dependent on a correct estimation of the VEM content of the grazed grass. This VEM content was likely to be underestimated in KR in 2016, due to inadequate sampling [5]. Therefore, in the current paper, we used the herbage VEM levels of SG for both systems. However, it would appear that this VEM level was an underestimation of the actual KR VEM level, which resulted in an overestimation of herbage intake for KR in 2016.

Generally speaking, in a year with sub-optimal conditions for grass growth, such as 2016, the difference between KR and SG was negligible, and KR had a small advantage related to the higher load bearing capacity during wet periods. However, in 2017, when grass growth conditions were generally good, SG resulted in a slightly higher FPCM production per ha.

4.2. Limited Effect of CP Level in Concentrate on Milk Production

For the calculation dietary CP content and CP intake, we assumed that the silage intake was the same for the HP and LP groups (silage intake was recorded at the grazing system level only) and that differences between the HP and LP groups were the result of difference in CP content in concentrate and potentially intake of grazed grass.

In contrast with our hypothesis, during 2016, the FPCM production was lower for the low compared to the high CP level. The difference between HP and LP was mainly apparent at the start of the grazing season until the end of July. In contrast, during 2017, there was no effect of CP level on FPCM yield (in line with our hypothesis). In 2016, the average CP content of the total intake was lower compared to 2017 (156 and 180 g kg^{-1} DM, respectively). This was due to lower grass intake (5.7 vs.

6.6 kg DM cow^{-1} day^{-1}) which was related to the lower grass growth in 2016, and lower CP content of the grazed grass (192 and 242 g CP kg $^{-1}$ DM in 2016 and 2017, respectively [5]). As a result, the CP content of the total ration for the LP systems remained below 150 g kg^{-1} DM until the end of July, after which the herbage CP content and thus the ration CP content increased. We found no indication that the two breeds were differentially affected by CP level. A number of other studies have shown that decreasing the dietary N intake through reduced concentrate N content only has a minor effect on milk yields [17,18].

In order to increase our insight in the mechanism behind the reduction in FPCM in the current study, we performed a regression analyses between the weekly difference in FPCM yield between LP and HP ($\delta FPCM_{LP\text{-}HP}$) and the CP content of the intake at the LP level (g CP kg^{-1} DM). This analysis showed a positive correlation between the CP content and $\delta FPCM_{LP\text{-}HP}$ for the SG system in 2016 and both systems in 2017 (Figure 2a,b). Closer inspection showed that the intersection with the x-axis (the point at which there was no difference in FPCM production between LP and HP) was at 150–160 g CP kg^{-1} DM, which is very close to the theoretical minimum CP requirement of 150 g CP kg^{-1} DM to avoid impaired ruminal digestion [7,8]. However, for KR in 2016, there was no significant correlation between the CP content of intake and delta FPCM. This may be related to the underestimation of the CP content of ingested KR herbage in 2016 because of the sampling technique as discussed by with Hoekstra et al., [5] and above.

Similarly, $\delta FPCM_{LP\text{-}HP}$ was positively correlated to the milk urea levels, which remained below 10 mg 100 g^{-1} milk for SG-LP until the end of July, whereas the milk urea level was significantly higher for KR-LP. In this case the intersection with the x-axis was 17 and 22 mg urea 100 g^{-1} milk in 2016 and 2017, respectively. This is in line with [19], who suggested a milk urea level of 18 mg 100 g^{-1} milk as a benchmark for optimal bulk milk urea concentration.

Therefore, in contrast with our hypothesis, there was a negative impact of feeding LP concentrate on FPCM yield in 2016. This could be related to the lower than expected herbage production and CP contents in 2016. The intake and CP content of grazed grass is not routinely monitored at Dutch dairy farms, however, by monitoring milk urea levels at a regular basis, a lack of CP in the ration can be identified and the risk of a yield penalty can be minimised, while still reducing the risk of N losses (see also below).

4.3. N Use Efficiency and Loss

N use efficiency (N output/N input) was not significantly affected by grazing system and was on average 30% in 2016 and 25% in 2017. In general, it is much harder to optimise N use efficiency in grazing systems compared to stable fed diets, due to the unpredictability of herbage intake and quality during grazing [20]. Research has shown that herbage management measures such as N fertiliser application rate and the length of regrowth period can affect the herbage N content and thus the N use efficiency [21,22]. However, even though the herbage management was very different for the two grazing systems (herbage regrowth period ranged from 1 day for KR to on average 20 days for SG), this did not significantly affect the N use efficiency in the current study. The N intake of grazed grass may have been underestimated in the current study (particularly during 2016), due to difficulties of taking a representative sample of the short KR grass. This would be supported by the higher milk urea levels under KR compared to SG (Figure 1), which could indicate a lower N use efficiency.

In line with our hypothesis, there was a strong effect of CP level on N efficiency, which ranged from 22% for HP in 2017 to 33% for LP in 2016. These results are in line with [17,18], who also showed an increase in the N use efficiency in response to reduced concentrate N intake. Whereas in 2016, this increased efficiency had a negative effect on N-output in the form of milk production, this was not the case in 2017. As discussed above, the results indicate that as long as the CP content of the overall ration stays above 150 g kg^{-1} DM, the N-efficiency can be improved without negatively affecting production levels. The reduction in concentrate CP intake resulted in a reduction of N loss of 34% in 2016 and 27% in 2017. Both the N use efficiency and N loss were strongly correlated to the milk urea content. Milk urea content has been directly linked to ammonia emissions, and Duinkerken et al. [23] showed that ammonia emission increased exponentially with increasing milk urea concentration: at a level of 20 mg urea per 100 g milk, ammonia emission increased 2.5% when milk urea concentration increased by 1 mg 100 g^{-1}, whereas the increase in ammonia emission was 3.5% at a milk urea level of 30 mg per 100 g milk. Jonker et al. [24] have suggested that milk urea N (MUN) may be used as a management tool to improve dairy herd nutrition and monitor the nutritional status of lactating dairy cows. Elevated MUN indicates that excess CP has been fed to the dairy cow for her given level of production [25,26] and identifies excess nutrient loading to water resources [24] and ammonia volatilisation [23]. Therefore, optimising the use of MUN on dairy farms, also during the grazing season, could reduce N losses to the environment while maintaining productivity.

5. Conclusions

- In contrast with our hypothesis, there was no indication that the intake of grazed grass was negatively affected by the low pre-grazing mass at KR. Even at the relatively high stocking rates and high supplementary feeding levels, cows still achieved substantial fresh grass intake (on average >6 kg DM cow^{-1} day^{-1}) for both systems.
- Despite the lower level of grass production under KR management, at system level, the difference in FPCM production between KR and SG was small and non-significant. In the relatively wet and cold 2016, KR performed marginally better, which was related to better load bearing capacity of the dense KR sward. However, during the more productive growing season in 2017, the FPCM production per ha was slightly (but not statistically significant) higher for SG compared to KR.
- Feeding concentrate with a lower CP level, had no negative impact on FPCM yield, provided that the CP content of the total ration remained larger than 150 g kg^{-1} DM and milk urea content above 18 mg 100 g^{-1} milk.
- Reducing the CP content in the concentrate significantly increased the N use efficiency to 28% and reduced N losses with up to 150 kg N ha^{-1}. Both parameters were strongly related to the milk urea content. Therefore, optimising the use of milk urea as a management tool on dairy farms, also during the grazing season, could reduce N losses to the environment while maintaining productivity.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/3/1055/s1, **Table S1:** concentrate composition fed for the low CP (LP) and high CP (HP) level; **Figure S1.** Mean monthly temperature and precipitation in 2016 and 2017 compared to the long term average (since 1980) for KTC Zegveld (KNMI weatherstation De Bilt); **Figure S2.** Mean daily grass silage intake (kg DM cow^{-1} day^{-1}) for the kurzrasen (KR) and strip-grazing (SG) grazing systems during 2016 and 2017. **Table S2**. Regression output of the effect of grazing system and CP concentration of the LP diet or milk urea content on the difference in FPCM production in the LP compared to the HP feeding level ($\delta FPCM_{LP\text{-}HP}$).

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