Early lactation feed intake and milk yield responses of dairy cows offered grass silages harvested at early maturity stages

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ABSTRACT

The main objective was to evaluate the potential of grass silages of very high quality to support a high milk yield with a low or moderate, or even without concentrate supplementation. Production responses to increased levels of concentrate supplementation with 3 primary growth grass silages differing in digestibility were studied using 66 Norwegian Red dairy cows. Roundbale silage was produced from a timothy-dominated sward at very early (H1), early (H2), and normal (H3) stages of crop maturity. Crops were rapidly wilted (<24 h) and a formic acid-based additive was applied. All silages were restrictedly fermented. Silage digestible organic matter in dry matter (DM) values were 747, 708, and 647 g/kg of DM for H1, H2, and H3, respectively. Dietary treatments were fed in a 3 × 3 factorial arrangement of the 3 silages supplemented with 3 concentrate levels (4, 8, and 12 kg/d) and, additionally, H1 was offered without concentrates and H3 with 16 kg/d, giving a total of 11 diets. Cows, blocked according to parity and calving date, were introduced to the experiment before calving and kept in the experiment until wk 16 of lactation. Silage was offered *ad libitum* in loose housing and concentrate was available in automatic feed stations. Intake of grass silage when fed as the sole feed was 16.9 kg of DM on average for lactation wk 1 to 16. When H1 was supplemented with 4 or 8 kg of concentrates, silage DM intake did not change, but total DM intake increased to 20.6 and 23.7 kg/d, respectively. Energy-corrected milk (ECM) yield increased from 23.4 kg when H1 was offered without concentrate supplement to 29.1 and 32.8 kg when supplemented with 4 or 8 kg concentrate, respectively. None of the other diets equaled the yield obtained by H1 plus 8 kg of concentrate. Feed intake and yield of cows offered H3 plus 4 kg of concentrates were strongly constrained by high dietary fiber concentration. They consumed 16.5 g of neutral detergent fiber/kg of body

weight and spent more time eating silage than cows offered other diets. The highest concentrate level within each silage quality produced similar or lower ECM yield than that with 4 kg less concentrates. The obtained milk yield responses suggest that provision of 8.0, 8.4, and 11.5 kg of concentrates to H1, H2, and H3, respectively, would maximize ECM yield within each silage type. However, H1 may successfully be used with less concentrates, or even without, if future conditions should limit the amount of concentrates available for ruminant production.

Key words: crop maturity, grass silage, early lactation, milk yield

INTRODUCTION

On a global basis, grasslands cover approximately two-thirds of agricultural land. The increasing demand for human food, including meat and milk, may favor sustainable grassland-based ruminant systems in the future, so that more arable land may be used for crops for direct human consumption and for concentrate feeds for nonruminant species. Grass silage is a valuable forage because of its relatively lower production cost and high nutritive and feeding value for dairy cows if produced at an early growth stage (Zebeli et al., 2010). Compared with other forages, conserved and grazed grasses are complete feeds, rich in energy, protein, and minerals (Peeters, 2008).

Grasses show a wide variation in nutrient composition depending on, for example, species, soil quality, fertilization, and climate. Forage maturity, however, may be the most important factor because increased lignification of fiber with increasing maturity reduces digestibility, especially of plant stems. Grass or grass-legume swards grazed or harvested at a young stage of maturity may support reasonable milk production even without supplements (Steinshamn and Thuen, 2008). When grasses are conserved as silages, the fermentation quality adds a new source of variation to the feed quality. The fermentation quality depends on the weather during harvesting and on the harvesting technique: mowing, wilting, chopping, compaction, type and dos-

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age of silage additive, air exclusion, storage time, and temperature (Charmley, 2001; Borreani and Tabacco, 2008). Silage digestible organic matter in dry matter (DOMD) and the total concentration of fermentation acids were found to be the most important factors determining silage intake by dairy cows (Huhtanen et al., 2007). Silage DM intake by dairy cows is normally lower than DM intake of the same herbage when fed fresh (Cushnahan and Gordon, 1995). However, in recent years, with well-fermented silage, intake may approach that of fresh herbage (Cushnahan and Mayne, 1995; Charmley, 2001).

Kristensen and Skovborg (1990) examined grass silages harvested at 3 stages of maturity supplemented with 3.5, 6.5, and 9.5 kg of concentrate DM to dairy cows in 3×3 factorial continuous design in early lactation. They concluded that it was not possible to obtain the same milk production with low energy silage as with high energy silage by increasing concentrate supplementation, possibly because of reduced fiber digestion and increased partitioning of nutrients toward body stores at higher concentrate intake. In that experiment, silage and concentrates were fed separately twice daily. Using TMR based on high and medium feed value silages to dairy cows, Ferris et al. (2001) detected reduced fiber digestibility with increasing inclusion of concentrates. However, total ration ME concentration remained unaffected (high feed value) or increased (medium feed value) with increasing concentrate inclusion in the diet. Maximum milk yields, that were similar for the 2 silages, were obtained when offered with maximum concentrate allowance, 70% of diet DM for the high feed value silage and 80% of diet DM with the medium feed value silage.

The main objective of the present study was to determine to what extent silage from very early or early harvested grass-clover crops could support high milk yield with a low or moderate, or even zero, input of concentrates. Possible silage by concentrate interactions were the main interest.

MATERIALS AND METHODS

Preparation of Grass Silages

The primary growths of 5 leys, all sown with the same grass-red clover seed mixture comprising timothy (*Phleum pratense*) 'Grindstad' (50%), meadow fescue (*Festuca pratensis*) 'Fure' (35%), and red clover (*Trifolium pratense*) 'Nordi' (15%) were used for silage preparation. The swards were fertilized on April 26–27, with 69 kg of N, 13 kg of P, and 33 kg of K/ha. A fixed proportion (50, 30, and 20%, respectively) of each

sward was cut at each of 3 maturity stages (harvesting times) in the primary growth: May 30 to June 1 (H1), June 6 to 8 (H2), and June 14 to 16 (H3). The botanical composition for H1, H2, and H3, respectively, was 68, 56, and 53% timothy; 21, 32, and 33% meadow fescue; 5, 4, and 5% red clover; and 6, 8, and 9% other species, mainly common couch grass (*Elytrigia repens*). The maturity of timothy at harvest, given as mean stage by weight (Moore et al., 1991), was measured within 3 d of harvesting. The mean stage by weight values of 2.44, 2.73, and 3.30 for the 3 harvesting times, respectively (interpolated to the date of harvest), indicated that stage 1 and 2 were dominated by tillers in the stem elongation phase with 2 and 3 visible nodes, respectively, and stage 3 was dominated by tillers with visible heads, but without head stems (early heading). Compared with common Norwegian practice, H1, H2, and H3 represented harvesting at very early, early, and normal maturity stages for timothy, respectively. Late harvesting was not examined. Yields of harvested herbage in the primary growth were 3.7, 5.1, and 6.2 t of DM/ha for H1, H2, and H3, respectively.

The crop was wilted for 2 to 7 h during daytime or for 14 to 22 h overnight, aiming to reach a DM content of 300 g/kg. The weather was mainly sunny with no precipitation during the wilting period, but with some fog and morning dew at the second harvesting time. The crop was baled using 2 Orkel GP 1260 (Orkel AS, Fannrem, Norway) fixed-chamber roundbalers with 20 fixed knives. GrasAAT Lacto (780 g/kg formic acid, 70 g/kg NH_3) silage additive (Addcon Nordic AS, Porsgrunn, Norway) was applied to the crop at 4.4, 4.3, and 4.3 L/t during H1, H2, and H3, respectively. The bales were wrapped in 6 layers of white stretch-plastic film, 0.75 m wide and 0.025 mm thick (Raniwrap, AS Rani Plast OY, Finland). Silage was chopped to a median particle length of approximately 100 mm before feeding. Further details on the preparation of the silages and the composition of fresh herbage are given by Randby et al. (2010).

Diets, Animals, and Design of the Experiment

The study was conducted at the Animal Production Experimental Centre at the University of Life Sciences (Ås, Norway). Dietary treatments in a 3×3 factorial arrangement consisted of silages harvested at the 3 maturity stages and supplemented with 3 concentrate levels: 4, 8, and 12 kg/d (C4, C8, and C12, respectively) on fresh weight basis. These 9 diets were designated H1C4, H1C8, H1C12, H2C4, H2C8, H2C12, H3C4, H3C8, and H3C12, respectively. Additionally, H1 was offered without concentrates (H1C0) and H3

was offered with 16 kg of concentrate daily (**H3C16**), so in total 11 diets were studied. Sixteen kilograms of concentrate was considered the highest level that might improve milk yield when offered with H3, and equal to the highest amount of concentrates commonly used with grass silages harvested at normal or late maturity stages.

Two concentrates, one mixture based mainly on grain ingredients and one with a higher proportion of protein ingredients, were used. The ingredient composition of the grain concentrate was 30.0% oats, 18.0% peas, 17.9% barley, 10.0% wheat, 10.0% wheat bran, 6.0% extracted heat-treated rapeseed meal, 4.5% molasses, 1.3% CaCO₃, 0.5% MgO, 0.8% NaCl, and 1.0% of a mineral and vitamin mix. The composition of the protein concentrate was 32.6% barley, 15.0% peas, 15.0% extracted heat-treated rapeseed meal, 15.0% rapeseed cake, 10.0% wheat bran, 5.0% fish meal LT, 4.5% molasses, 0.8% CaCO₃, 0.03% MgO, 1.0% NaCl, and 1.0% of a mineral and vitamin mix. The mineral and vitamin mix contained 25.3% Ca, 8.0% P, 0.8% Mg, 6.5 g/kg of Zn, 2.5 g/kg of Fe, 2.0 g/kg of Mn, 1.5 g/kg of Cu, 202 mg/kg of I, 35.1 mg/kg of Se, 26.2 mg/kg of Co, 500,000 IU/kg of vitamin A, 4.5 g/kg of vitamin E, and 200,000 IU/kg of vitamin D. All cows except those not fed concentrates were offered 4 kg of the protein concentrate. Cows offered 8, 12, and 16 kg of concentrates received 4, 8, and 12 kg of grain concentrate, respectively, in addition to the protein concentrate. Grain and protein concentrates were both offered in automatic feed stations.

The experiment had a continuous design, with 6 cows on each diet. Cows were assigned to 6 blocks, where block 1 comprised primiparous cows irrespective of calving date, and blocks 2 to 6 included cows in their second to eighth lactations, with the earliest calving cows placed in block 2 and the latest calving cows in block 6. One cow (receiving H2, block 6) was offered, in error, 16 kg instead of 12 kg of concentrate daily, and was therefore excluded from all analyses.

The experiment started in September 2006, and each cow was introduced to the experiment 2 to 3 wk before expected calving date. Grass silage was fed *ad libitum* during the entire study, and a mineral mixture (Pluss Multitilskudd Appetitt, Felleskjøpet Førutvikling, Trondheim, Norway) containing 11.0% Ca, 7.0% P, 6.5% Mg, and 9.0% Na was available for *ad libitum* intake. All cows, except those in H1C0, were offered 2 kg daily of the protein concentrate before calving. From d 1 postcalving, the concentrate allowance (the sum of the grain and protein concentrate) was increased by 0.5 kg daily, so that the full ration was available from DIM 4, 12, 20, and 28, for cows offered 4, 8, 12, and 16 kg, respectively.

Four cows, 1 in each of H1C0, H2C4, H2C8, and H3C4, were treated for ketosis. Three cows, 1 in H1C0 and 2 in H1C4, were diagnosed to have laminitis without being severely affected. Two cows, 1 in each of H1C0 and H3C4, were treated for parturient paresis. Twelve cows, 1 in each of H1C4 and H1C8, 2 in H1C12, 1 in each of H2C4, H2C8, H2C12, and H3C4, and 4 in H3C8, were treated for mastitis. One cow in H1C4 was slaughtered at 100 DIM due to gastric ulcer. Apart from the cases of ketosis, the observed diseases were not assumed related to treatments.

Housing and Management

Cows were housed in freestalls with concrete slatted floors and rubber mat beds with sawdust. Grass silage was fed in bins with vertically moving gates where automatic cow identification ensured each cow access to the correct silage. Eating time for silage was monitored electronically as the time each cow kept the gate open, and intake was recorded by weigh cells underneath each feed bin. The number of available beds and feed bins was the same as the number of cows in the experiment at any time. Feed bins containing the same silage were placed next to each other, and cows could visit any bin containing the offered silage. Eating time for concentrates was assumed to be 4 min/kg of concentrate DM intake (Nørgaard et al., 2010). Cows had access to water, silage, concentrates, and mineral mix all day. Silage was fed into the feed bins twice daily. Silage residues were removed Monday, Wednesday, and Friday morning. The bin weighing mechanisms were calibrated weekly.

Milking and Milk Analyses

Cows were milked twice daily, at 0615 to 0900 h and 1500 to 1715 h. Milk yield was recorded at each milking, and BW of the cows was recorded after each milking by an electronic balance. Milk samples were collected from 6 milkings every week, conserved with Bronopol (2-bromo-2-nitropropane-1,3-diol) and stored at 4°C. Pooled weekly samples from each cow, based on proportional production, were analyzed for fat, protein, lactose, MUN, and FFA with an infrared spectrophotometer (MilkoScan 6000, Foss Electric, Hillerød, Denmark). Energy-corrected milk yield was calculated from chemical composition (Sjaunja et al., 1991). Weekly individual milk samples from the first 12 wk in milk (**WIM**) were stored at -20°C and analyzed colorimetrically for acetone concentration using a Technicon Autoanalyzer II (Bran + Luebbe GmbH, Norderstedt, Germany) as described previously by Randby et al. (1999).

Digestibility Studies, Feed Samples, Analyses, and Estimation of Feed Values and Nutrient Use Efficiency

Feed sampling and analyses, sheep digestibility trials, and rumen in sacco studies are described by Randby et al. (2010). The contents of ME and NE_L in the feed were calculated from feed chemical composition and digestibility values according to Van Es (1978). Metabolizable protein expressed as AA absorbed in the intestine, protein balance in the rumen (**PBV**), and requirements for MP [maintenance: MP, g/d = $3.25 \times BW^{0.75}$, lactation: MP, g/d = $40 \times ECM$ (kg) + $0.2 \times ECM^2$] and for PBV (minimum -200 g of PBV/d) were calculated according to Madsen et al. (1995). Daily energy balance (**EB**; MJ of NE_L) was calculated as feed energy intake minus energy requirement for maintenance ($0.335 \times BW^{0.75}$; NRC, 2001) and milk yield ($3.036 \times \text{kg of ECM} + 0.0050321 \times ECM^2$; Ekern, 1991).

Nitrogen (N) use efficiency was calculated as grams of milk N (milk protein/6.38)/grams of total N intake. Feed conversion rate was calculated as kilograms of ECM/kilograms of DM intake.

Statistical Analyses

Effect of diet on feed intake and milk yield traits were analyzed using the PROC MIXED procedure in SAS (SAS Institute, 2008). The models for milk yield, milk composition, EB, N use efficiency, and feed conversion rate included fixed effects of diet (11 classes), block (6 classes), and WIM (16 classes), and the diet $\times$ WIM interaction. An autoregressive covariance structure using the "random" (cow within diet) and "repeated" (WIM) statements was chosen, with estimation method REML or MIVQUE0 (if iteration stopped because of infinite likelihood). Body weight and BW gain (**BWG**) data were analyzed using models including only the fixed effects of diet and block. For treatment comparisons, the sum of squares for experimental diets were further divided into single degree of freedom comparisons of linear and quadratic effects of harvesting time and concentrate level (4, 8, or 12 kg) and their interactions. Because of 1 excluded cow (H2 with 16 kg instead of 12 kg of concentrates), SEM values of the H2C12 diet (presented in Tables 3 to 7) shown in the tables must be multiplied by 1.10. Correlations and regressions were also calculated using SAS. Optimal concentrate intake for maximal ECM yield within each H was estimated using the PROC RSREG procedure.

Results were considered statistically significant at $P < 0.05$, and P -values between 0.05 and 0.1 were

considered to indicate trends. Values for $P \geq 0.1$ were considered nonsignificant.

RESULTS

Feed Composition and Quality

Composition of grass silages and concentrates are presented in Table 1. Concentrations of fiber (NDF, ADF, and acid detergent lignin) increased, whereas concentrations of N-containing substances (CP, NH_3 -N, and buffer-soluble N) decreased with increased crop maturity at harvest. Protein concentration decreased more than sulfur concentration, so the N/S proportion decreased with increased crop maturity. Water-soluble carbohydrates were high and fermentation acids low, indicating that all silages were of restricted fermentation. The rumen soluble plus degradable portion of N, and the degradable NDF, decreased with increasing crop maturity (Table 2). The apparent total-tract digestibilities in sheep of all nutrients were high for H1 and decreased consistently with increased maturity at harvest. Calculated DOMD for H1 was intermediate between the grain and protein concentrates. The estimated content of MP derived from RUP was much higher in concentrates than in silages, particularly in the protein concentrate, whereas MP derived from rumen microbial protein was higher in silages than in concentrates. The PBV content was high in the protein concentrate and close to zero in the grain concentrate. In silages, it decreased with increased maturity at harvest.

Feed Intake

On average over all 16 WIM, cows offered H1 as the sole feed ingested approximately the same amount of silage DM as cows offered H1 with C4 or C8 (Table 3). When supplementation was increased to C12, silage DM intake (**SDMI**) was reduced. Also for H2, SDMI was similar for cows offered C4 and C8, but was reduced for cows offered C12. Cows offered H3 had reduced SDMI with increasing concentrate DM intake (**CDMI**).

Silage DM intake decreased with increasing crop maturity at harvest. Total daily DM intake (**TDMI**) decreased linearly with increasing maturity at harvest and increased curvilinearly with increased concentrate supplement, indicating diminishing intake response with increased concentrate level. Expressed on a BW basis, greater depressions in SDMI and TDMI from H1 to H2 than from H2 to H3 produced nonlinear responses to crop maturity at harvest. On a BW basis, SDMI decreased and TDMI increased linearly with increased

Table 1. Chemical composition of grass silages harvested at 3 maturity stages (H1, H2, H3), and of concentrates

Item	Harvesting time for grass silage ¹						Concentrates ²			
	H1		H2		H3		Grain		Protein	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
DM, g/kg	299	11.4	271	8.1	322	12.2	923	5.0	926	3.4
pH	4.43	0.04	4.18	0.02	4.31	0.02				
NH ₃ -N, g/kg of N	111	6.0	130	9.3	140	5.7				
NH ₃ -N, g/kg of N ³	82	4.8	94	8.6	101	4.4				
BSN, ⁴ g/kg of N	714	23.0	692	5.7	622	23.3	267	NA ⁵	324	NA
	g/kg of DM									
OM	927	2.1	929	3.0	935	1.4	926	0.9	919	1.9
CP	166	5.9	145	4.1	113	2.4	165	2.1	240	1.8
Starch							405	7.9	251	2.2
WSC ⁶	81.8	4.8	80.3	6.8	62.5	3.4	36.8	NA	56.7	NA
NDF ⁷	477	7.2	533	8.5	601	8.0	207	1.7	190	3.8
ADF ⁸	284	3.3	321	5.0	359	3.6	98.2	NA	102	NA
ADL ⁹	46.4	2.01	51.2	1.46	64.7	1.89	26.5	NA	30.7	NA
Fat	38.0	1.66	29.6	0.81	25.2	0.70	44.5	1.6	77.3	3.0
S	1.77	NA	1.75	NA	1.46	NA	2.65	NA	3.61	NA
Lactic acid	62.4	5.3	74.7	4.0	41.1	2.5				
Formic acid	11.1	0.81	17.7	0.93	11.7	0.75				
Acetic acid	6.3	0.58	7.2	0.65	5.2	0.59				
Propionic acid	0.83	0.83	0.00		0.00					
Butyric acid	0.02	0.01	0.00		0.01	0.01				
Ethanol	8.2	0.72	17.1	0.97	10.1	0.81				

¹For silages: DM, pH, WSC, acids, and ethanol: n = 12 for H1, and 13 for H2 and H3. For S: n = 1, otherwise n = 5.

²For concentrates: n = 6 where SE is given, otherwise n = 1.

³Corrected for NH₃-N applied with silage additive.

⁴BSN = buffer-soluble N.

⁵NA = not available.

⁶WSC = water-soluble carbohydrates.

⁷Analyzed with amylase and sodium sulfite and expressed exclusive of residual ash.

⁸Expressed exclusive of residual ash.

⁹ADL = acid detergent lignin determined by oxidation of lignin with permanganate.

concentrate level. The lowest SDMI (/kg of BW) was found for cows in H3C16 and the highest for cows in H1C0. The lowest and highest TDMI (/kg of BW) were found for cows offered H1, supplemented with C0 and C12, respectively.

The lowest and highest silage NDF intake (/kg of BW) was found for cows offered H3, when supplemented with C16 and C4, respectively. Within the C4 to C12 range, NDF intake from silage, and in total, was highest for H3 and lowest for H2, when assessed on a BW basis. Silage NDF intake (/kg of BW) decreased linearly with increased concentrate level.

All measures of DM and fiber intake increased with increasing stage of lactation until WIM 8 to 16, where the maximum values were reached at 14.5 kg of SDMI, 21.5 kg of TDMI, 36.3 g of DM/kg of BW, and 15.4 g of NDF/kg of BW on average over all diets. For TDMI, however, a significant diet × WIM interaction appeared, which also tended to be significant for SDMI ($P = 0.09$): For H1C0 and H1 or H2 supplemented with C4 or C8, SDMI and TDMI increased considerably with

time, whereas a more moderate increase was found for H3C4 and H3C8 diets. For C12 diets, SDMI did not increase with time, but was rather constant throughout the 16 WIM, approximately at 14, 13, and 12 kg for H1, H2, and H3 diets, respectively. For cows receiving H3C16, SDMI declined from 10.7 to 8.5 kg through WIM 1 to 6, increasing thereafter to approximately 9 kg during WIM 8 to 16.

Diet Composition

The total diet composition for each treatment, calculated from the measured feed intakes, is presented in Table 4. The diet energy concentrations decreased with plant maturity at harvest and increased slightly with the level of concentrate supplement for H1 and H2, and clearly for H3. The silage-only diet provided the poorest MP supply. Increasing concentrate level improved diet MP concentration considerably, whereas only a small decrease in diet MP concentration was found with increased maturity at harvest. However, the

Table 2. Sheep apparent digestibility of nutrients, in sacco degradation, and calculated feed values of grass silages harvested at 3 maturity stages (H1, H2, H3), and of concentrates (partly after Randby et al., 2010)

Item	Harvesting time for silage			SEM	Contrasts, <i>P</i> -value			Concentrates	
	H1	H2	H3		H1–H2	H2–H3	H1–H3	Grain	Protein
Sheep digestibility									
DM	0.794	0.756	0.690	0.0092	0.1	0.04	0.02	0.791	0.830
OM	0.806	0.763	0.693	0.0087	0.07	0.03	0.01	0.779	0.822
CP	0.781	0.755	0.682	0.0085	NS	0.03	0.01	0.830	0.837
NDF	0.805	0.750	0.669	0.0098	0.06	0.03	0.01	0.248	0.470
DOMD ¹	0.747	0.708	0.647	0.0081	0.08	0.03	0.01	0.725	0.761
In sacco degradation of total N									
Soluble N	0.732	0.755	0.662	0.0041	0.02	<0.001	<0.001	0.252	0.368
Degradable N	0.217	0.159	0.171	0.0042	<0.001	NS	0.002	0.709	0.580
N k _d ² /h	0.072	0.043	0.059	0.0033	0.004	0.03	0.06	0.074	0.059
EPD _s ³ /h	0.835	0.810	0.734	0.0026	0.003	<0.001	<0.001	0.591	0.612
Digestibility of RUP ⁴	0.810	0.797	0.764	0.0002	<0.001	<0.001	<0.001	0.923	0.864
Indigestible N ⁵	0.031	0.038	0.063	0.0002	0.002	<0.001	<0.001	0.032	0.053
In sacco degradation of total NDF									
Degradable NDF	0.906	0.872	0.791	0.0023	0.009	0.002	<0.001	0.711	0.645
NDF k _d ⁶ /h	0.058	0.047	0.046	0.0029	0.06	NS	0.04		
iNDF ⁷	0.094	0.128	0.209	0.0023	0.009	0.002	<0.001	0.289	0.355
ENDFD ₃ ⁸	0.582	0.513	0.450	0.0075	0.003	0.004	<0.001		
Energy and protein values									
ME, MJ/kg of DM	11.36	10.67	9.62	0.123	0.06	0.03	0.01	11.58	13.0
NE _L , MJ/kg of DM	6.75	6.26	5.52	0.086	0.06	0.03	0.01	6.96	7.96
MP _{RUP} ⁹ , g/kg of DM	14.2	13.6	14.1	NA ¹⁰	NA	NA	NA	53.1	66.2
MP _{RMP} ¹¹ , g/kg of DM	63.1	61.8	59.3	0.69	NS	NS	0.06	58.5	52.3
MP, g/kg of DM	77.2	75.4	73.3	0.69	NS	NS	0.06	111.6	118.5
PBV ¹² , g/kg of DM	29.6	8.2	–21.6	1.17	0.006	0.003	0.001	–0.9	54.2

¹Digestible OM in DM.²Fractional degradation rate of degradable N, per h.³Effective rumen protein degradability, calculated with rumen passage rate of 0.08 per h.⁴Intestinal digestibility of RUP.⁵Rumen and intestinal indigestible N.⁶Fractional degradation rate of degradable NDF, per h.⁷Indigestible NDF after 288 h of rumen incubation.⁸Effective rumen NDF degradability, calculated with rumen passage rate of 0.03 per h.⁹MP derived from RUP.¹⁰NA = not available.¹¹MP derived from rumen microbial protein.¹²Protein balance in the rumen.

concentration of PBV was strongly affected by plant maturity at harvest.

Eating Time

The time each cow kept the gate of the silage feed bin open, here used as a measure of eating time, is presented in Table 5. The time spent eating silage increased linearly with plant maturity at harvest and decreased linearly with increasing concentrate allowance. Eating time per kilogram of silage DM and NDF intake increased linearly with plant maturity at harvest, but was not affected by concentrate allowance. The total time spent eating, assuming 4 min/kg of CDMI, increased linearly with plant maturity at harvest and decreased linearly with increasing concentrate allowance within the C4 to C12 range. Cows offered silage only, however,

spent the shortest time eating. Eating time per kilogram of total DM and NDF intake increased linearly with plant maturity and decreased linearly with concentrate allowance.

The time spent eating silage and the total time spent eating increased with increasing WIM. The time spent eating per kilogram of SDMI also increased slightly with time, from 14 to 15.5 min/kg of SDMI during WIM 1 to 16, but for TDMI no overall effect of WIM was seen. However, eating time per kilogram of TDMI differed among diets. For diet H2C4 and H3C4, eating time per kilogram of TDMI increased from approximately 12 to 14 min, and from 14 to 16 min, respectively, in the course of the 16 wk. For diet H3C16, the full concentrate allowance was not consumed until WIM 6, and during the first 5 wk, eating time per kilogram of TDMI was reduced from approximately 16 to 10.5 min, after

Table 3. Effect of harvesting time for grass silage (H1, H2, H3) and level of concentrate supplement on daily DM and fiber (NDF) intake of cows (mean values for lactation wk 1–16)

Silage harvest time	Concentrate level, kg ¹	DM, kg							
		Concentrates				DM, g/kg of BW		NDF, g/kg of BW	
		Protein	Grain	Silage	Total diet	Silage	Total diet	Silage	Total diet
H1	0	0	0	16.9	16.9	30.1	30.1	14.3	14.3
	4	3.62	0	17.0	20.6	29.7	36.1	14.2	15.4
	8	3.61	3.42	16.7	23.7	27.6	39.3	13.2	15.5
	12	3.31	6.14	14.2	23.6	24.4	40.8	11.7	14.9
H2	4	3.65	0	14.5	18.2	24.9	31.3	13.3	14.5
	8	3.61	3.13	14.4	21.1	23.9	35.2	12.7	15.0
	12	3.52	6.37	12.9	22.8	20.5	36.2	10.9	14.1
H3	4	3.65	0	14.4	18.0	25.4	31.9	15.2	16.5
	8	3.62	3.37	13.3	20.3	21.3	32.5	12.8	15.0
	12	3.54	6.31	11.9	21.7	20.0	36.7	12.0	15.4
	16	3.30	8.74	9.3	21.4	16.6	38.1	10.0	14.3
SEM ²				0.49	0.55	0.91	1.10	0.48	0.52
P-value	Diet ³			<0.001	<0.001	<0.001	<0.001	<0.001	NS
P-value	Contrasts ⁴								
	LH			<0.001	<0.001	<0.001	<0.001	NS	NS
	QH			0.09	NS	0.02	0.01	0.02	0.02
	LC			<0.001	<0.001	<0.001	<0.001	<0.001	NS
	QC			0.08	0.03	NS	NS	NS	NS
	H × C			NS	NS	NS	NS	NS	NS
P-value	WIM ⁵			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Diet × WIM			0.09	0.03	0.08	NS	NS	NS

¹Where 4 kg is protein concentrate only; 8, 12, and 16 kg = 4 kg of protein concentrate plus grain concentrate to total level.

²For the diet with 1 missing value (H2, 12 kg of concentrate), SEM was multiplied by 1.10.

³All 11 diets.

⁴Contrasts including only the 9 diets with 4, 8, or 12 kg concentrates. LH and QH = linear and quadratic effects of harvesting time, LC and QC = linear and quadratic effects of concentrate level, H × C = harvesting time × concentrate level interaction.

⁵WIM = week in milk.

which it remained stable. For other diets, eating time per kilogram of TDMI was rather stable throughout the 16 wk. Eating time per kilogram of silage NDF and total NDF increased with increasing WIM.

Milk Production and Composition

Milk yield decreased linearly with increasing plant maturity at harvest and increased linearly with increasing concentrate allowance (Table 6). However, within H1, when C0 was included, milk yield tended to be quadratically related to concentrate level ($P = 0.06$, contrast not presented), with a negative response to the highest level. For H2, milk yield was similar for C8 and C12, and for H3, no milk yield response to the highest concentrate level was found. Similar yield responses were also found for ECM, fat, protein, and lactose. Based on quadratic regression, the concentrate intake for maximum ECM yield was at 7.4, 7.7, and 10.6 kg of DM, equivalent to 8.0, 8.4, and 11.5 kg of concentrate on an as-fed basis.

Milk fat concentration tended to decrease curvilinearly with increasing maturity at harvest, with lower concentrations for H3 than for H2 and H1 ($P = 0.01$,

contrast not presented). Milk urea concentrations decreased linearly with increasing plant maturity at harvest. Milk FFA concentrations increased linearly with increasing plant maturity at harvest and decreased with increasing concentrate level.

All yield and milk concentration measurements were affected by WIM, and diet × WIM interactions were found for all yield measurements and for milk fat concentration. On average, over all diets, daily milk yield peaked at 30.4 kg in WIM 5, and decreased thereafter by 0.28 kg/wk. Cows on the H1C8 diet produced the highest total milk yield, and their maximum yield, 34.9 kg, was also found in WIM 5, with a subsequent weekly decrease of 0.24 kg. Daily milk yield of cows offered silage only (H1C0) was highest in WIM 2 (25.4 kg) and decreased thereafter by 0.34 kg/wk, whereas cows offered H3C16 increased milk yield slowly after calving and reached maximum yield (31.3 kg) in WIM 8, with a weekly decrease thereafter of only 0.18 kg.

On average, over all diets, daily milk fat concentration decreased from 45.8 g/kg in WIM 1 to a stable minimum value of 39.4 g/kg during WIM 5 to 13, after which a slight increase to 40.3 g/kg in WIM 16 was observed. This increase during the last weeks of the

Table 4. Effect of harvesting time for grass silage (H1, H2, H3) and level of concentrate supplement on diet composition (mean values for lactation wk 1–16)

Silage harvest time	Concentrate level, kg ¹	g/kg of DM						MJ/kg of DM		g/kg of DM	
		OM	CP	Fat	NDF	ST + WSC ²	Acids + ethanol	ME	NE _L	MP	PBV ³
H1	0	927	161	38	477	82	89	11.4	6.75	77.2	29.6
	4	926	175	46	426	120	73	11.7	6.97	84.6	34.0
	8	926	174	45	394	167	62	11.6	6.97	88.5	29.0
	12	926	173	45	367	205	53	11.7	6.97	91.9	25.2
H2	4	927	160	40	462	124	93	11.2	6.61	84.3	17.7
	8	927	160	40	425	171	79	11.2	6.66	88.2	14.8
	12	927	162	40	390	213	67	11.3	6.72	92.0	12.8
H3	4	932	135	36	516	110	54	10.3	6.02	82.6	−6.0
	8	931	141	38	462	167	45	10.6	6.19	87.7	−4.6
	12	930	146	39	421	210	37	10.7	6.33	91.7	−3.3
	16	929	151	40	380	250	30	10.9	6.47	95.6	−1.6
SEM ⁴		0.074	0.58	0.25	2.33	1.96	0.57	0.015	0.011	0.26	0.30
P-value	Diet ⁵	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
P-value	Contrasts ⁶										
	LH	<0.001	<0.001	<0.001	<0.001	NS	<0.001	<0.001	<0.001	<0.001	<0.001
	QH	<0.001	<0.001	<0.001	0.005	<0.001	<0.001	<0.001	<0.001	0.06	<0.001
	LC	<0.001	<0.001	0.006	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	QC	NS	NS	NS	0.07	0.003	0.08	NS	NS	NS	NS
	H × C	<0.001	<0.001	<0.001	<0.001	<0.001	0.02	<0.001	<0.001	0.001	<0.001
P-value	WIM ⁷	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	NS
	Diet × WIM	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

¹Where 4 kg is protein concentrate only; 8, 12, and 16 kg = 4 kg of protein concentrate plus grain concentrate to total level.

²ST+WSC = starch + water-soluble carbohydrates.

³PBV = protein balance in the rumen.

⁴For the diet with 1 missing value (H2, 12 kg of concentrate), SEM was multiplied by 1.10.

⁵All 11 diets.

⁶Contrasts including only the 9 diets with 4, 8, or 12 kg of concentrates. LH and QH = linear and quadratic effects of harvesting time, LC and QC = linear and quadratic effects of concentrate level, H × C = harvesting time × concentrate level interaction.

⁷WIM = week in milk.

experiment was, however, due to increases in milk fat concentrations for cows on the H1C0, H1C4, and H2C4 diets only, the same diets that also gave the highest mean milk fat concentrations, whereas fat concentrations remained close to the minimum values toward the end of experiment for the other diets. On average, over all diets, milk protein concentration decreased sharply from 38.4 g/kg in WIM 1 to the minimum value of 31.2 g/kg in WIM 6 and 7, and increased thereafter to 32.7 g/kg in WIM 15 and 16. The lactose concentration was more stable than that of other milk constituents, and on average, over all diets, it increased from 44.3 g/kg in WIM 1 to 45.7 g/kg in WIM 5, before it decreased slightly to 45.2 g/kg in WIM 16.

The yields of ECM, milk fat, and lactose followed similar patterns for the various diets as did milk yield. However, compared with milk yield, ECM and milk fat yields of diets H1C0, H1C4, and H2C4 were slightly more persistent toward the end of experiment because of the increases in milk fat concentration. On average for cows on all diets, MUN increased during the entire period. The average milk FFA concentration was 0.52 mEq/L in WIM 1, followed by a stable low value at

approximately 0.38 mEq/L in WIM 2 to 7 and then an increase to 0.60 mEq/L in WIM 16.

BW, EB, and Milk Acetone Concentration

Some dietary treatments included cows with an initial higher BW than other treatments, but differences in BW at the onset of lactation were not significant (Table 7). Final BW was higher for cows offered C12 compared with C4, in spite of similar initial BW of cows in these treatments within crop maturity stages. Body weight gains increased linearly within the C4 to C12 range and decreased linearly with increasing stage of crop maturity. The increase due to concentrate level was caused by differences occurring during the first 5 wk, when cows offered C4 with H1, H2, and H3 lost 140, 769, and 732 g/d, respectively, whereas cows offered C12 showed increased BW (184 and 153 g/d for H1 and H2, respectively) or stable BW (−36 g/d for H3; data not presented). In contrast, the decrease in BW due to increased crop maturity stage was mainly due to differences occurring from WIM 6 to 11, when cows within the C4 to C12 range offered H1, H2, and H3 had

Table 5. Effect of harvesting time for grass silage (H1, H2, H3) and level of concentrate supplement on daily eating time (mean values for lactation wk 1–16)

Silage harvest time	Concentrate level, kg ¹	Eating time for silage			Total ration eating time ²		
		min	min/kg of DM	min/kg of NDF	min	min/kg of DM	min/kg of NDF
H1	0	186	11.0	23.1	186	11.0	23.1
	4	203	12.3	25.8	218	10.8	25.3
	8	209	12.6	26.5	237	10.0	25.5
	12	163	11.7	24.5	201	8.6	23.4
H2	4	221	15.7	29.4	235	13.2	28.6
	8	206	14.5	27.2	233	11.1	26.1
	12	170	13.2	24.9	210	9.2	23.7
H3	4	257	18.1	30.1	271	15.2	29.4
	8	235	17.8	29.6	263	13.0	28.2
	12	212	17.9	29.9	251	11.6	27.7
	16	192	21.3	35.4	240	11.6	30.5
SEM ³		11.0	0.99	1.83	11.6	0.64	1.52
<i>P</i> -value	Diet ⁴	<0.001	<0.001	0.001	<0.001	<0.001	0.01
<i>P</i> -value	Contrasts ⁵						
	LH	<0.001	<0.001	0.007	<0.001	<0.001	0.005
	QH	0.08	NS	NS	0.1	NS	NS
	LC	<0.001	NS	NS	0.03	<0.001	0.03
	QC	NS	NS	NS	NS	NS	NS
	H × C	NS	NS	NS	NS	NS	NS
<i>P</i> -value	WIM ⁶	<0.001	<0.001	<0.001	<0.001	NS	0.01
	Diet × WIM	NS	NS	NS	NS	<0.001	NS

¹Where 4 kg is protein concentrate only; 8, 12, and 16 kg = 4 kg of protein concentrate plus grain concentrate to total level.

²Calculated assuming 4 min eating time per kg of concentrate DM.

³For the diet with 1 missing value (H2, 12 kg of concentrate), SEM was multiplied by 1.10.

⁴All 11 diets.

⁵Contrasts including only the 9 diets with 4, 8, or 12 kg of concentrates. LH and QH = linear and quadratic effects of harvesting time, LC and QC = linear and quadratic effects of concentrate level, H × C = harvesting time × concentrate level interaction.

⁶WIM = week in milk.

BW changes of +326, +313, and −66 g/d, respectively (data not presented). At the start of lactation, cows offered H1C0, H2C4, and H3C4 lost approximately 30 kg before their BW started to increase, and only cows fed these 3 diets lost weight, on average, for the entire period (Table 7).

Calculated daily EB decreased linearly with increased crop maturity and increased linearly with increased concentrate level (Table 7). On average, over all diets, EB increased during the entire period, from −20 MJ of NE_L in WIM 1 to 17 MJ of NE_L in WIM 16, with zero EB in WIM 3 to 4, and with a diminishing weekly increase with time.

Milk acetone concentrations peaked at 1.7, 1.7, 2.0, and 2.8 mM for the 4 cows diagnosed with and treated for clinical ketosis. Apart from those cows, the total mean acetone concentration was 0.09 mM and the maximum individual concentration 0.66 mM. Acetone concentrations decreased linearly with increased concentrate level, but were not affected by crop maturity stage (Table 7). However, milk acetone concentrations were influenced by the block of cows ($P = 0.02$), and cows calving late in the season had the highest average values. On average, over all diets, acetone concentra-

tion was 0.08 mM in WIM 1 and increased to 0.20 mM in WIM 6 (the time when the 4 cows got ketosis), after which it fell to a constant level of approximately 0.11 mM in WIM 7 to 12.

Nitrogen Use Efficiency and Feed Conversion Rate

Nitrogen use efficiency for milk production increased with increasing stage of crop maturity and tended to decrease with increasing concentrate level (Table 7). In WIM 1, the average N use efficiency was 0.38. It decreased sharply to 0.30 in WIM 3, and fell slowly thereafter to 0.26 in WIM 16. Feed conversion rate tended to decrease with increasing concentrate level. It also decreased with increasing stage of lactation, from 1.71 in WIM 1 to 1.25 in WIM 16.

DISCUSSION

Feed Intake

Silage DMI was high compared with other studies (Rinne et al., 1999a; Dewhurst et al., 2003; McNamee et al., 2005). On a BW basis, maximum TDMI (H1C12)

Table 6. Effect of harvesting time for grass silage (H1, H2, H3) and level of concentrate supplement on daily milk yield and composition (mean values for lactation wk 1–16)

Silage harvest time	Concentrate level, kg ¹	Milk yield					Milk composition				
		Milk, kg	ECM, kg	Fat, g	Protein, g	Lactose, g	Fat, g/kg	Protein, g/kg	Lactose, g/kg	MUN, mg/dL	FFA, mEq/L
H1	0	23.7	23.4	975	742	1,049	41.4	31.5	44.4	11.5	0.63
	4	29.1	29.1	1,200	930	1,315	41.3	32.2	45.2	13.5	0.39
	8	32.8	32.8	1,337	1,069	1,495	40.9	32.8	45.6	12.2	0.31
	12	31.6	31.0	1,246	1,037	1,420	39.7	33.2	45.1	12.9	0.26
H2	4	26.7	27.1	1,141	854	1,189	42.6	32.0	44.6	12.7	0.55
	8	29.4	29.3	1,206	932	1,339	41.2	31.8	45.5	11.6	0.40
	12	29.2	28.8	1,145	969	1,332	39.6	33.6	45.6	11.3	0.35
H3	4	25.8	24.9	994	822	1,165	38.8	32.2	45.3	11.4	0.61
	8	27.6	27.3	1,093	902	1,263	39.5	32.8	45.6	11.2	0.72
	12	30.8	30.1	1,197	987	1,432	38.9	32.2	46.5	12.3	0.37
	16	29.3	28.7	1,153	945	1,334	39.5	32.3	45.4	10.6	0.46
SEM ²		1.70	1.60	71.0	46.2	74.0	0.97	0.69	0.54	0.56	0.110
P-value	Diet ³	0.02	0.008	0.03	<0.001	0.004	NS	NS	NS	0.02	0.1
P-value	Contrasts ⁴										
	LH	0.03	0.009	0.006	0.006	0.05	0.06	NS	NS	0.01	0.01
	QH	NS	NS	NS	NS	NS	0.07	NS	NS	NS	NS
	LC	0.02	0.03	NS	0.002	0.007	0.07	NS	NS	NS	0.05
	QC	NS	NS	NS	NS	NS	NS	NS	NS	0.09	NS
	H × C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
P-value	WIM ⁵	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	NS
	Diet × WIM	<0.001	<0.001	<0.001	<0.001	<0.001	0.03	NS	NS	NS	NS

¹Where 4 kg is protein concentrate only; 8, 12, and 16 kg = 4 kg of protein concentrate plus grain concentrate to total level.²For the diet with 1 missing value (H2, 12 kg of concentrate), SEM was multiplied by 1.10.³All 11 diets.⁴Contrasts including only the 9 diets with 4, 8, or 12 kg of concentrates. LH and QH = linear and quadratic effects of harvesting time, LC and QC = linear and quadratic effects of concentrate level, H × C = harvesting time × concentrate level interaction.⁵WIM = week in milk.

was higher than obtained by Ferris et al. (1999, 2001) with TMR and a maximum concentrate proportion of 80%. However, most studies have been performed later in lactation, when the physiological status (hormones) of the cow supports milk yield to a lower degree (Yan et al., 2006), and therefore also feed intake, compared with the present study. Kuoppala et al. (2008), however, obtained slightly higher feed intakes compared with this study, also with early harvested, well-preserved grass, from the primary growth in northern latitudes. At the same morphological stage, the digestibility of the whole grass crop is higher at northern than at southern latitudes due to lower temperatures that delay stem lignifications. The daily decline in digestibility, however, is higher at northern latitudes due to a more rapid stem development and a smaller proportion of leaf DM (Deinum et al., 1981). Silage DM intake indexes (SDMI index; Huhtanen et al., 2007) were calculated to be 120, 109, and 104 for H1, H2, and H3, respectively, where a well-fermented standard silage with 25% DM, 68% DOMD, and 80% total fermentation acids in DM has an index of 100.

Substitution rates (**SR**; reduction in silage DM intake/kg DM increased concentrate intake) calculated for WIM 5 to 16, when the increase in concentrate al-

lowance following calving was completed for all diets, were close to zero for H1 and H2, for concentrate allowances up to C8. This might be related to the protein concentrate used for the first 4 kg, because clear evidence exists that protein supplements reduce SR (Thomas, 1987; Huhtanen et al., 2008c). The low EB of cows offered diets H1C0, H2C4, and H3C4 might have contributed to this low SR (Faverdin et al., 1991). Huhtanen et al. (2008c) found a quadratic relationship between CDMI and SDMI, which suggests that SR may be very low at low CDMI. For H3, SR increased with increasing concentrate allowance, and was 0.31, 0.49, and 0.95 in the intervals C4 to C8, C8 to C12, and C12 to C16, respectively, which is in agreement with results of Faverdin et al. (1991) and Huhtanen et al. (2008c). In the interval C8 to C12, SR decreased with increasing crop maturity stage, and was 1.11, 0.55, and 0.49 for H1, H2, and H3, respectively. For SR calculated for lactation stages WIM 6 to 10 and 11 to 16, respectively, no time effect was detected, which is in line with Huhtanen et al. (2008c). The TDMI observed for the 11 diets on average for WIM 1 to 16 were well predicted by the relative total diet intake index (Huhtanen et al., 2008c): $TDMI (kg) = 9.58 + 0.105 \times TDMI \text{ index}$; $R^2 = 0.88$, root mean square error = 0.85, $P < 0.001$.

Table 7. Effect of harvesting time for grass silage (H1, H2, H3) and level of concentrate supplement on BW, BW gain (BWG), energy balance (EB), milk acetone concentrations, N use efficiency, and feed conversion rate [mean values for lactation week (WIM) 1–12 for acetone, otherwise WIM 1–16, except for BW]

Silage harvest time	Concentrate level, kg ¹	BW, kg		BWG, g/d	EB, MJ of NE _L /d	Milk acetone, mM	Milk N/N intake ²	ECM/DMI ³
		WIM 1	WIM 16					
H1	0	579	566	−134	1.4	0.21	0.275	1.42
	4	566	581	152	12.0	0.11	0.256	1.42
	8	610	619	88	19.3	0.11	0.258	1.40
	12	565	591	264	26.0	0.09	0.249	1.32
H2	4	608	588	−204	−5.8	0.18	0.295	1.52
	8	602	619	166	6.3	0.11	0.275	1.41
	12	620	652	330	19.5	0.09	0.260	1.27
H3	4	592	573	−185	−9.4	0.20	0.333	1.39
	8	630	631	16	−2.6	0.07	0.311	1.35
	12	590	606	153	1.3	0.08	0.309	1.40
	16	567	572	58	8.6	0.07	0.295	1.37
SEM ³		22.5	20.7	103.0	5.18	0.042	0.0143	0.077
P-value	Diet ⁴	NS	NS	0.008	<0.001	NS	0.001	NS
P-value	Contrasts ⁵							
	LH	NS	NS	0.04	<0.001	NS	<0.001	NS
	QH	NS	NS	NS	NS	NS	NS	NS
	LC	NS	0.04	<0.001	<0.001	0.03	0.08	0.07
	QC	NS	0.1	NS	NS	NS	NS	NS
	H × C	NS	NS	NS	NS	NS	NS	NS
P-value	WIM ⁷				<0.001	0.03	<0.001	<0.001
	Diet × WIM				NS	NS	0.05	NS

¹Where 4 kg is protein concentrate only; 8, 12, and 16 kg = 4 kg of protein concentrate plus grain concentrate to total level.

²N use efficiency = N in milk/total N intake.

³Feed conversion rate = ECM yield, kg/DM intake, kg.

⁴For the diet with 1 missing value (H2, 12 kg of concentrate), SEM was multiplied by 1.10.

⁵All 11 diets.

⁶Contrasts including only the 9 diets with 4, 8, or 12 kg of concentrates. LH and QH = linear and quadratic effects of harvesting time, LC and QC = linear and quadratic effects of concentrate level, H × C = harvesting time × concentrate level interaction.

⁷WIM = week in milk.

Cows offered H3C16 increased TDMI and milk yield much more slowly in early lactation than cows offered other diets. The 0.5-kg daily concentrate increase contained slightly more starch and WSC (422 g/kg of DM) than the daily increase given to other cows (308, 397, and 415 g/kg of DM for C4, C8, and C12, respectively). For cows offered H3C16, the increase in concentrate intake was followed by a concomitant decrease in SDMI from WIM 2 to 6, giving an increased ratio of rapidly (starch + WSC) to slowly (NDF) digestible carbohydrates, which reached a maximum of 0.768 in WIM 7 to 8. During the same weeks, eating time decreased for these cows, and thereby the buffering effect from saliva on the rumen environment. Although none of the cows offered H3C16 went “off feed” or were sick at any time, and milk fat depression did not occur, NDF digestion might have been reduced when concentrate level increased (Rinne et al., 1999a; Ferris et al. 2001) to such a level that diet OM digestibility was also reduced (Nousiainen et al., 2009).

For all diets, total NDF intake was above the level (12.5 g/kg of BW) recommended by Mertens and Fahey (1994) that is assumed to support maximum milk yield

on maize-based diets. Nordic grass crops have higher NDF concentration than North American maize-based diets (Huhtanen and Hristov, 2009). However, the high NDF intake by cows offered H3C4 suggests that diet intake was strongly constrained by rumen fill. Those animals spent more time eating silage than other cows in an effort to meet their nutrient requirements.

Eating Time

The observed eating times for silage were much shorter than those recorded using the IGER behavior recorder (Rutter et al., 1997) with silage supplemented with 6 kg of concentrates and grass silages with similar DOMD values to H1 and H2 in a previous study (Garmo et al., 2008). In that study, silages had lower DM concentrations but were restrictedly fermented, and SDMI was high. In the meta-analysis of studies with chewing time performed by Nørgaard et al. (2010), only one study had similar eating time to the 271 min/d for H3C4 in the present study: 282 min/d for cows consuming 14 kg DM of grass silage supplemented with 2.6 kg DM of concentrates. Eating time for silage calculated accord-

ing to Nørgaard et al. (2010) was found to be 100, 90, and 60% higher than the observed eating times for H1, H2, and H3, respectively. Whereas the study of Garmo et al. (2008) and the majority of studies underlying the investigation of Nørgaard et al. (2010) were undertaken in tie-up barns, the present study was performed with cows in loose housing. However, because the numbers of feed bins and cows were always the same, cows had no reason to be stressed and thus eat extremely rapidly. The present study was performed somewhat earlier in lactation than the study by Garmo et al. (2008), where cows were in WIM 4 to 22. Eating time for silage increased slightly with time in the present study, but the full reason for the short silage eating times was not found.

Milk Production, EB, and Nutrient Utilization

The mean daily milk yield of cows fed silage only (H1C0) was slightly greater than that obtained by Steinshamn and Thuen (2008) in organic production. Cows fed silage only were in negative EB until WIM 5 and had MP supply below requirements until WIM 10. Although moderate negative EB in early lactation may be easily compensated for by mobilization of body fat stores, a deficient supply of MP may be compensated only to a smaller extent by mobilization (NRC, 2001), with a resultant reduction in milk yield. Due to increased energy intake, any supplementation of H1 with concentrates is expected to reduce the risk of ketosis and, at the same time, the first kilograms of supplementary concentrate would give a high milk yield response. The response to the first 4 kg of protein supplement to H1 was 1.6 kg of ECM/kg of CDMI, or 0.12 kg of ECM/MJ of ME, and the response to the next 4 kg (grain concentrate) was 1.1 kg of ECM/kg of additional CDMI, or 0.10 kg of ECM/MJ of ME.

Cows offered H1C4 and H1C8 diets were in positive EB from WIM 3 and 2, respectively, and met their MP requirements from WIM 4 and 3, respectively. None of the other diets equaled the milk yield of diet H1C8, which is in line with the findings of Kristensen and Skovborg (1990) and Aston et al. (1994). Diet H1C8 contained 30% concentrate and supported a daily yield of 1.34 kg of milk fat and 1.07 kg of milk protein, slightly below that reported by Ferris et al. (2001). Cows offered H2C4 and H3C4 were in positive EB from WIM 11 and 10, respectively, and met their MP requirements from WIM 11 and 8, respectively. Their milk yield was most probably limited by energy intake because they were provided with more MP (/MJ of NE_L) than cows offered H1C4, but TDMI and milk yield were considerably lower.

The negative EB of cows offered H1C0, H2C4, and H3C4 corresponded well with the BW loss observed for these cows during the first weeks of lactation. The relatively high MP supply provided to cows offered C4 diets from the protein concentrate was probably of great importance for their milk yield. The system used for concentrate allocation (protein concentrate as the first 4 kg and later grain concentrate) was chosen because it is known that forage plus grain provides too little MP to support a high milk yield, and the AA composition in such a diet is not optimal for milk protein synthesis, with histidine as the first-limiting amino acid (Vanhatalo et al., 1999). On the other hand, the system for concentrate allocation seems to have been unfavorable to cows offered the highest concentrate levels. The highest concentrate allowance within each silage type appears to have reduced rumen fiber digestion so that milk yield declined (H1 and H3) or remained similar to the yield obtained with 4 kg less concentrates (H2). Both energy (ME and NE_L) concentrations and MP concentrations were overestimated for the C12 and C16 diets, because diet NDF digestion decreases linearly with increased concentrate intake (Nousiainen et al., 2009). At least for H3 diets, concentrate with higher protein content for cows offered C12 and C16 would probably have improved fiber digestion (Nousiainen et al., 2009) and reduced silage SR, giving improved supply of both energy and MP. Maximum diet digestibility and maximum milk yield were found at diet CP concentrations of 220 g/kg of DM (NRC, 2001; Nousiainen et al., 2009), whereas the present diets contained from 135 to 175 g of CP/kg of DM. Compared with concentrates offered in 2 daily meals, as in the study by Kristensen and Skovborg (1990), the feeding of small amounts of concentrate in frequent meals, as in the present study, did not seem to improve the milk yield response to high CDMI.

Although milk fat concentration tended to decrease with increased concentrate intake, no milk fat depression was observed. A high acetate plus butyrate to propionate ratio in the rumen of cows fed restrictedly fermented grass silages provides easily available precursors for milk fat synthesis (Huhtanen et al., 2003). Therefore, milk fat depression is seldom found in cows fed grass silage. Milk fat concentration decreased from 45.7 to 35.7 g/kg in the study of Ferris et al. (2001) when the concentrate proportion in the TMR was increased from 32 to 80%. De Brabander et al. (1999) suggested that feeding grass silage might result in a lower risk of ruminal disorders than feeding maize silage.

Milk urea N was slightly below that often found for high-yielding dairy cows (Rinne et al., 1999b; Huhtanen et al. 2008b). The increase in milk FFA concentrations

with increasing crop maturity stage and with decreasing concentrate level suggest that FFA increases with decreasing energy intake or decreasing EB in dairy cows in early lactation.

The efficiency of transferring dietary N to milk N found for cows offered silage as the sole feed (H1C0) was below that found by Steinshamn and Thuen (2008) for grass silages containing 34% red or white clover. The total average N use efficiency was 0.283, in line with Huhtanen et al. (2008a), who found, in a meta-analysis, that N use efficiency averaged 0.277 and was poorly related to milk yield, and that dietary CP concentration was the best predictor of N use efficiency. In the present study, N use efficiency was highest with H3 diets, which contained the lowest CP concentrations and gave milk with the lowest MUN concentrations. The high values found for N use efficiency and feed conversion rate in the first weeks of lactation were most likely due to mobilization of body reserves.

CONCLUSIONS

The present study documents that a reasonably high milk yield can be obtained solely from grass silage if herbage is harvested at a very early stage of maturity and is well preserved. Highly digestible grass silage resulted in the highest milk yield. The lower digestibility of silage could not be compensated for by increasing the concentrate supplementation. The energy-corrected milk yield response to concentrate intake with H1, H2, and H3 suggested that 8.0, 8.4, and 11.5 kg of concentrate supplementation of the 3 respective silages was optimal for high milk yield. Higher concentrate input reduced milk yield and thereby decreased efficiency of nutrient use.

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