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Shortened first regrowth interval of grass silage as a harvesting strategy to improve nutrient supply for dairy cows: a case study

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Dairy cows have a highly valuable ability to convert grass into milk. A modification of the normal three-cut harvesting strategy was evaluated consisting of shortened first grass regrowth period to increase the energy value of the silage crop over the whole growing season under Boreal conditions. Grass was ensiled from timothy-meadow fescue-red clover swards over two years at three consecutive harvests within the growing season. Diets based on the silages (D1, 1st cut; D2, 2nd cut and D3, 3rd cut) were fed to dairy cows in two milk production experiments using change-over designs and an average concentrate proportion of 0.41 on dry matter basis. Consistently high energy value in silages was achieved and despite minor differences in silage D-values, feed intake was highest for D1. The differences in energy-corrected milk yield between treatments were limited to an increase for D2 in Exp 2 so that feed energy conversion into milk was decreased with D1. A shortened first regrowth interval for grass silage harvest was a viable option, but forage area per animal and other farm specific factors should be considered when choosing the silage harvesting strategy.

Key words: D-value, dairy cow feeding, feed intake, forage quality, milk production, *Phleum pratense*

Introduction

Under northern European conditions, intensive milk production and dairy cattle feeding is based on grass silages and complementary concentrates (Virkajärvi et al. 2015). The level of concentrate supplementation has been high in recent years due to the relatively high production response to supplementation compared to the ratio of concentrate costs and milk price (Knaus 2016). The cereal grain yield potential is 5–6 tonnes dry matter (DM) ha^{-1} in Southern Finland and gradually cereal production ceases towards the Northern parts of Finland, whereas grass yield potential is 9–12 tonnes DM ha^{-1} (Virkajärvi et al. 2015). These numbers are in line with the results of the Official Finnish variety trials of cereals and grasses showing a two-fold DM yield for grasses compared to barley and oats grains (Luke 2023a). In general, the use of a high forage diet reduces total field area required per animal, which is beneficial from environmental point of view, and provides the opportunity to exploit the unique ability of ruminants to convert fibrous forages into milk and meat. The cultivation of grass also provides many ecosystem services such as carbon sequestration and biodiversity benefits.

Due to harsh over-wintering conditions, timothy, meadow fescue and red clover dominate the swards cultivated for silage production in Boreal areas (Virkajärvi et al. 2015). The silage harvesting strategy chosen at farms depends on how much grassland is available for forage production relative to the herd size. With small field area per animal the grass yield must be maximised by harvesting the forage at a late stage of maturity (Hyrkäs et al. 2015). This results in low digestibility, and if high milk production is targeted, high proportion of concentrate in the diet is required (Kuoppala et al. 2008, Sairanen et al. 2022). It is possible to harvest silage at early maturity stage and decrease the concentrate supplementation, if animal numbers per field area are low. The cost of cereal grains has increased recently (FAO 2022) and the price looks likely to remain high in the future due to climate change and international crises. This suggests that a low-concentrate-input strategy in dairy cattle feeding is probably becoming a more profitable alternative despite of somewhat lower milk yield.

The length of the growing season and type of grass species suitable in those conditions limit the number of successive harvests that can be taken at Northern latitudes. A three-cut harvesting strategy utilises the whole growing season and produces the highest average grass digestibility but delays the last harvest into late autumn (Hyrkäs et al. 2015), with a risk that the harvest may not be achieved because of the weather conditions. Even at similar digestibility, the milk production potential of regrowth silages has been lower compared with the first harvest (Kuoppala et al. 2008, Sairanen et al. 2021). In the silage dry matter index (SDMI) concept, a reduction of 4.4% in *ad libitum* silage intake was estimated for regrowth silages if otherwise similar in quality to primary growth silages

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(Huhtanen et al. 2007). The intake potential of silage and consequently the milk yield decreases with prolonged regrowth period (Kuoppala et al. 2008, Pang et al. 2021).

One solution to increase the quality of regrowth silage is to shorten the period between first and second harvests. To achieve this, the timing of the first harvest must be early enough so that regrowth rate stays at a reasonably high level (Bonesmo and Skjelvåg 1999) to produce a grass yield of 1500–2000 kg DM ha^{-1} as a target for the second harvest. This strategy decreases the total grass yield, but the digestibility is maintained at a high level. Subsequently the second regrowth starts relatively early in July and the third harvest can be conducted in the end of August or early in September. With this strategy farmers can avoid unfavourable autumn growing conditions and the average quality of silage remains high (Sairanen et al. 2021). The net growth rate of grass is low in September and, consequently, earlier harvest does not compromise the total yield to a large extent (Hyrkäs et al. 2016).

In this study, a modification of the normal three-harvest strategy under Boreal conditions was used. The objective was to evaluate DM intake and milk production of dairy cows fed silages from 1st, 2nd and 3rd harvest using a shortened first regrowth period. The hypothesis is that a short grass regrowth interval maintains high silage digestibility and consequently high milk yield in the first and second regrowths of grass.

Materials and methods

Production of the experimental silages

The study was conducted at Natural Resources Institute Finland (Luke), Maaninka, Finland (63°09'N, 27°18'E) and it consisted of two dairy cow feeding experiments. The silages used in the experiments were produced during the growing season of 2019 in experiment 1 (Exp 1) and during 2020 in experiment 2 (Exp 2). The swards were cut using a mower conditioner and pre-wilted in the field for 6–24 h. Exp 1 included primary growth (H1) and second regrowth (H3) grass silages and Exp 2 included primary growth (H1), first regrowth (H2) and second regrowth (H3) grass silages. The harvest dates were 15th June (H1) and 29th August (H3) in Exp 1 and 16th June (H1), 16th July (H2) and 20th August (H3) in Exp 2. The first regrowth silage was cut on 10th July in Exp 1 but was not used in the feeding trial because, due to drought, the yield was so low that there was not enough silage.

The timings for the first harvest were based on the recommended grass D-value (concentration of digestible organic matter in DM) of 680–700 g kg^{-1} DM. The first regrowth was harvested 4–5 weeks after the primary cut with a target yield of 1500–2000 kg DM ha^{-1}. Thus, the growing period was shorter than typically used with a three-cut strategy in Finland. The harvest date of the final harvest was chosen according to weather conditions at the end of August.

In Exp 1, H1 was harvested from eight field plots with a self-propelled forage harvester and ensiled into a bunker silo. A single field plot was used for H3, which was harvested with an integrated round baler and wrapper using eight layers of stretch-plastic film. In Exp 2, H1 was harvested from seven field plots and H3 from six fields plots with a self-propelled forage harvester and ensiled into bunker silos. H2 was harvested from two field plots with a round baler with the same method as in Exp 1. All the plots used were homogeneous and the harvest dates of all of them within a harvest were the same so that use of variable plots should not confound the results. All silages were treated with a formic acid-based additive (AIV 2 Plus Na, Eastman, Oulu, Finland) at a target rate of 5 l litres per ton of fresh forage. The grass yields were measured using a fixed vehicle weighing scale (DAS-15 automated weighbridge, Vaakatalo Oy, Tampere, Finland) when transported to the silo, and with round baler scale (Agronic Combi, Haapavesi, Finland) when stored into bales.

In both experiments the grass was harvested from mixed timothy (*Phleum pratense*) and meadow fescue (*Festuca pratensis*) leys containing some red clover (*Trifolium pratense*). The age of the leys varied from 1 to 5 years. Botanical analysis was not conducted but the red clover proportion was estimated using the calcium concentration of silage (Rinne et al. 2010) and ranged from 11 to 22% in the experimental silages.

In Exp 1, the fields were fertilised with 100 kg N ha^{-1} in May. After H1, the fields were fertilised with 90 kg N ha^{-1} and after H2, with 28 kg N ha^{-1}. Most of the N fertiliser was mineral based. Slurry was applied only to two plots with an average application rate of 32 tons ha^{-1} (total N applied approximately 36 kg ha^{-1}). In Exp 2, the fields were fertilised with 100 kg N ha^{-1} in May. After H1 the fields were fertilised with 83 kg N ha^{-1} and after H2 with 34 kg N ha^{-1}. Most of the N fertiliser was mineral based, but slurry was applied to five plots with an average application rate of 25 tons ha^{-1} (total N applied approximately 42 kg ha^{-1}).

Animals, diets and experimental design

The use of animals in scientific experimentation was in line with Directive 2010/63/EU. No invasive research methods were used so that a formal license was not required according to the National Ethics Committee (Hämeenlinna, Finland). The cows were kept in a loose-house dairy barn, offered grass silage based total mixed rations (TMR) *ad libitum* and given free access to drinking water. The TMR intake was measured using automated troughs (Insentec BV, Marknesse, the Netherlands). The cows were milked twice a day in a herringbone milking parlour at approximately 0600 and 1500 h. In both experiments, the length of the period was 21 d including 7 days of data collection in the end of each period. The experimental diets were formed so that TMR was prepared using the silages H1, H2 and H3 as the main component resulting in diets D1, D2 and D3, respectively. The TMR recipes and chemical composition are presented in Table 1.

Table 1. The ingredients of total mixed ration diets and their nutritional composition for diets based on first (D1), second (D2) and third harvest (D3) grass silage in Experiments 1 and 2

	Experiment 1		Experiment 2		
	D1	D3	D1	D2	D3
Ingredients, g kg^{-1} dry matter (DM)					
Grass silage	565	580	643	634	643
Grain [1)]	315	305	257	263	257
Rapeseed meal	104	100	85	88	85
Minerals [2)]	16	16	15	15	15
Chemical composition, g kg^{-1} DM					
Crude protein	163	155	174	199	176
Neutral detergent fibre	407	375	392	340	369
Metabolisable energy, MJ kg^{-1} DM	11.5	11.9	11.7	11.9	11.6
Metabolisable protein	95	96	95	99	95
Protein balance in the rumen	25	14	35	55	37

[1)] Barley in Experiment 1; wheat and barley (75:25 on air dry basis) in Experiment 2. [2)] Commercial mineral mixture (Lypsykivennäinen Sorkka+, Hankkija Ltd., Hyvinkää, Finland; composition Ca 220 g kg^{-1}, Mg 80 g/kg^{-1}, Na 100 g kg^{-1}, Na-selenite (3bE8) 30 mg kg^{-1}, Se-methionine (3b8.11) 4 g kg^{-1}, Vitamin E (3a700) 1500 mg kg^{-1} and D-biotine (3a880) 70 mg kg^{-1}) and NaCl (85:15 on air dry basis)

Exp 1 was conducted using 44 dairy cows (29 Holstein and 15 Nordic Red). The average pre-experimental milk yield was 32.8 (SD 6.50) kg and days in milk (DIM) 166 (SD 55.2). Live weight of the cows was measured using an automated scale placed in concentrate feeding stations and, thus, the cows received 1 kg day^{-1} commercial concentrate from automated feeding stations (DeLaval, Tumba, Sweden). The average metabolisable energy (ME) concentration of the commercial concentrate was 12.3 MJ kg^{-1} DM and average crude protein (CP) concentration 173 g kg^{-1} DM. The diets were fed as TMR where the target forage to concentrate ratio was 570:430 on DM basis. The concentrate of TMR consisted of barley grain, rapeseed meal and a commercial mineral mixture (Table 1). The energy values were 13.4 and 11.0 MJ ME kg^{-1} DM and CP concentrations 117 and 377 g kg^{-1} DM for barley and rapeseed meal, respectively. The cows were divided into four blocks according to their pre-experimental milk yield, DIM and parity. The first block included primiparous cows (n=14). Other three blocks included high (n=10) and moderate yielding (n=9) and late-lactating (n=11) multiparous cows. The experiment was conducted as a complete cross-over design, with two periods and two dietary treatments.

Exp 2 was conducted using 39 dairy cows (34 Holstein and 5 Nordic Red). The average pre-experimental milk yield was 31.1 (SD 7.91) kg and DIM 181 (SD 77.4). Diets were fed as TMR where the target forage to concentrate ratio was 640:360 on DM basis (Table 1). The concentrate of TMR consisted of wheat, barley, rapeseed meal and a commercial mineral mixture. The energy values were 13.6 and 11.2 MJ ME kg^{-1} DM and CP concentrations 113 and 385 g kg^{-1} DM for wheat-barley mixture and rapeseed meal, respectively. The cows also received 1.5 kg commercial concentrate (with an energy value of 12.6 MJ ME kg^{-1} DM and CP concentration of 213 g kg^{-1} DM) from automated feeders. The cows were divided into seven blocks according to their parity, pre-experimental milk yield and DIM. The first three blocks included primiparous cows as follow: low yielding (n=5), high yielding (n=6) and late-lactating (n=5) cows. The other four blocks included multiparous cows: moderate yielding (n=6), high yielding (n=6), late-lactating low yielding (n=4) and late-lactating high yielding (n=7) cows. The experiment was conducted as an incomplete cross-over design, with two periods and three dietary treatments.

Sampling and analyses of milk and feeds

The milk yield was recorded at every milking. Milk samples were collected from four consecutive milkings in the end of each experimental period, and analysed separately for fat, protein, lactose and urea in a commercial laboratory (Valio Ltd., Seinäjoki, Finland) using an infrared analyser (Milcoscan FT6000, Foss Electric A/S, Hillerød, Denmark). The milk composition was determined based on the weighted means of the morning and afternoon milkings.

The DM content of TMR was measured daily during the data collection period. Silages and concentrates were sampled separately before TMR mixing during the data collection period, pooled per each experimental period, and stored at –20 ˚C. The DM content of the feed samples was determined by drying the samples at +105 ˚C for 20 h. Feed samples for chemical analysis were dried at +60 ˚C until dry. Feed samples were analysed at Luke laboratory as described by Sairanen et al. (2021) except that in Exp 2, pH, water soluble carbohydrates, total volatile fatty acids and ammonium N of the silage samples, and in Exp. 1 all analyses were conducted by near infrared (NIR) spectroscopy in the laboratory of Valio Ltd. (Seinäjoki, Finland).

Calculations and statistical analysis

The ME values for barley and rapeseed meal were calculated based on chemical composition and tabulated digestibility coefficients, and for silages it was calculated as 0.016 × D-value (g kg^{-1} DM) (Luke 2023b). The ME concentration of the commercial concentrate was provided by the manufacturer. The ME intake of the cows was calculated by multiplying feed intake with respective feed ME concentrations, and after that corrected by taking into consideration the effects of diet composition and DM intake (Luke, 2023b). Metabolisable protein (MP, indicated as amino acids absorbed from the small intestine) and protein balance in the rumen were calculated according to Luke (2023b) for all feeds. The relative intake potential of silage DM (SDMI index) was calculated according to Huhtanen et al. (2007). The energy-corrected milk (ECM) yield was calculated according to Sjaunja et al. (1990).

The efficiency of utilisation of ME for milk production (k_l) was calculated using the following equation:

$$k_l = \frac{ECM \times 3.14}{ME\ intake\ -\ ME\ for\ maintenance}$$

The MP balance was calculated as follows:

$$MP\ balance, g/d = MP\ requirement - (MP\ for\ maintenance + MP\ for\ milk\ production)$$

The N use efficiency in milk production (NUE) was calculated as follows:

$$NUE = \frac{N\ excereted\ in\ milk, g/d}{N\ intake, g/d}$$

Data were analysed separately for Exp 1 and Exp 2 using SAS MIXED procedure (version 9.4; SAS Institute Inc., Cary, NC, USA) including period, harvesting cycle of grass silage and block as fixed variables and animal as a random variable. In both experiments no breed × diet interactions were found and removing the breed effect from the statistical model was considered justified. The significance of the pairwise differences between harvests in Exp 2 was analysed with the Tukey test using a 5% error rate.

Results

During 2019 when grass was ensiled for Exp 1, the growing season started early, but the average temperature was relatively low during early summer resulting in a harvest date for H1 that was typical for the area (Table 2). The weather was dry and average temperature was high after the first harvest so that grass regrowth was impaired. The chemical composition of H2 showed that high quality crop was achieved: D-value 712 g kg^{-1} DM, NDF 478 g kg^{-1} DM and crude protein 183 g kg^{-1} DM. The respective weather data for the 25-day growth period were 294 degree days, 33 mm of rain and average temperature 15.2 °C. The silage was not included in the feeding experiment, because not enough silage for the feeding trial could be collected. The same field was used for H2 and H3 to maintain the short regrowth period.

The start of the growing season in 2020 was slightly delayed in Exp 2, but reasonably high average temperature maintained good growth rate of the grass and the first harvest was conducted early enough for a three-cut strategy. The regrowth silages were harvested as planned. Average grass yields are presented in Table 2.

Table 2. Description of conditions during the growing seasons and grass yield for first (H1), second (H2) and third (H3) harvest grass silages

	Experiment 1			Experiment 2		
	H1	H2	H3	H1	H2	H3
Beginning of growing season	25 April 2019			18 May 2020		
Date of harvest	15 June	9 July	28 August	16 June	16 July	20 August
Growing days [1)]	51	28	50	30	30	35
Effective temperature sum during growing season (+5°C), °C d [1)]	314	287	509	271	357	404
Precipitation, mm [2)]	85	33	45	6	126	49
Average temperature, °C [1)]	10.6	15.1	15.1	14.0	16.9	16.5
Grass yield, kg DM ha^{-1}	2400	1500	2400	2700	1400	2900

[1)] Since the onset of the growing season for H1, and since the previous cut for H2 and H3. [2)] Accumulated precipitation since the onset of the growing season for H1, and since the previous cut for H2 and H3.

The characterisation of the experimental silages is presented in Table 3. Dry matter contents of the experimental silages were quite similar with the exception of H1 in Exp 2, which was clearly dryer than the other silages. The pH values were within the recommended range except of a high pH and ammonium N proportion of total N of H3 in Exp 1. However, this did not lead to impaired fermentation quality in terms of volatile fatty acid concentrations. The D-value of silages was around 680 g kg^{-1} DM in all silages, which was the lower target limit. The D-values of H3 in Exp 1 and H2 in Exp 2 were somewhat higher than those of the other feeds used. The SDMI index of all silages was over 100 and variation was small indicating overall good silage quality.

Table 3. Chemical composition of the first (H1), second (H2) and third harvest (H3) grass silages

	Experiment 1			Experiment 2		
	H1	H2	H3	H1	H2	H3
Dry matter (DM), g kg^{-1}	288	364	286	423	296	288
pH	4.24	4.50	5.03	4.54	4.21	4.10
Ammonium N, g kg^{-1} N	40	57	77	27	41	35
In DM, g kg^{-1}						
Ash	79	74	83	79	93	92
Crude protein	154	183	141	174	213	178
Water soluble carbohydrates	69	106	119	102	61	85
Neutral detergent fibre	569	477	504	513	434	476
Total volatile fatty acids	12.1	7.7	7.4	5.5	13.0	8.5
Metabolisable protein	82	87	85	87	93	87
Protein balance in the rumen	31	52	13	45	77	49
D-value, g kg^{-1}	679	710	724	704	721	698
Metabolisable energy, MJ kg^{-1} DM	10.9	11.4	11.6	11.3	11.5	11.2
SDMI index [1)]	107	114	113	118	112	107

[1)] The relative intake potential of silage DM (Huhtanen et al. 2007)

In Exp 1, D1 had the highest silage DM intake, while in Exp 2, total DM and ME intake were similar for D1 and D2 (Table 4). In both experiments, D3 had the lowest total DM intake, which resulted in lowest nutrient intake as well. In Exp 2, the highest CP intake and protein balance in the rumen were observed when D2 was fed. Highest neutral detergent fibre intake was achieved in D1 in both experiments.

Table 4. Feed and nutrient intake of cows offered diets based on first (D1), second (D2) and third harvest (D3) grass silages

	Experiment 1				Experiment 2				
	D1	D3	SEM	*p*-value	D1	D2	D3	SEM	*p*-value
Dry matter (DM) intake, kg d^{-1}									
Silage	12.4	11.8	0.17	< 0.001	15.0^{a}	14.4^{b}	14.3^{b}	0.24	< 0.005
Concentrate	10.2	9.3	0.15	< 0.001	9.0^{a}	9.1^{a}	8.6^{b}	0.13	< 0.001
Total	22.6	21.1	0.28	< 0.001	24.0^{a}	23.5^{a}	22.9^{b}	0.36	< 0.01
Nutrient intake, d^{-1}									
Organic matter, kg	20.9	19.4	0.26	< 0.001	22.2^{a}	21.5^{b}	20.9^{c}	0.33	< 0.01
Crude protein, kg	3.70	3.29	0.046	< 0.001	4.21^{a}	4.71^{b}	4.06^{c}	0.070	< 0.01
Neutral detergent fibre, kg	9.13	7.88	0.111	< 0.001	9.27^{a}	7.91^{b}	8.33^{c}	0.134	< 0.001
Metabolisable energy, MJ [1)]	243	233	2.8	< 0.001	261^{a}	259^{a}	248^{b}	3.6	< 0.001
Metabolisable protein, kg	2.15	2.03	0.027	< 0.001	2.29^{a}	2.34^{a}	2.18^{b}	0.034	< 0.001
PBV, kg	0.56	0.32	0.012	< 0.001	0.85^{a}	1.30^{b}	0.86^{a}	0.024	< 0.001

SEM = standard error of the mean; PBV = protein balance in the rumen. [1)] Metabolisable energy intake was calculated according to Luke (2023b) considering the effects of diet composition and intake level. Means in a row in the experiment 2 without a common superscript letter are significantly different from each other ($p < 0.05$) according to the Tukey test.

The milk yield of D1 was slightly higher compared to D3 in Exp 1 (Table 5), while there was no difference in ECM yield between the harvests. In Exp 2, the highest milk and ECM yield were achieved with D2. There were no effects of harvest on milk protein and fat content. Milk urea content of D1 was higher compared to D3 in Exp 1. In Exp 2, the milk urea content was markedly higher with D2 than with the other two treatments.

Table 5. Milk production of cows offered first diets based on first (D1), second (D2) and third harvest (D3) grass silages across experiments

	Experiment 1				Experiment 2				
	D1	D3	SEM	*p*-value	D1	D2	D3	SEM	*p*-value
Production kg d^{-1}									
Milk	30.0	29.2	0.65	< 0.05	28.5^{a}	29.8^{b}	28.5^{a}	0.48	< 0.05
Energy corrected milk (ECM)	32.6	31.9	0.86	ns	31.4^{a}	33.0^{b}	31.3^{a}	0.65	< 0.05
Protein	1.126	1.104	0.0217	ns	1.119^{ab}	1.167^{a}	1.103^{b}	0.0205	< 0.01
Fat	1.353	1.330	0.0497	ns	1.292	1.365	1.293	0.0379	ns
Lactose	1.371	1.333	0.0032	< 0.05	1.288	1.345	1.291	0.0232	ns
Milk composition, g kg^{-1}									
Protein	37.8	38.1	0.39	ns	39.8	39.5	39.4	0.38	ns
Fat	45.0	45.6	1.12	ns	46.1	46.2	45.8	1.08	ns
Lactose	45.6	45.5	0.23	ns	45.2	45.2	45.2	0.25	ns
Milk urea, mg dl^{-1}	20.2	14.0	0.49	< 0.001	23.4^{a}	29.6^{b}	21.8^{c}	0.62	< 0.01
kg ECM (kg dry matter intake)$^{-1}$	1.44	1.51	0.033	< 0.001	1.30^{a}	1.40^{b}	1.36^{ab}	0.028	< 0.01
MJ ME (kg ECM)$^{-1}$	5.54	5.28	0.138	< 0.01	6.28^{a}	5.95^{b}	5.98^{b}	0.140	< 0.05
ME balance, MJ d^{-1}	7.2	0.3	3.84	< 0.001	31.8^{a}	22.5^{b}	19.9^{b}	3.82	< 0.05
Efficiency of ME utilisation for milk production, k_l	0.584	0.611	0.0132	< 0.001	0.509^{a}	0.541^{b}	0.544^{b}	0.0115	< 0.01
Metabolisable protein balance, g d^{-1}	9	–59	27.7	<0.001	137^{a}	126^{ab}	64^{b}	31.4	< 0.05
Nitrogen use efficiency, g milk N output (g feed N intake)$^{-1}$	0.298	0.330	0.0055	<0.001	0.260^{a}	0.243^{b}	0.266^{a}	0.0048	< 0.01

SEM = standard error of the mean; ME = metabolisable energy. Means in a row in the experiment 2 without a common superscript letter are significantly different from each other ($p < 0.05$) according to the Tukey test

Feed efficiency represented as ECM kg^{-1} DM intake or MJ ME kg^{-1} ECM was the lowest with D1 in both experiments (Table 5). The efficiency of ME utilisation for milk production (k_l) was also the lowest with D1. High ME intake of D1 resulted in the highest ME balance in D1 in both experiments. Highest NUE was achieved with D3 in Exp 1 and D1 and D3 in Exp 2, respectively.

Discussion

Silages and harvesting strategy

Timothy and meadow fescue were the dominant species in the experimental silages. Meadow fescue has a higher regrowth rate (Bonesmo and Skjelvåg 1999, Virkajärvi 2003) compared with timothy and consequently the proportion of meadow fescue increases in regrowth silages. Most probably this has no effect on silage nutritional value because the plant morphological structure and feed characteristics of the species are very similar (Virkajärvi 2003). The proportion of red clover also typically increases with progressing growth season (Nykänen et al. 2000, Rinne and Nykänen 2000). In this study the proportion of red clover ranged between 11 to 22% of DM so that most probably it had only minor effects on intake or milk yield. The aim of this study was to investigate the effects of a shortened first regrowth interval of grass ensiled under practical conditions. Thus, the changes in botanical composition during growing season is one part of the chosen strategy.

The experimental silages were harvested from different field plots. However, grass species and soil type were comparable between fields, so the field effect can be considered to have been small. The most dominant factors affecting grass quality within species are weather conditions (temperature and precipitation) and timing of harvest (Kuoppala et al. 2008, Hyrkäs et al. 2018, Sairanen et al. 2021). The effect of harvest is confounded with biotic and environmental factors, so the treatment conclusions of this study include the sum of different effects connected with each experimental diet. The storage methods also varied between the silages as some were ensiled into bunker silos and some in round bales due to practical reasons. Although differences have been observed between bunker and round bale silages (e.g., Randby and Bakken 2021), the main pattern should be similar, particularly as the same acid-based silage additive was used in all silages.

The shortened regrowth period of H2 differs from a typical three-cut strategy and results in H2 having a smaller grass yield but with high digestibility. This approach also improves the opportunities to harvest the third cut relatively early, when autumn humidity does not compromise the harvesting conditions. Typically, the ME content of the first regrowth is the lowest in farm conditions (unpublished data from Finnish farm samples, Valio Ltd. 2022). In line with that, Sairanen et al. (2021) reported that the D-value of H2 in three separate experiments conducted over three different years was clearly lower (663, 650 and 656 g kg^{-1} DM for Experiments 1, 2 and 3, respectively) than in the current experiment. In the current material, the D-values of H2 (years 2019 and 2020) were over 700 g kg^{-1} DM supporting our hypothesis that high quality silage can be produced from the first regrowth by decreasing the interval between harvests.

Mid-summer drought may limit grass growth and delay the regrowth harvests making it impossible to carry out the short regrowth strategy under such conditions. However, drought delays grass maturity development and the digestibility maintains at a high level (Fariaszewska et al. 2017, Järvenranta et al. 2022) resulting in high quality silage even after a prolonged regrowth period.

The total grass yields over all 3 harvests of 6250 kg DM ha^{-1} for Exp 1 and 6910 kg DM ha^{-1} for Exp 2 were obtained, which are above the average yields of grass silage in Finland (ca. 5 500 kg DM ha^{-1}; Luke (2023a) using the average silage DM concentration of 339 g kg^{-1} from Valio Ltd. (n=8914)), showing that they were in an acceptable range for farm conditions. Frequent cutting maintains early maturity stage of the tillers but also decreases the maximum grass mass production due to low leaf area after harvest (Hyrkäs et al. 2012). However, it is not reasonable to increase the yield by postponing the last harvest to late autumn. The regrowth rate is slow during autumn, and poor weather conditions (humidity, frost) increase the risk of impaired hygienic quality of the silages. The limitations of the growing season related to multiple harvests under Finnish conditions can be demonstrated by the number of samples received by the laboratory of Valio Ltd. (Seinäjoki, Finland), where the proportions of 1st, 2nd, 3rd and 4th harvest silages were 56, 36, 8 and 0.04% (years 2019–2021, n=68 825). For practical applications, the production costs of silage, forage area to herd size ratio and other farm specific factors should be taken into account when choosing the harvesting strategy.

Feed intake

The average intake of regrowth silages within both experiments was 0.61 kg DM d^{-1} less than with primary growth, and a similar reduction is predicted by the SDMI index (Huhtanen et al. 2007). The intake of regrowth silages is typically lower compared with those harvested from primary growth (Peoples and Gordon 1989, Kuoppala et al. 2008, Pang et al. 2021), especially if the second regrowth period includes late autumn cut grass (Sairanen et al. 2021). The difference was evident in the SDMI concept even when other silage characteristics such as D-value, DM and neutral detergent fibre (NDF) concentrations as well as extent of fermentation were taken into account (Huhtanen et al. 2007). The silage pH and the proportion of ammonium N of total N were elevated in H3 in Exp 1 showing some difficulties during ensiling. Increased ammonia N proportion of total N has been linked with decreased intake (Sánchez-Duarte and Garcia 2017) despite of high SDMI with H3 in Exp 1. The high intake potential of primary growth silage was confirmed also in the present study despite of the highest NDF concentration in D1. Obviously, the NDF concentration of early harvested regrowth grass was not a limiting factor for intake here as hypothesised by Van Soest (1994).

Forbes (2007) has presented a minimum discomfort approach to predict feed selection and intake. In this method, feed intake is guided by multiple factors instead of one first limiting factor. The main idea is to define the magnitude of nutrient deficiency or excess. High digestibility of grass prevents energy deficiency and promotes intake but high energy content of the diet combined with low fibre content may increase ruminal discomfort. The reason to discomfort factors of the late season silages may be found in variable growing conditions during autumn. In here the DM intake was similar between D1 and D2 in Exp 2 but the lowest with D3. Chemical composition of silages did not fully explain the difference. Thus, discomfort factors could be found among unspecified palatability variables.

The conditions for plant pests also become more favourable with progressing growing season due to higher temperature and humidity, and prolonged access to biomass. The plant morphological differences between primary growth and regrowth, i.e., more leafy and dense canopy structure in regrowth (Rinne and Nykänen 2000), may influence the hygienic quality. It has been speculated that presence of moulds and mycotoxins produced by them could increase in late summer, and subsequently decrease the intake of regrowth grass material. Such pattern could however not be demonstrated in a survey of Finnish farm silages (Manni et al. 2022).

When TMR feeding is used, high palatability of silage results in increased concentrate intake. The combined effect led to the highest organic matter intake with D1 diets. This emphasises the importance of high silage quality in TMR feeding, when forage and concentrate intake are interdependent. In Exp 2, the energy content of the H2 silage was so high that ME intake was the same for D1 and D2.

Milk yield and nutrient utilisation

The ME intake is the most accurate predictor of milk production (Huhtanen and Nousiainen 2012). This was realised in Exp 1 where the ME content of H3 silage was high but limited intake decreased total ME intake and milk yield. One MJ ME increase in energy intake between D3 and D1 resulted in an increase in ECM yield of 0.07 kg. This is lower than the average response of 0.11 kg ECM MJ^{-1} ME reported by Huhtanen and Nousiainen (2012) and the expected value of 0.19 kg ECM MJ^{-1} ME according to nutrient requirements (Luke 2023b). The results demonstrated lower energy utilization with H1 compared with regrowth silages, or overestimation of H1 energy concentration.

In Exp 2 the ECM response to increased energy intake of 13 MJ was practically non-existing when comparing D1 and D3. The negligible response means that additional ME of D1 was positioned to the body tissue gain or the utilisation of it was low. Both the high silage ME and CP contents have been linked with lowered energy utilisation (Pang et al. 2021) but in this study the values differed little between D1 and D3. Agnew and Yan (2000) reported increased maintenance requirement for high NDF diets due to increasing gut mass and metabolic activity, which could at least partly explain the decreased ME utilisation of D1 compared to D3. Another factor resulting in lower than expected energy provision of H1 diet could be faster feed passage from the rumen, which would result in reduced fibre digestion (Van Soest 1994).

The response to incremental ME intake follows the law of diminishing returns and the energy balance in Exp 2 was high explaining partially the observed result. In general, the relatively high ME utilisation of regrowth silages agrees with Pang et al. (2019), where the milk production potential of regrowth silages was higher compared with primary growth silages of equal D-values.

The specific interest of this study was the diet based on H2. The short regrowth period maintained high silage ME content. The same ME intake between D1 and D2 in Exp 2 combined with higher ME utilisation with D2 resulted in the highest ECM production with D2. The findings support our hypothesis about high milk production potential of silages harvested after a short regrowth period compared with typical three-harvest strategy (Pang et al. 2021, Sairanen et al. 2021). In general, the energy utilisation in milk production was exceptionally low in Exp 2. The k_l values were on average 0.59 for early and mid-lactating cows but varied between 0.46–0.50 for the late lactating low yielding groups resulting in low average ME utilisation in Exp 2. Changes in weight gain, BCS and body composition could modify k_l values, but their effect should be relatively small during the three-week measurement periods.

The CP content of early harvested grass is unnecessarily high for the nutrient requirements of the cows, resulting in high milk urea content and reduced NUE. High digestibility, together with high CP content of grass, is linked with ME losses via urinary output (Krizsan et al. 2020, Pang et al. 2021) and consequently reduced ME efficiency. The milk production potential of D2 was so high that energy losses in the form of phenolic compounds were not remarkable compared with total ME intake. However, excess nitrogen is excreted via urine, which is vulnerable as loss of ammonia during manure storage and application.

A disadvantage of the short regrowth interval strategy is decreased grass yield and consequently increased production costs and greater area needed for forage production. Average grass regrowth rate in July is 80 kg DM per day per hectare, so seven days shorter growing period equals 560 kg DM decrease in total yield per hectare (Hyrkäs et al. 2012, 2015). Excluding the growing time in late season is not a major factor because the net growth rate of grass is low (< 40 kg DM per day per hectare) after August under Northern European conditions (Hyrkäs et al. 2016). Low grass fibre content combined with high ME content increases the risk of acidosis so the short regrowth interval strategy is not recommended with high concentrate feeding, which may be needed if the forage area per animal is low.

Conclusions

This study demonstrated that short first regrowth period maintained grass energy content and promoted high milk yield. High grass energy and crude protein content of the first regrowth silage was not reflected in milk constituents except for the high milk urea content combined with poor N use efficiency. The advantages in feed quality of the third harvest in late summer were smaller compared with second harvest but the strategy also maintained the grass quality at the end of the growing season.

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