Vol. 18 (2009): 234–256.

Formic acid treated whole crop barley and wheat silages in dairy cow diets: effects of crop maturity, proportion in the diet, and level and type of concentrate supplementation

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Three trials in dairy cows were carried out to study the effects of replacing grass silage (GS) with whole-crop silage (WCS) made of barley (BS) or wheat (WS) harvested at dough stage with a dry matter (DM) concentration of 300−450 g kg^{-1}. All silages were ensiled using a formic acid based additive 5 l t^{-1}. Milk production responses to energy and protein supplementation of diets were studied. In Exp. 1, BS replaced GS at the rates of 0, 200, 400 or 600 g kg^{-1} forage DM. Also 10 kg of concentrate containing 0 or 2 kg of rape seed meal was fed. In Exp. 2, barley was harvested at three times (BS1, BS2, BS3) at one week intervals. Barley silages were fed as a mixture with GS (40:60) and in addition BS2 and GS alone. Silages were supplemented with a cereal based farm-made concentrate (FC) or a commercial compound having a lower concentration of starch than FC. In Exp. 3, barley and wheat were harvested at two week intervals, fed as a mixture with GS (40:60) and supplemented with low or high amount of concentrate.

The fermentation quality of whole crop silages was good. Weather conditions and maturity affected the proportion of ear in the crop and subsequently the ratio of non-structural carbohydrates to NDF in the silage. The inclusion of WCS depressed diet OM digestibility depending on the digestibility of GS and the proportion of WCS in the diet. However, mixing GS and WCS did not depress intake. Subsequently the use of mixtures maintained or even increased milk yield as compared with GS diet in Exp. 2 and 3. In Exp. 1, higher proportions (400, 600 g kg^{-1}) of BS decreased milk yield. Minor effects of growth stage on milk production were observed with barley whereas delaying wheat harvest increased milk yield. Different types and levels of concentrate induced mainly similar intake and milk yield responses with diets based on GS alone or on mixtures of GS and WCS. The synergistic effect of mixing GS and WCS was more positive in experiments where the protein concentration of concentrate was high (200 g kg^{-1} DM).

Key-words: whole-crop, barley, wheat, grass, silage, dairy cow, milk

Manuscript received March 2009

Vol. 18 (2009): 234–256.

Introduction

Agronomic and economic information indicates that inclusion of harvest of the whole crop (WC) cereals in the farming system has many advantages (Stark and Wilkinson 1995). Most of the literature on the use of whole crop silage (WCS) in dairy cow feeding is for wheat silage. Being suitable for the northern climate, barley and oats have been the dominant small grain cereals in Finland. Due to the lower fibre concentration and better feeding value (Kristensen 1992), barley is regarded as a better alternative than oats for high yielding dairy cows. Since harvesting as WCS does not require full maturity of cereals, higher yielding wheat varieties could be an option in areas where barley or oats has been used.

The variation in the composition and feeding value of cereal crops is mainly associated with the differences in the proportion of grain and straw (Kristensen 1992, Südekum and Arndt 1998). Much of the variation is caused by variety and timing of harvest, in addition to environmental factors like location, weather and growth conditions. However, the effects of straw proportion are not clear since increased grain proportion, by advancing maturity or by elevated cutting heights does not necessarily affect intake of WC silage or animal performance (e.g. Sutton et al. 2002, Sinclair et al. 2003).

There is ample evidence that feeding a mixture of grass silage and fermented or alkaline WC cereals in dairy cow feeding may increase silage intake (e.g. Leaver and Hill 1995, Phipps et al. 1995, Sutton et al. 1997). However, some negative effects like lack of positive milk yield responses, low energy value, low starch digestibility and potential pollution caused by nitrogen have been observed when using urea-treated WC wheat silage (Sutton et al. 2002). Successful preservation with alkalis, principally urea, requires a dry matter (DM) concentration of approximately 500 g kg^{-1}. When immature low DM cereals are ensiled with NaOH or urea, butyric acid fermentation may occur (Deschard et al. 1987, Tetlow 1992). In Finland, ensiling of untreated and urea-treated WC silage resulted in clostridial fermentation (Alaspää 1986) which, besides reducing the nutritive value of silage, poses a high risk for the quality of dairy products. In Nordic climatic conditions, the DM concentration of whole crop cereals is often low, even at late maturity of grain. Thus, ensiling of cereal crops should preferably be based on low pH generated by fermentation and/or additives, and the harvest should be done at the dough stage with a DM concentration of 300–400 g kg^{-1} (Vanhatalo et al. 1999). In the experiment by Vanhatalo et al. (1999) formic acid proved to be a potential preservative for whole crop cereals at dough stage by restricting in-silo fermentation and protein breakdown as compared to untreated silage. The early harvested small grain cereal crops have been ensiled successfully (Edwards et al. 1968, Bergen et al. 1991, Südekum and Arndt 1998) and fermented whole crop silages do not necessarily present problems with aerobic stability (Sutton et al. 2002) as observed in earlier works (Tetlow 1992).

No previous studies were conducted on the use of WC silage in dairy cow feeding in Finland. Thus there was a need to identify the correct stage of harvest and appropriate concentrate supplementation of formic acid treated barley silage. It was essential to understand the relationship between growth conditions and cereal crop development, and subsequently, how it affects the ensiling characteristics and nutritive value of whole crop cereals. The present series of experiments were undertaken to evaluate the effects of inclusion of formic acid treated whole crop barley or wheat silages in a grass silage based diet on intake and milk production in dairy cows. The effects of advancing maturity of barley and wheat during dough stage, and the effects of protein supplementation, type of concentrate and concentrate level in dairy cow diet were studied.

Material and methods

Harvest

Spring-sown barley (*Hordeum vulgare* L. cv. Inari, two-rowed) was used in three experiments and spring-sown wheat (*Triticum aestivum* L. cv. Mahti) in one experiment. Both were harvested on the farm of Jokioinen Estates in MTT Agrifood Research Finland, Jokioinen (60°49'N, 23°28' E). In the first experiment (Exp. 1) barley was harvested on 14th August 1996 at the early dough stage 27 days after the start of heading (Table 1). In the second experiment (Exp. 2), barley was harvested three times (BS1-BS3) at one week intervals (on 22nd July, 29th July and 4th August 1999) starting from the early dough stage 14 days after heading. In the third experiment (Exp. 3), whole crop barley and wheat were harvested at the early and soft/hard dough stages. Barley was harvested 23 (BS1) and 36 (BS2) days (on 3rd and 16th August 2000), and wheat 30 (WS1) and 44 (WS2) days after the onset of heading (on 10th and 24th August 2000). The harvest dates were determined by a combination of crop DM concentration and colour and grain DM and texture. Growing season was exceptionally warm and dry during Exp. 2. The mean temperature in June and July was 13.6, 17.5 and 14.6 °C, and precipitation 188, 79 and 165 mm in Exp. 1, 2 and 3, respectively.

The whole crops were harvested direct-cut using a flail harvester (Taarup 1500, Kerteminde, Denmark; Exp. 1) or a double chop harvester (Tupla-Junkkari, Junkkari Oy, Finland; Exp. 2 and Exp. 3) at stubble height of about 10 cm. Silages were treated with a formic acid based additive applied at the rate of 5 l t^{-1} (Exp. 1: AIV-10 containing formic acid 775, orthophosphoric acid 20 and ethylbenzoate 25 g kg^{-1}, Kemira Chemicals Oyj; Exp. 2 and Exp. 3: AIV2000 containing formic acid 550, ammoniumformate 240, propionic acid 50, benzoic acid 10 and ethylbenzoate 10 g kg^{-1}, Kemira Chemicals Oyj) and ensiled in bunker silos. Grass silage (GS) was harvested from a primary (24th June Exp. 1 and 15th-16th June Exp. 3) or secondary growth (27th-29th September Exp. 2) of mixed timothy (*Phleum pratense* L.) and meadow fescue (*Festuca pratensis* Huds.) swards. The herbage was mown using a mower conditioner, harvested with a precision-chop forage harvester after a 4−6 h wilting period, treated with the same additives and application rates as the whole crop silages, and ensiled in bunker (Exp. 1 and 2) or tower (Exp. 3) silos. The additives were applied using a pump applicator (Ylö HP-20, Ylöjärvi, Finland) attached to the forage harvester.

Experimental design and diets

Three feeding experiments were conducted using a cyclic change-over design (Davis and Hall 1969) with 16 (Exp. 1) or 20 (Exp. 2 and 3) cows. The duration of all the experiments was 84 days consisting of four 21-day experimental periods with an adaptation period from day 1 to 13 followed by a sampling period from day 14 to 21. Finnish Ayrshire cows were selected from the dairy herd of Jokioinen Estate. The cows were housed in individual stalls and had free access to silage allowing 5 to 10% refusals. Silages were grass silage or whole crop silage alone or a combination mixed using a mixer wagon. Daily concentrates were offered as three equal meals at 5.30, 12.30 and 16.30 h.

Exp. 1 was conducted with eight dietary treatments and with two replicate blocks of eight multiparous cows each. The cows were divided into blocks according to milk yield and feed intake, and allocated at random to the experimental treatments. At the beginning of the experiment, the cows had a mean (s.d.) live weight of 575 kg (47.5), a parity of 3.4 (1.55) and were 62 days (15.1) in lactation, producing 31.8 kg (2.93) milk per day. Dietary treatments in a 4 × 2 factorial arrangement consisted of four silage mixtures and two protein supplement rates (no supplement (−RSM) and rapeseed meal (+RSM)).

Grass silage (GS) was gradually replaced by barley silage (BS) in the diet at the rates of 0 (BS0), 200 (BS20), 400 (BS40) or 600 (BS60) g kg^{-1} of silage DM. The basal concentrate mixture (Table 2) was formulated from barley (384 g kg^{-1}) and oats (384 g kg^{-1}) coarsely ground with a hammer mill, dry molassed sugar beet pulp (192 g kg^{-1}) and mineral and vitamin supplement (40 g kg^{-1}) (Ca 160, P 64, Na 90, Mg 80 g kg^{-1}, vitamin A 150 000, vitamin D 100 000 IU kg^{-1}, and vitamin E 500 mg kg^{-1}; Viher-Hertta-Minera, Suomen Rehu Ltd, Helsinki, Finland). In protein-supplemented diets

Vol. 18 (2009): 234–256.

Table 1. Yield and characteristics of grass (GS), barley (BS) and wheat (WS) harvested at different growth stages (1, 2, 3) before ensiling and respective silages (g kg^{-1} dry matter unless otherwise stated)

Experiment	Experiment 1		Experiment 2				Experiment 3				
Silage	GS	BS	GS	BS1	BS2	BS3	GS	BS1	BS2	WS1	WS2
Harvest											
Days after sowing	-	82	-	69	76	82	-	87	100	94	108
Days after heading	-	27	-	14	21	27	-	23	36	30	44
Dry matter, g kg^{-1}, n=3											
Whole crop	246	308	242	318	391	441	249	282	343	288	378
Ear	-	423	-	367	472	555	-	379	502	345	495
Yield, t dry matter ha^{-1}	-	-	-	5.4	6.7	6.8	-	8.4	9.4	9.2	10.5
Ear proportion	-	-	-	510	590	660	-	460	560	430	580
Plant height, cm	-	-	-	56	60	57	-	82	81	90	91
Silage raw material, n=2 or 3											
Crude protein	138	100	111	118	120	104	131	116	102	118	112
Neutral-detergent fibre	586	543	502	443	400	417	580	496	528	522	509
Starch	-	142	-	156	201	278	-	61	160	67	196
Water soluble carbohydrates	104	196	189	206	176	118	139	144	88	144	52
Silage, n=4											
Dry matter, g kg^{-1}	251	311	221	356	390	418	264	282	334	300	340
Ash	82	75	85	63	62	66	64	73	77	89	85
Crude protein	138	100	110	113	113	113	129	107	107	126	122
Neutral-detergent fibre (NDF)	562	488	519	417	360	339	542	502	460	494	451
Acid-detergent fibre	-	-	265	198	171	153	305	266	239	282	240
Lignin	-	-	23	20	17	19	27	31	32	37	33
Indigestible NDF	73	158	80	92	85	86	65	127	148	152	145
Starch	-	124	-	137	222	257	-	94	175	66	177
pH	4.04	3.78	3.88	3.86	3.88	4.07	4.17	3.98	4.07	4.00	4.21
Water soluble carbohydrates	53	27	67	44	40	96	82	35	84	42	96
Lactic acid	50	53	53	46	41	29	53	41	33	55	24
Acetic acid	19	22	16	24	21	13	14	20	7	24	9
Butyric acid	1.0	0.2	0.2	0.3	0.1	0.2	0.1	0.3	0.3	0.1	0.1
Propionic acid [1]	0.0	0.0	1.1	0.6	0.5	0.4	0.8	0.8	0.7	0.9	0.8
Ammonia N, g kg^{-1} N [2)]	44	62	22	33	36	33	35	38	58	66	90
In vitro OM digestibility	0.732	0.662	0.709	0.709	0.722	0.729	0.727	0.665	0.669	0.634	0.660
ME, MJ kg^{-1} dry matter [3)]	10.8	9.5	10.4	10.3	10.5	10.6	10.9	9.6	9.6	9.0	9.4
AAT [4)]	80	62	75	83	85	85	82	76	74	74	75
PBV [5)]	2	–6	–18	–28	–32	–32	–12	–22	–19	–1	–8

[1)] Includes propionic acid from silage additive in Exp. 2 and Exp. 3, [2)] Corrected for N from silage additive, [3)] ME = Metabolisable energy, based on *in vitro* measurement of organic matter (OM) digestibility and correction equations (Huhtanen et al. 2006), [4)] AAT = Amino acids absorbed in the small intestine (MTT 2006) [5)] PBV = Protein balance in the rumen (MTT 2006) solvent-extracted rapeseed meal (Raisio Feed Ltd, Raisio, Finland) replaced 2 kg of the basal mixture. Concentrate (110 or 164 g crude protein (CP) kg^{-1} DM) was offered at a rate of 10 kg per day.

Exp. 2 was conducted with ten dietary treatments and with two replicate blocks (one for primiparous, one for multiparous) of 10 cows each. The cows were selected so that each block involved group of cows which was as homogenous as possible on the basis of milk yield and feed intake. Within the blocks the cows were allocated at random to the experimental treatments. The cows had a mean (s.d.) live weight of 580 kg (72.9), and were 75 days (29.2) in lactation, producing 30.6 kg (7.50) milk per day. Dietary treatments in a 5×2 factorial arrangement consisted of five silages and two types of concentrates.

Silage treatments were GS, BS2, GS+BS1, GS+BS2, GS+BS3. The proportion of whole crop silage was 400 g kg^{-1} silage DM. A farm made concentrate mixture (FC) and a commercial compound (CC) having equal crude protein (197 g kg^{-1} DM) and ME (12.7 MJ ME kg^{-1} DM) concentrations were compared (Table 2). Concentrate was offered at 11.0 kg per day. The farm made mixture was formulated (g kg^{-1}) from barley (470) and oats (250) coarsely ground with a hammer mill, rapeseed cake (Mildola, Helsinki, Finland) (250), mineral and vitamin supplement (18.2) (Ca 160, P 64, Na 90, Mg 80 g kg^{-1}, A vitamin 150 000, D vitamin 100 000 IU kg^{-1}, and E vitamin 500 mg kg^{-1}; Viher-Hertta-Minera, Suomen Rehu Ltd, Helsinki, Finland), calcium carbonate (8.2) and sodium chloride (3.6). Pelleted CC (Raisio Feed Ltd, Raisio, Finland) consisted of (g kg^{-1}) of wheat (125), oats (125), barley (125), molassed sugar beet pulp (125), wheat middling (120), soybean meal (120), wheat molasses (60), rape seed meal (60), rape seed cake (60), vegetable oil (21), propylene glycol (10) and vitamin and trace element premix (49).

Exp. 3 was conducted with ten dietary treatments and with two replicate blocks (one for primiparous, one for multiparous) of 10 cows each. The cows were selected so that each block involved group of cows which was as homogenous as possible on the basis of milk yield and feed intake. Within the blocks the cows were allocated at random to the experimental treatments. The cows had a mean (s.d.) live weight of 556 kg (39.9), and were 57 days (17.7) in lactation, producing 33.6 kg (6.70) milk per day. Dietary treatments in a 5×2 factorial arrangement consisted of five silage mixtures and two amounts of concentrates. Silage treatments were as follows: GS, GS+BS1, GS+BS2, GS+WS1, and GS+WS2. The proportion of whole crop silage was 400 g kg^{-1} of silage DM. A pelleted commercial compound (Raisio Feed Ltd, Raisio, Finland) was offered at either 9 or 14 kg per day for the multiparous cows. The primiparous cows received proportionately 0.80 of concentrates (7.2 and 11.2 kg) fed to multiparous cows. Concentrate consisted of oats (154 g kg^{-1}), barley (200 g kg^{-1}), molassed sugar beet pulp (120 g kg^{-1}), wheat middling (120 g kg^{-1}), rape seed meal (300 g kg^{-1}), wheat molasses (70 g kg^{-1}) and vitamin and trace element premix (36 g kg^{-1}) (Table 2).

Table 2. Mean chemical composition of concentrates (g kg^{-1} dry matter, unless otherwise stated) (n = 2 for each experiment).

	Experiment 1		Experiment 2		Experiment 3
	–RSM [1)]	+RSM	FC [2)]	CC [3)]	
Dry matter, g kg^{-1}	885	886	885	879	862
Ash	82	78	67	66	71
Crude protein	110	164	202	193	210
Ether extract	-	-	58	63	48
Neutral-detergent fibre	249	258	235	235	270
Starch	-	-	353	249	204
Metabolisable energy, MJ kg^{-1} dry matter	12.2	12.0	12.6	12.7	11.9
Amino acids absorbed in the small intestine	98	110	113	112	114
Protein balance in the rumen	–36	0	10	20	16

[1)] RSM = rape seed meal, [2)] FC = farm-made concentrate, [3)] CC = commercial compound

Vol. 18 (2009): 234–256.

Sampling and analyses

Both barley and wheat fields were divided into three sub-areas. The yield of the whole crop was estimated before harvesting by taking plant samples from four replicates of 0.25 m^2 on each sub-area. The height of the cereals was measured, the samples were cut at the height of 8 cm, pooled over the sub-areas resulting in three samples, weighed and analysed for DM concentration separately for whole crop and ears. Samples of whole crop cereals and grass were collected from every load at the time of ensiling and immediately stored at 4 °C. The samples were pooled over three loads resulting in two or three samples per treatment. Once ensiling was completed, samples were submitted for the determination of DM, total nitrogen (N), neutral detergent fibre (NDF) and water soluble carbohydrates (WSC), and whole crop cereal samples also for starch determination. During the sampling period of the animal experiment, representative samples of silages were collected before mixing, and samples of silage mixtures and concentrates were collected daily. Concentrates were analysed for DM, ash, N, NDF, starch and acid insoluble ash (AIA). Silages were analysed for DM, ash, N, NDF, acid detergent fibre (ADF), lignin, starch, AIA, *in vitro* organic matter digestibility, indigestible NDF (iNDF), pH, lactic acid, VFA, WSC and ammonia N. Silage samples and DM concentration of concentrate were analysed separately for each period. For the determination of chemical composition, concentrate samples were pooled over two periods resulting in two separate determinations.

Feed intake and milk yield were recorded daily. Cows were milked twice daily at 6.30 and 15.30 h. Milk samples were obtained from four consecutive milkings on day 18 to 20 and analysed by an infrared milk analyser (Milko-Scan 133B, Foss Electric, Hillerød, Denmark) for fat, protein and lactose. A separate milk sample from two consecutive milkings on day 20 was taken for urea determination. Cows were weighed on two consecutive days at the beginning of the experiment and on days 20 and 21 of each experimental period at 10.00 h.

Whole tract apparent digestibility was estimated using AIA as an internal marker (van Keulen and Young 1977). During the last 5 days of each period spot faecal samples were collected at 06.30 and 15.30 h from 8, 10 and 10 cows assigned to the blocks of multiparous cows in Exp. 1, 2 and 3, respectively. At the end of each period, samples were pooled on an individual cow basis, thoroughly mixed, subsampled and stored at –20 ºC.

Energy value for concentrates was calculated using published digestibility coefficients (MTT 2006) for each ingredient. Grass and whole crop silage ME values in the Table 1 are based on *in vitro* –measurement. Protein balance in the rumen (PBV) and amino acids absorbed in the small intestine (AAT) were calculated according to a modified Nordic AAT-PBV protein evaluation system adopted in Finland (MTT 2006). Forage AAT and PBV concentrations were calculated using the equations based on crude protein concentration and measured digestible organic matter (OM) in DM (MTT 2006). Concentrate AAT and PBV concentrations were calculated using published values for individual concentrate ingredients (MTT 2006). Estimates of the efficiency of utilization of AAT for milk protein synthesis and milk production were calculated ignoring changes in live weight.

The metabolisable energy (ME) concentration of the diets was calculated based on predicting ME intake from digestible OM measured in cows assuming a ME concentration of 16 MJ kg^{-1} digestible OM (MAFF 1975). Calculations were conducted using AIA based digestibility measurements for individual cows within block 1 and mean treatment values for block 2, since individual measurements of digestibility were not made for these animals. Milk energy concentration was estimated according to Sjaunja et al. (1990) and ME requirement for maintenance according to MAFF (1984). The efficiency of utilization of ME (k_l) for milk production was calculated ignoring changes in live weight.

Chemical analyses of the feed and faecal samples, and milk urea measurement were made as reported previously by Huhtanen and Heikkilä (1996). Total N concentrations in fresh silage samples were measured by the Kjeldahl method using Cu as a digestion catalyst and a Tecator 1028 Distilling Unit. In Exp. 1 starch concentrations in feed and faecal samples were measured as described by Bach Knudsen et al. (1987). In Exp. 2 and 3 starch concentrations were analysed by the method of McCleary et al. (1994) with assay format 2 without pullulanase/ß-amylase treatment. A modification of the pepsin-cellulase method (Friedel 1990) described by Nousiainen et al. (2003) was used to measure *in vitro* OM digestibility of the forages. The results were calculated with a correction equation to convert pepsin-cellulase solubility values into *in vivo* digestibility by equations based on a data set consisting of Finnish *in vivo* digestibility trials (Huhtanen et al. 2006). The concentration of indigestible NDF in silages was measured as described by Ahvenjärvi et al. (2006).

Statistical analysis

Measurements collected during the sampling period were used when calculating the feed intake and milk production results. Experimental data was subjected to Analysis of Variance using the General Linear Model procedure (PROC GLM) of the Statistical Analysis Systems Institute (SAS®, 1989). The statistical model was $y_{ijkl} = \mu + B_i + C(B)_{ij} + P_k + T_l + (B{\times}P)_{ik} + (B{\times}T)_{il} + e_{ijkl}$, where B, C(B), P, and T are the effects of block, cow within block, period, and treatment, respectively, and eijkl is the error term. Treatment carry-over effect was included for milk production and feed consumption data, but no significant effects were found.

Sums of squares for treatment effects were further separated using orthogonal contrasts into single degree of freedom comparisons. In Exp. 1 the comparisons for the main effects were the protein supplement (Prot) and the linear (L), quadratic (Q) and cubic (C) effect of the barley silage proportion in the silage mixture. The interactions were Prot × L, Prot × Q and Prot × C. In Exp. 2 the comparisons for the main effects were the concentrate type (Conc), the L and Q effects of barley growth stage, and grass silage vs. BS2 silage. The interactions were Conc × L, Conc × Q and Conc × (grass silage vs. BS2). In Exp. 3 the comparisons for the main effects were the concentrate level (Conc), grass silage vs. cereal silages, barley silage vs. wheat silage, and the effect of growth stage of barley and wheat. The interactions were Conc × (grass vs. cereal), Conc × (barley vs. wheat) and Conc × growth stage. The results of the main treatment effects of Exp. 2 and 3 are presented in the tables. Only a few significant interactions were observed and they are mentioned in the text.

Results

Silages

The chemical composition of the barley, wheat and grass ensiled, and the respective silages are shown in Table 1 and that of the concentrates in Table 2. During harvesting at the dough stage the DM concentration of barley varied between 282 and 441 g kg^{-1}, and that of wheat between 289 and 378 g kg^{-1}. The proportion of ear increased with the advancing maturity of barley from 510 to 660 g kg^{-1} DM in Exp. 2 and from 460 to 560 g kg^{-1} DM in Exp. 3. In wheat the proportion of ear corresponded to the values observed with barley (Exp. 3). The height of barley was in Exp. 2 much lower than that of barley and wheat in Exp. 3.

The advancing maturity had a minor effect on cereal crude protein concentration, which was on average 110 g kg^{-1} DM in barley (Exp. 1-3) and 115 g kg^{-1} DM in wheat (Exp. 3) at harvest. The concentration of NDF in barley was much lower in Exp. 2 (mean 420 g kg^{-1} DM) than in Exp. 1 and 3 (522 g kg^{-1} DM) whereas the starch concentration was higher in Exp. 2 (mean 212 *vs*. 121 g kg^{-1} DM). The harvest time had only a minor effect on the NDF concentration, whereas the starch concentration increased from 156 to 278 g kg^{-1} DM in Exp. 2, and from 61 to 160 g kg^{-1} DM in Exp. 3 in barley, and from 67 to 196 g kg^{-1} DM in wheat (Exp. 3). The change was reflected as a decrease in the concentration of water soluble carbohydrates.

Vol. 18 (2009): 234–256.

The DM concentration of grass was similar in all experiments (mean 246 g kg^{-1}). Compared to cereals, grass had higher concentration of crude protein (from 111 to138 g kg^{-1} DM) and NDF (from 502 to 586 g kg^{-1} DM). Indigestible NDF concentration was distinctly higher in cereal crop silages than in grass silages in Exp. 1 and 3. However, in Exp. 2 no difference was observed between the second cut grass silage and whole crop barley silages. Advanced maturity increased (Exp. 3 barley) or slightly decreased (Exp. 2 barley, Exp. 3 wheat) the iNDF concentration of silage.

The starch concentrations of whole crop silages after the ensiling period were in some silages slightly lower than those of the parent material while NDF and WSC concentrations clearly decreased during fermentation process. Exception was NDF concentration in BS1, and WSC concentration in BS2 and WS2 (Exp. 3).

The fermentation quality of whole crop silages was good in all experiments, as evidenced by low pH and concentrations of VFA (Table 1). Only traces of butyric acid were observed. Compared to whole crop silages, grass silages were of similar good fermentation quality. In Exp. 2 harvesting barley at the late dough stage (BS3) resulted in higher pH and WSC concentration, and more restricted fermentation as compared with other barley silages. No effects of the harvest time on the proportion of ammonia N in the barley silage were observed. In wheat silages the ammonia-N proportion was higher than in barley silages and higher in WS2 than in WS1 (90 vs 66 g kg^{-1} N).

In Exp. 1 the CP concentration of protein supplemented concentrate (+RSM) was 164 g kg^{-1} DM, clearly higher than that of the control concentrate (110 g kg^{-1} DM). In Exp. 2 and 3, concentrate CP concentration was higher (mean 202 g kg^{-1} DM) than in Exp. 1. In Exp. 2 the use of different ingredients resulted in lower starch concentration in CC than in FC concentrate. However, there was no difference in the NDF concentration.

Feeding experiment 1

The inclusion of barley silage in the diet tended (p<0.10) to change silage DM intake in a quadratic manner, such that the intake was highest with the BS20 and lowest with the BS60 diet (Table 3). Diet OM, NDF and CP digestibility decreased linearly (p <0.001) with the increasing proportion of barley silage. Protein supplementation increased significantly silage intake (p<0.001) and OM, NDF (p<0.01) and CP (p<0.001) digestibility. However, the increase in OM digestibility was different with different silage diets (interaction RSM × BS cubic). Due to the changes in intake and digestibility, inclusion of barley silage linearly decreased (p<0.001) and that of RSM increased (p<0.001) ME and AAT intake.

Milk and milk constituent yields decreased linearly (p<0.001) with the increasing proportion of barley silage in the diet, and increased (p<0.001, p<0.01) with the inclusion of RSM in the diet (Table 4). A significant interaction between BS cubic effect and RSM was observed in milk fat concentration (p<0.05). Rape seed meal increased (p<0.001) milk protein and urea concentrations, while replacing grass silage with barley silage decreased linearly (p<0.01) milk urea concentration.

The efficiency of dietary N utilization, assessed as the ratio of milk N/N intake, decreased linearly with the increasing rate of barley silage in the diet (p<0.05) but no effect in AAT and ME utilization was observed. The use of RSM decreased the ratio of milk N/N intake (p<0.001) but increased AAT utilization (p<0.001). The efficiency of ME utilization decreased (p<0.05) with RSM supplementation. Feed efficiency, assessed as the ratio of kg ECM kg^{-1} DM intake, decreased linearly with the increasing proportion of barley silage.

Feeding experiment 2

Harvesting barley at one week intervals had no effect on silage DM intake (p>0.05) whereas the starch intake increased linearly (p<0.001) (Table 5). Cows fed the grass silage diet ate more NDF (p<0.001) and ME (p<0.05) but less starch (p<0.001) than those

Table 3. The effect of replacing 0, 200, 400 or 600 g kg^{-1} grass silage dry matter (DM) with whole crop barley silage (BS), and the effect of including 0 (–) or 2 kg (+) rape seed meal (RSM) in concentrate mixture on DM and nutrient intake and digestibility (Experiment 1).

Barley silage proportion	0		200		400		600		SEM	Statistical significances				
Rape seed meal	–	+	–	+	–	+	–	+		RSM	BS Lin	BS Qua	BS Cub	Interaction
Intake														
Number of observations	8	8	8	8	8	8	8	8						
Silage, kg DM d^{-1}	11.7	13.0	12.5	13.3	12.0	12.5	11.8	12.5	0.25	***				
Concentrate, kg DM d^{-1}	9.0	8.7	8.6	8.8	8.7	8.9	9.0	8.8	0.08					
Total, kg DM d^{-1}	20.7	21.7	21.1	22.1	20.7	21.4	20.8	21.3	0.28					
Organic matter, kg d^{-1}	19.0	20.0	19.4	20.3	19.1	19.7	19.1	19.7	0.26	**				
Neutral-detergent fibre, kg d^{-1}	8.80	9.51	8.91	9.53	8.51	8.92	8.42	8.81	0.143					
Crude protein, kg d^{-1}	2.55	3.12	2.39	3.02	2.41	2.98	2.37	2.92	0.048					
ME, MJ d^{-1} [1)]	209	227	212	224	204	218	200	206	2.7	***	***			
AAT, g d^{-1} [2)]	1807	1988	1794	1972	1720	1882	1686	1829	21.4	***	***			
Digestibility coefficients														
Number of observations	4	4	4	4	4	4	4	4						
Organic matter	0.686	0.711	0.684	0.690	0.668	0.690	0.653	0.654	0.0047	**	***			* RSM × BSCub
Crude protein	0.596	0.670	0.579	0.641	0.558	0.650	0.542	0.596	0.0094	***	***			
Neutral-detergent fibre	0.600	0.632	0.567	0.580	0.533	0.549	0.462	0.488	0.0092	**	***			

[1)] ME = Metabolisable energy, calculation based on measured *in vivo* organic matter digestibility in cows

[2)] AAT = Amino acids absorbed in the small intestine (MTT 2006)

SEM = Standard error of the mean, SEM has been given for the interaction effect (n=8 for intake data, and n=4 for digestibility data)

RSM is the effect of rapeseed meal; BS Lin, Qua and Cub are the linear, quadratic and cubic effect of BS inclusion. Interactions are given as letter combinations.

Significant differences at $p < 0.05$, $p < 0.01$ and $p < 0.001$ levels are indicated by *, ** and ***, respectively.

Vol. 18 (2009): 234–256.

Table 4. The effect of replacing 0, 200, 400 or 600 g kg^{-1} grass silage dry matter (DM) with whole crop barley silage (BS) and the effect of including 0 (–) or 2 kg (+) rape seed meal (RSM) in concentrate mixture on milk production, live weight and nutrient utilization for milk production (Experiment 1).

Barley silage	0		200		400		600		SEM	Statistical significances				
Rape seed meal	–	+	–	+	–	+	–	+		RSM	BS Lin	BS Qua	BS Cub	Interaction
Number of observations	8	8	8	8	8	8	8	8						
Yield														
Milk, kg d^{-1}	29.3	30.7	28.3	30.2	27.3	29.1	26.3	26.9	0.40	***	***			
ECM, kg d^{-1} 1)	32.3	33.8	31.1	33.7	30.2	31.8	29.1	30.0	0.46	***	***			
Fat, g d^{-1}	1430	1473	1366	1489	1336	1384	1292	1321	24.4	**	***			
Protein, g d^{-1}	911	994	896	975	855	941	829	888	12.3	***	***			
Lactose, g d^{-1}	1447	1504	1399	1481	1345	1428	1281	1308	21.4	**	***			
Milk composition														
Fat, g kg^{-1}	49.3	48.3	48.5	49.1	49.9	48.1	50.0	49.8	0.46					* RSM × BSCub
Protein, g kg^{-1}	31.3	32.5	31.7	32.2	31.6	32.5	31.8	33.4	0.33	***				
Lactose, g kg^{-1}	49.6	49.0	49.4	49.1	49.3	49.2	48.9	48.8	0.28					
Urea, mg 100 ml^{-1}	13.3	23.3	11.2	21.5	10.4	18.3	11.2	18.6	0.97	***	**			
Live weight, kg	565	574	570	581	570	575	570	583	2.2	***	*			
Live weight change, kg d^{-1}	–0.20	–0.15	–0.02	0.42	0.10	–0.21	–0.03	0.70	0.149		*		*	* RSM ×BSCub
Efficiency of utilization														
Milk N / N intake	0.358	0.320	0.371	0.323	0.355	0.316	0.350	0.306	0.005	***	*			
AAT utilization 2)	0.623	0.654	0.635	0.644	0.625	0.654	0.625	0.651	0.0058	***				
ME utilization 3)	0.686	0.639	0.643	0.648	0.661	0.638	0.656	0.654	0.0095	*				
ECM / dry matter, kg kg^{-1}	1.57	1.56	1.47	1.52	1.46	1.49	1.40	1.41	0.019		***			

1) ECM = Energy corrected milk

2) AAT = Amino acids absorbed in the small intestine (MTT 2006)

3) ME = Metabolisable energy, calculation based on measured *in vivo* organic matter digestibility in cows

SEM = Standard error of the mean, SEM has been given for the interaction effect (n=8)

RSM is the effect of rapeseed meal; BS Lin, Q and C are the linear, quadratic and cubic effect of BS inclusion. Interactions are given as letter combinations.

Significant differences at $p < 0.05$, $p < 0.01$ and $p < 0.001$ levels are indicated by *, ** and ***, respectively.

Table 5. Mean effects of silage (grass (GS) or barley silage (BS) harvested at three stages of maturity (BS1, BS2, BS3)) and concentrate (C) type (FC, farm-made concentrate and CC, commercial compound) on dry matter (DM) and nutrient intake and digestibility in diets based on grass silage, BS2, and a mixture of GS and barley silages. In the mixtures, the proportion of whole crop silage was 400 g kg^{-1} of silage DM (Experiment 2).

	Silage					Concentrate		SEM	Statistical significances				
	Grass	BS2	Grass+ BS1	Grass + BS2	Grass + BS3	FC	CC		C	BS Lin	BS Qua	Grass vs BS2	Interaction
Intake													
Silage, kg DM d^{-1}	10.7	10.5	11.9	12.0	12.2	11.9	11.0	0.23	***				
Concentrate, kg DM d^{-1}	9.5	9.2	9.5	9.2	9.2	9.3	9.3	0.13					
Total, kg DM d^{-1}	20.2	19.6	21.4	21.1	21.4	21.2	20.3	0.20	***				
Organic matter, kg d^{-1}	18.7	18.3	19.8	19.6	19.8	19.7	18.9	0.19	***				
Crude protein, kg d^{-1}	3.01	3.06	3.15	3.13	3.16	3.19	3.01	0.029	***				
Neutral-detergent fibre, kg d^{-1}	7.61	6.24	7.86	7.77	8.02	7.70	7.30	0.118	**			***	
Starch, kg d^{-1}	2.84	4.62	3.52	3.66	3.92	4.24	3.18	0.041	***	***		***	
ME, MJ d^{-1} [1]	209	200	219	218	221	212	215	2.1				*	
AAT, g d^{-1} [2]	1869	1923	1993	1978	1995	1991	1912	17.7	***				
Digestibility coefficients													
Organic matter	0.699	0.682	0.695	0.691	0.691	0.673	0.710	0.0042	***			*	
Crude protein	0.638	0.647	0.644	0.629	0.633	0.619	0.657	0.0070	***				
Neutral-detergent fibre	0.581	0.419	0.541	0.531	0.540	0.515	0.529	0.0070				***	
Starch	0.938	0.944	0.947	0.942	0.952	0.894	0.995	0.0090	***				

[1] ME = metabolisable energy, calculation based on measured *in vivo* organic matter digestibility in cows

[2] AAT = amino acids absorbed in the small intestine (MTT 2006)

SEM = standard error of the mean

SEM has been given for the main effect of silage treatments with 16 observations in intake data and 8 observations in digestibility data. For the main effect of concentrate treatments the number of observation is 40 (intake) or 20 (digestibility), and SEM should be multiplied by 0.632.

Lin and Qua are the linear and quadratic effects of barley maturity. C is the effect of concentrate type. Interactions are given as letter combinations.

Significant differences at $p < 0.05$, $p < 0.01$ and $p < 0.001$ levels are indicated by *, ** and ***, respectively.

Vol. 18 (2009): 234–256.

fed the barley silage diet (BS2). The digestibilities of OM ($p<0.05$) and NDF ($p<0.001$) were lower on the BS2 diet than on the GS diet.

Feeding of farm-made starch based concentrate resulted in higher silage and total DM intake and lower OM, CP and starch digestibility ($p<0.001$) compared with CC-concentrate. As a result, the intakes of NDF ($p<0.01$), OM, CP, starch and AAT ($p<0.001$) were higher with the FC diet, but no difference was observed in ME intake.

The same milk, ECM, fat and lactose yield was obtained with GS and BS2 diets (Table 6). However, feeding BS2 resulted in a higher milk protein concentration ($p<0.001$) and protein yield ($p<0.05$) than feeding GS.

No difference was observed between the concentrate types in milk or ECM yield ($p>0.05$). Milk protein concentration and yield increased with increasing maturity on the FC diet and decreased on the CC diet (interaction C × BSL $p<0.05$). On the FC diet milk protein concentration was 33.6, 34.1 and 34.3 g kg^{-1} on diets G+BS1, G+BS2, G+BS3, respectively. On the CC diet the values were 33.3, 34.0 and 32.6, respectively. Milk lactose concentration was higher on the CC than FC diet ($p<0.05$). The cows gained more weight with FC than CC concentrate ($p<0.05$).

Nitrogen and AAT utilization was more efficient with cows eating CC rather than FC concentrate ($p<0.001$, $p<0.01$). In ME utilization the cows having the FC diet were more efficient than those on the CC diet, although the value of kg ECM kg^{-1} DM intake was higher with CC ($p<0.001$). When comparing GS and BS2 diets, the k_l value was higher on the BS2 diet with CC concentrate whereas only a small difference was observed with the FC diet (interaction C × GS *vs.* BS2, $p<0.05$). The k_l values were 0.620, 0.584, 0.631 and 0.642 on diets GS-FC, GS-CC, BS2-FC and BS2-CC, respectively. For kg ECM kg^{-1} DM intake the respective values were 1.39, 1.40, 1.38 and 1.50 (interaction C × GS *vs.* BS2, $p<0.01$).

Feeding experiment 3

Compared to the grass silage diet, whole crop silage diets had, on average, lower digestibility of OM and NDF ($p<0.001$) (Table 7). However, lower digestibility was compensated by increased silage and total DM intake on mixed diets ($p<0.001$). Consequently, the intakes of OM and starch ($p<0.001$) and that of NDF ($p<0.05$) were higher with mixed diets than with the GS diet.

The intakes of NDF ($p<0.05$) and ME ($p<0.01$) were higher with the BS diet than with the WS diet, the latter being related to the lower ME intake of the WS1 compared to the WS2 diet ($p<0.01$). The advancing maturity resulted in increased starch intake for both BS and WS diets ($p<0.001$). The digestibility of NDF was higher with the BS than the WS diet ($p<0.05$).

An increase in concentrate feeding induced a higher ($p<0.001$) total DM intake, which was associated with a reduction in silage DM intake ($p<0.001$). Similarly, the intakes of OM, CP, starch, ME and AAT increased with the increasing concentrate proportion ($p<0.001$). The use of higher concentrate amount resulted in decreased digestibility of diet NDF ($p<0.05$).

The inclusion of whole crop silage in the grass silage diet had no effect on milk or milk components yields, or milk composition (Table 8). Neither were there any differences between the BS and WS diets, or between growth stages of barley. With wheat silages, the WS2 diet increased ECM yield compared to the WS1 diet ($p<0.05$). Milk urea concentration was lower with the GS diet than with mixed diets, which was explained by the higher CP concentration in the wheat silage diets as compared with barley silage diets ($p<0.001$).

An increase in concentrate amount induced higher milk, ECM, milk fat, protein and lactose yields ($p<0.001$). In addition, high concentrate amount resulted in increased milk protein and urea ($p<0.001$) and lactose ($p<0.05$) concentrations. Further, higher live weight gain was observed with higher concentrate amount ($p<0.01$).

Minor differences were observed between the silage diets in the efficiency of nitrogen and ME utilization. The only differences were between the

Table 6. Mean effects of silage (grass (GS) or barley silage (BS) harvested at three stages of maturity (BS1, BS2, BS3)) and concentrate type (FC, farm-made concentrate and CC, commercial compound) on milk production, live weight and nutrient utilization in diets based on grass silage, BS2, and a mixture of GS and barley silages. In the mixtures, the proportion of whole crop silage was 400 g kg^{-1} of silage DM (Experiment 2).

	Silage					Concentrate		SEM	Statistical significances				
	Grass	BS2	Grass+ BS1	Grass + BS2	Grass + BS3	FC	CC		C	BS Lin	BS Qua	Grass vs BS2	Interaction
Yield													
Milk, kg d^{-1}	27.6	27.5	29.3	28.7	28.9	28.2	28.6	0.24					
ECM, kg d^{-1} [1)]	28.3	28.2	30.4	30.2	29.6	29.4	29.4	0.31					
Fat, g d^{-1}	1157	1129	1230	1232	1187	1191	1184	21.1					
Protein, g d^{-1}	882	916	968	968	955	943	933	8.3				*	* C × BSLin
Lactose, g d^{-1}	1373	1372	1467	1436	1442	1404	1432	12.1					
Milk composition													
Fat, g kg^{-1}	42.8	41.7	42.6	43.6	41.7	42.8	42.1	0.69					
Protein, g kg^{-1}	32.5	33.7	33.5	34.1	33.6	33.8	33.1	0.19	**		*	***	* C × BSLin
Lactose, g kg^{-1}	50.0	50.1	50.3	50.2	50.3	50.1	50.3	0.13	*				
Urea, mg 100 ml^{-1}	21.3	24.1	21.1	21.2	22.1	21.7	22.3	0.48					
Live weight, kg	588	583	591	589	597	592	588	2.1					
Live weight change, kg d^{-1}	0.28	–0.20	0.37	0.22	0.50	0.40	0.07	0.127	*				
Efficiency of utilization													
Milk N / N intake	0.285	0.294	0.300	0.301	0.295	0.288	0.302	0.0031	***				
AAT utilization [2)]	0.593	0.596	0.602	0.606	0.594	0.586	0.610	0.0065	**				
ME utilization [3)]	0.603	0.637	0.608	0.609	0.587	0.615	0.602	0.0053	*	*		***	* C × GS vs BS2
ECM / dry matter, kg kg^{-1}	1.40	1.44	1.42	1.43	1.38	1.38	1.44	0.010	***			*	** C × GS vs BS2

[1)] ECM = energy corrected milk

[2)] AAT = amino acids absorbed in the small intestine (MTT 2006)

[3)] ME = metabolisable energy, calculation based on measured *in vivo* organic matter digestibility in cows

SEM = standard error of the mean

SEM has been given for 16 observations (main effect of silage treatments). When the number of observations is 40 (main effect of concentrate treatments), SEM should be multiplied by 0.632.

Lin and Qua are the linear and quadratic effects of barley maturity. C is the effect of concentrate type. Interactions are given as letter combinations.

Significant differences at $p < 0.05$, $p < 0.01$ and $p < 0.001$ levels are indicated by *, ** and ***, respectively.

Vol. 18 (2009): 234–256.

Table 7. Mean effects of silage (grass (GS), or barley (BS1, BS2) and wheat silage (WS1, WS2) harvested at two stages of maturity), and concentrate (C) level (L low, H high) on dry matter (DM) and nutrient intake and digestibility in diets based on grass silage, a mixture of GS and BS, and a mixture of GS and WS. In the mixtures, the proportion of whole crop silage was 400 g kg^{-1} of silage DM. Amount of concentrate ($kg^{-1}d$) was 9 (L) and 14 (H) for multiparous, and 7.2 (L) and 11.2 (H) for primiparous cows (Experiment 3).

	Silage					Concentrate			Statistical significances				
	Grass	Grass+ BS1	Grass+ BS2	Grass + WS1	Grass + WS2	L	H	SEM	C	Grass vs Whole crop	Barley vs Wheat	Barley maturity	Wheat maturity
Intake													
Silage, kg DM d^{-1}	12.2	13.2	13.2	12.8	13.2	13.8	12.0	0.14	***	***			
Concentrate, kg DM d^{-1}	9.0	8.8	8.8	8.9	8.8	7.0	10.7	0.08					
Total, kg DM d^{-1}	21.2	22.0	22.0	21.7	21.9	20.8	22.7	0.12	***	***			
Organic matter, kg d^{-1}	19.8	20.5	20.5	20.2	20.4	19.4	21.1	0.11	***	***			
Crude protein, kg d^{-1}	3.54	3.53	3.50	3.55	3.56	3.27	3.80	0.019	***				
Neutral-detergent fibre, kg d^{-1}	9.04	9.47	9.35	9.15	9.15	9.22	9.24	0.085		*	*		
Starch, kg d^{-1}	1.83	2.23	2.60	2.12	2.70	1.97	2.63	0.017	***	***		***	***
ME, MJ d^{-1} [1)]	227	231	227	220	227	216	237	1.5	***		**		**
AAT, g d^{-1} [2)]	2030	2056	2043	2028	2049	1904	2178	9.9	***				
Digestibility coefficients													
Organic matter	0.718	0.704	0.694	0.680	0.694	0.696	0.700	0.0062		**			
Crude protein	0.686	0.676	0.671	0.664	0.668	0.672	0.674	0.0071					
Neutral-detergent fibre	0.566	0.538	0.510	0.487	0.509	0.534	0.510	0.0104	*	***	*		
Starch	0.986	0.989	0.988	0.987	0.990	0.988	0.988	0.0007		*			*

[1)] ME = metabolisable energy, calculation based on measured *in vivo* organic matter digestibility in cows

[2)] AAT = amino acids absorbed in the small intestine (MTT 2006)

SEM = standard error of the mean

SEM has been given for the main effect of silage treatments with 16 observations in intake data and 8 observations in digestibility data. For the main effect of concentrate treatments the number of observation is 40 (intake) or 20 (digestibility), and SEM should be multiplied by 0.632.

C is the effect of concentrate level. No significant interactions were observed.

Significant differences at $p < 0.05$, $p < 0.01$ and $p < 0.001$ levels are indicated by *, ** and ***, respectively.

Table 8. Mean effects of silage (grass (GS), or barley (BS1, BS2) and wheat silage (WS1, WS2) harvested at two stages of maturity), and concentrate (C) level (L low, H high) on milk production, live weight and nutrient utilization in diets based on grass silage, a mixture of GS and BS, and a mixture of GS and WS. In the mixtures, the proportion of whole crop silage was 400 g kg^{-1} of silage DM. Amount of concentrate ($kg^{-1}d$) was 9 (L) and 14 (H) for multiparous, and 7.2 (L) and 11.2 (H) for primiparous cows (Experiment 3).

	Silage					Concentrate		SEM	Statistical significances				
	Grass	Grass+ BS1	Grass+ BS2	Grass + WS1	Grass + WS2	H	L		C	Grass vs Whole crop	Barley vs Wheat	Barley maturity	Wheat maturity
Yield													
Milk, kg d^{-1}	31.4	32.1	31.7	31.1	31.7	30.0	33.2	0.24	***				
ECM, kg d^{-1} 1)	32.0	32.5	32.2	31.7	33.2	30.8	33.9	0.36	***				*
Fat, g d^{-1}	1296	1296	1294	1279	1380	1259	1359	22.0	***				*
Protein, g d^{-1}	1026	1049	1037	1015	1034	967	1097	10.4	***				
Lactose, g d^{-1}	1537	1587	1561	1524	1564	1472	1638	13.4	***				
Milk composition													
Fat, g kg^{-1}	41.3	40.5	40.9	41.3	43.3	42.0	40.9	0.61					
Protein, g kg^{-1}	32.8	32.9	32.8	32.8	32.7	32.3	33.3	0.17	***				
Lactose, g kg^{-1}	49.1	49.6	49.3	49.1	49.4	49.1	49.5	0.14	*				
Urea, mg 100 ml^{-1}	25.2	26.0	25.5	28.4	27.6	24.7	28.3	0.48	***	*	***		
Live weight, kg	571	576	577	577	578	573	579	1.6	**	*			
Live weight change, kg d^{-1}	0.10	0.14	0.48	0.30	0.49	0.16	0.45	0.100	**				
Efficiency of utilization													
Milk N / N intake	0.288	0.297	0.296	0.286	0.289	0.295	0.288	0.0028	*		*		
AAT utilization 2)	0.621	0.628	0.625	0.619	0.620	0.635	0.610	0.0064	***				
ME utilization 3)	0.603	0.598	0.609	0.627	0.627	0.621	0.605	0.0091			*		
ECM / dry matter, kg kg^{-1}	1.51	1.47	1.46	1.46	1.51	1.47	1.49	0.0193					

1) ECM = energy corrected milk

2) AAT = amino acids absorbed in the small intestine (MTT 2006)

3) ME = metabolisable energy, calculated based on measured *in vivo* organic matter digestibility

SEM = standard error of the mean. SEM has been given for 16 observations (main effect of silage treatments). When the number of observations is 40 (main effect of concentrate treatments), SEM should be multiplied by 0.632.

C is the effect of concentrate level. No significant interactions were observed.

Significant differences at $p < 0.05$, $p < 0.01$ and $p < 0.001$ levels are indicated by *, ** and ***, respectively.

Vol. 18 (2009): 234–256.

cereal silages since the efficiency of dietary nitrogen utilization (milk N/N intake) was higher with barley than with wheat silage, whereas ME utilization was higher with wheat silage ($p<0.05$). Increasing concentrate amount resulted in decreased efficiency of N ($p<0.05$) and AAT ($p<0.001$) utilization.

Discussion

Chemical composition of crops at harvest and after ensiling

Advancing crop maturity increased the proportion of ear and the concentration of starch in barley and wheat, while minor changes were observed in NDF and crude protein concentrations. Compared to some other studies, the decrease in NDF concentration of wheat was relatively small (Kristensen 1992, Sutton et al. 2002). The timing and interval of harvests, and climatic factors, such as light intensity and temperature, affect the extent of compositional changes in cereals explaining the variation within the experiments. Chow et al. (2008) reported that delaying the planting day of barley altered barley's growing environment (temperature, precipitation) and affected nutrient composition and *in vitro* NDF digestibility.

The NDF concentration was much lower in whole crop cereals than in grass, whereas the concentration of iNDF measured in WC silages in Exp. 1 and 3 was at least twice as high as in grass silage. In Exp. 2, the iNDF concentration of barley silage was exceptionally low, which can be due to the low straw proportion in dry and warm climatic conditions, and probably to the low lignification of straw in relation to grain development. The mean temperature of June and July during Exp. 2 was 2.9 and 3.9 ^{o}C higher than during Exp. 1 and Exp. 3, respectively. Further, the precipitation was 109 and 86 mm less, respectively.

The increase in starch concentration of cereal crops with the advancing maturity was associated with a decrease in WSC concentration, which resulted in minor increases (from 34 to 43 g kg^{-1} DM, Exp. 2 and Exp. 3) in the concentration of total non-structural carbohydrates (NSC, starch + WSC). Hill and Leaver (1999a) reported lower concentrations of WSC in wheat at milk/early dough stages and the concentration appeared to decline faster than in the present experiment. A summary of the results of MacGregor and Edwards (1968) showed that the WSC concentration of barley reached a peak value (326 g kg^{-1} DM) at the milky ripe stage of growth when the DM concentration was 290 g kg^{-1}. In spring wheat, WSC concentration remained high (140 to 250 g kg^{-1} DM) until 4 to 5 weeks after the start of heading, after which it fell sharply (Kristensen 1992).

The variability of the starch concentration at the dough stage agrees with the results reported in the Nordic countries at the same growth stage (Kristensen 1992, Nadeau 2007, Wallsten et al. 2009). Comparison of different studies is, however, challenging since the deposition of sugar to starch depends on many factors. Givens et al. (1993) suggested that the assessment of growth stage alone may not be a good guide to the composition and digestibility of whole crop cereals. In the present experiment the ratio of NSC to NDF in barley seemed to be consistently more affected by the between-year differences in the climatic conditions than by the stage of maturity. The length and proportion of straw was exceptionally small and starch concentration high in Exp. 2. As a result the mean concentration of NSC was 150 g kg^{-1} DM higher and NDF concentration 95 g kg^{-1} DM lower in Exp. 2 than Exp. 3. Emphasizing the difficulties in controlling cereal development, the results of Sutton et al. (2002) showed that the crops may be physiologically at different maturity stages at the same DM concentration. Among other factors, the harvesting technique may affect the carbohydrate composition. Sinclair et al. (2003) reported that increasing cutting height (stubble heights 18 vs 38 cm) increased starch concentrations from 232 to 292 g kg^{-1} DM and reduced NDF from 433 to 384 g kg^{-1} DM.

The changes in starch concentration during ensiling were inconsistent, reflecting mainly the difficulties in taking representative samples rather than e.g. degradation of starch. Since the use of starch by lactic acid bacteria is limited the possible losses of starch may be due to the utilization by yeasts and fungi, plant respiration, and solubilisation (McDonald et al. 1991).

Fermentation quality of forages

The fermentation quality of whole crop silages was good as evidenced by the low pH and small amounts of VFA. No problems were observed regarding the aerobic stability of silages but it should be noted that the experiments were conducted at winter time when low temperatures decrease the susceptibility to aerobic deterioration. The formic acid based additives restricted fermentation equally well in grass and whole crop silages. Based on the ratio of WSC to lactic acid, the fermentation was slightly more restricted in grass silage as compared to WC silages harvested at the early dough stage. Due to the increasing DM concentration with advancing maturity, the fermentation in later harvested cereal silages was less extensive than in grass silages. The DM losses and protein degradation caused by fermentation may be substantial in whole crop silages of low DM (Tetlow 1992). The results observed here suggest that the losses may be decreased by a formic acid based additive and/or postponing the harvest until the late dough stage.

Formic acid is known to inhibit protein degradation and lactic acid fermentation during ensiling. The changes in the ratio of silage WSC to lactic acid affect the nutrient supply to the rumen microbes, and subsequently modify the microbial protein synthesis and molar proportions of VFA in the rumen (Jaakkola et al. 2006a) and affect milk production (Jaakkola et al. 2006b). With cereal silage, the intake of starch further complicates the nutrient supply and modifies the rumen fermentation pattern. The total amount of NSC in whole crop silages varied between 108 and 353 g kg^{-1} DM being much higher than the typical values of restrictively fermented grass silages (53 – 82 g kg^{-1} DM).

Growth stage and cereal type

Lignin deposition characterizes the process of maturation of the straw of small grain cereals. In terms of whole crop digestibility, lignification is compensated by grain development and deposition of starch. This explains why within the two weeks interval no effects of barley or wheat maturity on diet digestibility were observed in Exp. 2 and 3. Inconsistent effects of wheat maturity on diet digestibility have been reported (Südekum and Arndt 1998, Sutton et al. 2002). Decreased or increased digestibility with advancing maturity may be attributed to the specific stage of growth and characteristics of the crops as well as to the method used in the digestibility measurement. In the early stages of a crop maturity from heading to early dough stage the OM digestibility has decreased in sheep offered wheat silage (Crovetto et al. 1998) and in dairy cow offered barley silage (Wallsten and Martinsson 2009). At that stage the starch formation is still limited while the digestibility of NDF decreases. With advancing maturity the increase in the concentration of starch results in a recovery of crop OM digestibility (Sutton et al. 2002). With high DM wheat the increases in OM digestibility have been attributed to urea treatment (Tetlow 1992) and decreases in starch digestibility to the hard cereal grains which are poorly digested by dairy cows (Sutton et al. 1997, Abdalla et al. 1999, Sutton et al. 2002).

No differences were observed in silage DM intake with advancing maturity of barley or wheat (Exp. 2, Exp. 3) or between barley and wheat (Exp. 3). Sutton et al. (2002) noted increased intake with advancing wheat maturity, which might be attributed to a much greater difference between the maturity stages (DM 300 vs 580 g kg^{-1}) and the extent of silage fermentation than in the present experiment. However, they reported no effects of maturity on milk yield. In the present experiments, harvesting barley at one week (Exp. 2) or two week (Exp. 3) intervals had no significant effect on milk or milk component yields. The result indicates flexibility in the timing of harvest during dough stage of whole crop as timing is not as critical for the nutritive value as in case of grass. On the basis of the maximal crop yield the optimal harvest dates were at the soft/hard dough stage of barley.

Higher ECM yield with WS2 than with WS1 diet was associated with a slightly higher diet OM digestibility (P=0.147) and milk fat concentration (41.3 vs 43.3 g kg). The result suggests that the later harvest time for wheat was more optimal in terms of both crop yield and ECM yield. This is in accordance with other studies showing increased crop yield of wheat with advancing maturity before stabilizing at DM concentrations of about 400 g DM per kg (Tetlow 1992, Kristensen 1992, Sutton et al. 2002). In barley the maximum yield is obtained at DM concentration of approximately 350 g kg^{-1} or 4−5 weeks after the initial ear emergency according to Kristensen (1992).

Dietary inclusion rate of whole crop barley and wheat silages

The large variation in the characteristics of whole crop silages suggests that the production responses can be attributed to the variable composition of rumen fermentable carbohydrates of silages. Inclusion of whole crop silage in the silage mixture increased (Exp. 2 and 3) or had a minor effect (Exp. 1) on the intake of silage. Unlike with grass silage (Rinne et al. 1999), the intake responses could not be associated with forage digestibility. Even when the diet digestibility clearly decreased (Exp. 1) with the increasing proportion of whole crop barley silage, no corresponding negative effects on silage intake were observed. Increased intakes with a mixture of grass and WC silage have been observed both with fermented and urea treated wheat silage (Sutton et al. 1997, Abdalla et al. 1999, Sinclair et al. 2003). In the experiment of Hameleers (1998), the response was achieved when WC silage was of later maturity and grass silage of higher ME value than in the present experiment. Also the response has been realized with grass silage of poorer fermentation quality (ammonia N 128 g kg^{-1} N) (Phipps et al. 1995). In a data analysis by Huhtanen et al. (2007), responses to replacing grass silage partially or totally with whole-crop silage could not be accurately predicted from differences in silage digestibility, DM concentration or fermentation quality, and the observed silage DM intake was generally higher than the predicted intake.

Ahvenjärvi et al. (2006) examined the silages of Exp. 1 in a physiological study in cows equipped with rumen cannulas. They concluded that the characteristics of whole crop cereals allow cows more flexibility in regulating intake in relation to energy demand than grass silage. The lower NDF concentration of WC silage may be one reason for that (Huhtanen et al. 2007) since the animals were able to increase ruminal NDF pool at lower inclusion rates (0.2 and 0.4) (Ahvenjärvi et al. 2006). In Exp. 2, the NDF concentration of GS was 147 g kg DM^{-1} higher than the mean concentration in WC silages, which resulted in a higher silage-NDF concentration in the diets of GS alone than in the diets based on the mixtures of grass and whole crop silage (277 vs 210 g kg DM^{-1}).

The responses in intake to physical treatment of barley silage have also been studied. Soita et al. (2002, 2003) showed that reducing the chop length of barley silage increased feed intake in steers, while the effect depended on the concentrate level of the diet. Despite changes in chemical composition, elevating the cutting height of wheat or barley did not improve or even decreased intake and animal performance in cows (Sinclair et al. 2003, Jackson et al. 2004) or in beef cattle (Walsh et al. 2009). Neither did the mechanical processing of barley silage affect its nutritive value in dairy cow diet (Eun et al. 2004). In the present study, the cutting height was the same in all experiments. The particle size of the silage was longer in Exp. 1 than in other experiments due to the different harvester (particle size not measured). Although the mechanical treatment of silage during harvest may have some effect, the assessment of the importance of the chop lengths/types is not possible in the present study. The use of a mixer wagon in all experiments further affected the particle size of the silages.

The nutritive value of the control grass silage compared to the WC silage may partly explain the variation in the milk yield responses. The energy value of GS was higher in Exp. 1 (10.8 ME MJ kg^{-1} DM) and Exp. 3 (10.9) than in Exp. 2 (10.4). Much of the poor milk yield response to whole crop silage inclusion in Exp. 1 can be ascribed to its low digestibility as compared with grass silage. Ahvenjärvi et al. (2006) noted that the decreases in OM and NDF digestibility were attributed to the higher iNDF concentration of barley silage compared to that of grass silage. Decreased microbial N flow from the rumen further explained the poor milk responses to barley silage. However, the iNDF concentration of WC silages in Exp. 3 was also twice as high as in GS (65 vs 143 g kg^{-1} DM) but the intake of grass and WC silage mixtures was significantly higher than that of GS, and milk yield unchanged. Thus, the response to WC silage might also be attributed to other factors than the fibre characteristics of GS and WCS.

In the physiological study the daily averages of ruminal ammonia concentrations were lower (Ahvenjärvi et al. 2006) than the suggested minimum levels for optimum fibre digestion (Hoover 1986). It is possible that the rumen degradable N limited the microbial activity, especially with higher inclusion rates of WC. In Exp. 3, more positive milk yield response to feeding WC silage was observed, when the diet CP concentration was higher than in the protein supplemented diet in Exp. 1 (140 vs 162 g CP kg^{-1} DM). There was a substantial difference in CP concentration of concentrate (160 vs 210 g kg^{-1} DM) between the studies, which may explain the difference in milk yield response. The proportion of concentrate in diet DM was the same in both experiments (415 vs 407 g kg^{-1}).

The same milk yield with GS and BS2 in Exp. 2 suggests that the silages had similar energy value. This corresponds well with the same iNDF concentration of the forages but was associated with significantly lower OM and NDF digestibility of the BS2 diet than the GS diet. However, cows having a mixture of GS and BS2 produced on average 2.0 kg more ECM than those having only GS or BS2. The synergistic effect of feeding mixture suggests that the nutrient balance might be better than when silages were fed alone. Studies on rumen fermentation have shown inconsistent results. The proportion of acetate was lower and that of propionate higher in cows consuming WC silages rather than alfalfa or grass silage (Khorasani et al. 1996, Ahvenjärvi et al. 2006) or rumen acetate or butyrate has increased after inclusion of WC in the diet (Abdalla et al. 1999, Owens et al. 2008). In Exp. 3, daily DM intake on mixed silage diets was 0.7 kg higher than that of the GS diet, compensating the decreased digestibility. This resulted in equal milk yield with the mixed and GS diets. Similarly, the increased feed intake of silage mixtures has not led to corresponding increases in milk yield in other experiments (Leaver and Hill 1995, Phipps et al. 1995, Hameleers 1998).

Inclusion of WC silage in the diet had no effect on milk composition except in Exp. 2 in which milk protein concentration was higher with BS2 than with GS. Also in some earlier experiments protein concentration was higher with mixtures of grass silage and urea-treated whole crop wheat than with grass silage alone (Abdalla et al. 1999, Sutton et al. 2002).

Inclusion of barley silage in the diet decreased linearly N intake in Exp. 1 which explains the extremely low milk urea concentration. The high efficiency of N utilization in milk production is also attributed to the low N concentration of grass silage. In Exp. 2 and 3, due to the low N concentration of both grass and WC silages, N utilization was also good despite the high protein concentration of the concentrate.

Amount and type of concentrate supplementation

Silage DM intake increased by an average of 0.7 kg per day when rape seed meal was included in the WC diets, being less than with grass silage (1.3 kg, Exp. 1). In milk production the mean response to rape seed meal supplementation of the WC diet was 0.94 kg ECM and 41.5 g milk protein per kg DM of RSM. With the GS diet the values were 0.83 kg and 46.1 g, respectively. The responses correspond well with the mean values in a literature review of rape seed meal studies in Finland (Huhtanen 1998) although the crude protein concentration of the control diets was exceptionally low (mean 117 g kg^{-1} DM). A vari-

Vol. 18 (2009): 234–256.

ation was observed between the WC silages so that the highest responses in milk and protein yield were with BS20 silage (1.44 kg ECM) and BS40 (47.8 g protein), and the lowest with BS60 silage (0.50 kg and 32.8 g). Limited published data is available on the protein supplementation of barley silage. When urea treated whole-crop wheat was offered as a sole feed, additional protein supplement with fish meal but not with soya-bean meal increased milk yield (Hill and Leaver 1999b).

The mean daily starch intake in Exp. 2 was 1.1 kg lower in the diets including commercial compound than cereal based FC concentrate. Further, for the GS diet the mean daily starch intake was 1.8 kg lower than with the BS2 diet. The absence of interaction between concentrate and silage type indicates no benefit by supplementing cereal silages with low starch concentrates. Kristensen (1992) compared rolled barley, fodderbeet and dried sugar beet pulp as supplement for whole crop barley silage, and observed only minor effects on the production of milk and milk components. The lack of interaction in the present study may be associated with the concentration of total NSC in the concentrates, which was probably quite similar judging by the similar NDF concentration of concentrates (WSC not measured). In addition, there was no difference between the FC and CC diets in the proportion of silage-NDF concentration of the diet (224 vs 216 g kg DM^{-1}) which is considered to be an important criterion for optimal rumen function.

The cows offered FC concentrate ate significantly more silage than those having CC concentrate but there was no difference in milk yield due to the lower OM digestibility of the FC diet. The cows were able to compensate the lower digestibility of the FC diet by increasing silage intake. The low starch digestibility with the FC diet (0.89) suggests that some grain in the farm mixture remained intact after grinding. The reason for this is unlikely to be due to the WC starch digestibility since high starch digestibility with CC diet in Exp. 2, and with all diets in Exp. 3, indicates that starch of WC silages was completely digested.

The effects of concentrate level in Exp. 3 agree with the results of Hill and Leaver (1999b) who offered dairy cows urea treated whole crop wheat as a sole feed. In the present experiment, increasing the amount of concentrate decreased silage intake but total DM intake increased by 1.9 kg DM per day. With the mixture of GS and whole crop silages the substitution rate was 0.45 kg silage DM per kg concentrate DM and 0.59 with GS. The values are in good agreement with the mean value observed in studies with grass silage (Huhtanen 1998). Similarly, with whole crop wheat silage as the sole forage the substitution rate of concentrate was 0.59 (Hill and Leaver 1999b). The mean response in milk yield was 0.65 and 0.90 kg ECM per kg concentrate DM with grass silage and grass-whole crop silage mixtures, respectively, being higher than 0.52 kg in the experiment of Hill and Leaver (1999b). The result of the present experiments suggests that the responses to increased concentrate amount in the diets of mixed grass and WC silage are similar with diets based on grass silage as the sole forage.

Conclusions

Successful preservation can be achieved by preserving whole-crop barley and wheat with a formic acid based additive at dough stage with dry matter concentration of 300–450 g kg^{-1}. The results show that with barley, advancing maturity had no effect on milk yield, whereas with wheat silage harvest at soft/hard dough, rather than at early dough stage, increased milk yield. In terms of milk yield, the soft/hard dough stage is the optimal harvest time for both cereals.

Whole-crop cereals did not accomplish as high digestibility as is possible with grass silage. However, the results suggest that mixing grass silage and whole crop silage up to a whole crop silage proportion of 0.4 in forage DM may improve silage DM intake, and subsequently maintain or even increase milk yield. This can be explained by the good intake characteristics of whole crop silage and by the synergistic effect of combining grass and whole crop silages. The response in milk production may depend on the relative difference in the digestibility of grass and whole crop silage.

Protein supplementation, different levels of concentrate and energy source of concentrate induced mainly similar intake and milk yield responses with diets based on grass silage alone or on mixtures of grass and whole crop silages. However, the synergistic effect of mixing grass and whole crop silages was realized better in milk yield in the experiments where the protein concentration of concentrate was high (200 g kg^{-1} DM). Low N concentration of whole crop silage allows a use of a relatively high protein supplementation without excessively impaired efficiency of N utilization.

Acknowledgements. The authors wish to acknowledge the technical assistance and cooperation of the staff in Lintupaju Experimental Farm, and other staff of Animal Nutrition and Jokioinen Estates, MTT Agrifood Research Finland. We thank Rehuraisio Oy, Kemira Oyj, Valio Oy, Junkkari Oy, NHK-keskus and Konefarmi Oy for co-operation.

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Vol. 18 (2009): 234–256.

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SELOSTUS

Muurahaishapolla säilötty ohra- ja vehnäkokoviljasäilörehu lypsylehmän ruokinnassa: viljan kehitysasteen, kokoviljasäilörehun osuuden ja väkirehutäydennyksen määrän ja laadun vaikutus

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Kolmessa lypsylehmien ruokintatutkimuksessa tutkittiin nurmisäilörehun osittaista korvaamista kokoviljasäilörehulla. Kokeissa käytettiin taikinatuleentuneena korjattua ohraa tai kevätvehnää, joiden kuiva-ainepitoisuus vaihteli välillä 300−450 g kg^{-1}. Kaikki rehut säilöttiin laakasiiloon tai torniin ja säilönnässä käytettiin muurahaishappopohjaista säilöntäainetta (5 l t^{-1}). Ruokintakokeissa tutkittiin säilörehujen lisäksi myös rehujen energia- ja valkuaistäydennystä. Kokeessa I nurmisäilörehua korvattiin ohrasäilörehulla eri ruokinnoissa 0, 200, 400 tai 600 g kg^{-1} kuiva-ainetta (KA). Säilörehun lisäksi lehmät saivat päivittäin 10 kg väkirehua, joka sisälsi rypsirouhetta 0 tai 2 kg. Kokeessa II ohra korjattiin kolmena kertana (O1, O2, O3) viikon välein. Jokaista ohrasäilörehua syötettiin seoksena nurmisäilörehun kanssa ja ohrasäilörehun osuus karkearehusta oli 400 g kg^{-1} KA. Lisäksi O2-kokoviljasäilörehua ja nurmisäilörehua syötettiin ainoana karkearehuna. Väkirehuina (11 kg/pv) verrattiin viljapohjaista kotiseosta ja kaupallista täysrehua, jonka tärkkelyspitoisuus oli pienempi kuin kotiseoksen. Kokeessa III puolestaan sekä ohra että kevätvehnä korjattiin kahden viikon välein. Kokoviljasäilörehu syötettiin nurmisäilörehun kanssa seoksena, jossa kokoviljasäilörehun osuus oli 400 g kg^{-1} KA. Ruokintoja täydennettiin kahdella eri väkirehumäärällä (vanhemmat lehmät 9 tai 14 kg/pv, ensikot 7,2 ja 11,2 kg/pv).

Sekä nurmisälörehujen että kokoviljasäilörehujen käymislaatu oli hyvä. Vuosien väliset erot sääolosuhteissa sekä viljan kehitysaste vaikuttivat tähkän osuuteen kasvissa ja sen kautta sokerin, tärkkelyksen ja kuidun (NDF) pitoisuuksiin kokoviljasäilörehuissa. Kokoviljasäilörehun lisääminen ruokintaan huononsi rehuannoksen sulavuutta. Vaikutuksen voimakkuus riippui nurmirehun sulavuudesta ja kokoviljarehun osuudesta seoksessa. Kokovilja- ja nurmiseoksen syöttäminen ei kuitenkaan vähentänyt rehun syönnin kokonaismäärää. Tästä johtuen maitotuotos ei muuttunut tai tuotos jopa hieman lisääntyi kokeissa II ja III verrattuna nurmisäilörehuruokintaan. Sen sijaan kokeessa I maitotuotos väheni, kun kokoviljasäilörehun osuus karkearehusta oli 400 tai 600 g kg^{-1} KA. Tutkitut ohran kehitysasteet vaikuttivat hyvin vähän maitotuotokseen, mutta kevätvehnän korjuun siirto taikinatuleentumisvaiheen loppupuolelle lisäsi tuotosta. Väkirehuvaihtoehtojen välillä ei ollut juuri eroa nurmisäilörehun ja nurmi-kokoviljaseoksen täydentäjinä. Nurmisäilörehun ja kokoviljasäilörehun seoksen positiivinen vaikutus maitotuotokseen oli suurin kokeissa II ja III, joissa väkirehun raakavalkuaispitoisuus oli melko suuri (200 g kg^{-1} KA). Kokoviljasäilörehun pieni raakavalkuaispitoisuus mahdollistaa suhteellisen runsaan valkuaistäydennyksen ilman, että typen hyväksikäyttö heikkenee oleellisesti.