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Effect of silage dry matter content and rapeseed meal supplementation on dairy cows. 1. Milk production and feed utilisation

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Abstract

Twelve cows (8 multiparous and 4 primiparous) were divided into four treatments to study the effects of direct-cut and wilted silage with or without rapeseed meal supplementation (RSM0 or RSM16) on feed intake and milk production. Experimental design consisted of a 4×4 balanced Latin square with four 3-week periods. Silages were given ad libitum and the concentrate was provided in fixed amounts: 10 kg per day for multiparous cows and 8 kg per day for primiparous cows.

Both silages were well preserved. Wilted silage contained more soluble N and ammonium N than direct-cut silage. The dry matter intake (DMI) of wilted silage was on average 16% higher ($p<0.001$) than that of direct-cut silage, while milk yield was 2.9% higher ($p<0.05$) with direct-cut silage. Silage type had no effect on milk composition. The digestibility of organic matter in the diet was 4.5% lower ($p<0.01$) with wilted silage. The cows with wilted silage gained weight, whereas the cows with direct-cut silage lost weight. RSM supplementation increased silage DMI 10.4% ($p<0.05$) and milk yield 6.0% ($p<0.001$) as well as yields of fat, protein and lactose. There was a tendency towards higher milk yield response to RSM supplementation with wilted silage.

In conclusion, wilting increased silage DMI but the lower digestibility and energy content of the wilted silage decreased the energy intake difference between silages. Part of the extra energy with wilted silage was partitioned towards live weight gain. Higher milk yield with RSM supplementation was mainly due to an increase in energy intake. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Grass silage; Milk production; Wilting; Digestibility; Live weight change

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1. Introduction

Increasing dry matter content by wilting grass prior to ensiling is an alternative technique for making silage widely practised in many European countries. The need to prevent pollution from effluent further increases the attractiveness of high DM systems.

Many experiments have shown that wilting has increased silage DM intake as compared to direct-cut silage with minor or even negative effects on milk yield (Ettala et al., 1982; Bertilsson, 1987; Gordon, 1996). The decreased utilisation of silage after wilting is thought to be due to decreased digestibility, maybe because ash content in wilted silage is higher than in direct-cut silage (Castle and Watson, 1982). Furthermore, it has been suggested that wilting may increase energy partitioning towards live weight gain.

Microbial protein is the major source of amino acids with grass silage and cereal grain based diets. Diets containing a large proportion of silage have been thought to have a low efficiency of microbial protein synthesis in the rumen compared with grass or hay-based diets (Thomas and Thomas, 1988), resulting in inadequate post-ruminal flows of protein and reduced milk yields. This theory has been challenged recently with restrictively fermented silages and it has been suggested that protein value of restrictively fermented silage is not inferior to barn-dried hay (Huhtanen, 1998). Teller et al. (1992) reported that duodenal nitrogen flow was greater with wilted silage than with direct-cut silage. This was presumably due to higher organic matter intake and increased efficiency of bacterial protein synthesis.

Many experiments have shown substantial responses in milk output to protein supplements (Tuori, 1992). Aston et al. (1994) reported linear increases in yields of milk and protein as supplement crude protein content was increased from 120 to 240 g/kg DM. Gordon (1980) suggested that the responses could be higher with wilted silage than with direct-cut silage.

The objective of our experiment was to study the effects of direct-cut and wilted grass silage diets on the feed intake, digestibility, milk production and feed utilisation with or without rapeseed meal supplementation. The preliminary results of this experiment have been published in Tuori et al. (1994).

2. Materials and methods

The grass silages were made of second cut timothy–fescue swards cut with a drum mower and harvested with a precision chopper, either directly after cutting or after wilting overnight ($\approx$16–20 h). There was no rain during the wilting period; the weather was sunny and windy. The grass had been fertilised with 110 kg N/ha for the first cut and 76.5 kg N/ha for the second cut. Both silages were ensiled in plastic-covered clamp silos using formic acid as a preservative (4.9 l/ton).

The design of the experiment was a 4×4 balanced Latin square with 12 dairy cows [8 multiparous (7 Ayrshire, 1 Friesian) and 4 primiparous (Ayrshire)]. Four of the older cows had ruminal cannulas. At the start of the experiment, the average time since calving was 96 days. The treatments were in a 2×2 factorial arrangement with direct-cut or wilted silage, and the concentrate was a grain mixture (oat–barley) with or without 16% rapeseed meal (RSM). Silages were given ad libitum and the concentrate was offered in fixed amounts (10 kg per day for multiparous and 8 kg per day for primiparous) for the duration of the experiment. The experimental periods lasted three weeks.

The cows were tied in short stalls. Silage was distributed twice daily (6:30 and 14:30) and concentrates were given half an hour before each silage feeding. The cows had continuous access to the feed.

All animals were milked twice daily and samples were taken on four consecutive milkings on the two last weeks of each period. Fat, protein and lactose contents were analysed with infrared analysis (Milkoscan 605). The urea content of milk samples was measured with an enzymatic colorimetric method (Rajamäki and Rauramaa, 1984). Cows were weighed on two consecutive days at the beginning, the middle and the end of each period. Feeds were weighed daily. Orts were collected and recorded daily, except on weekends.

Silages were sampled once a week during the first two weeks of the period. During the 6 last days of the period, silages were sampled daily and the daily samples pooled. Silage pH and dry matter content were determined weekly. Part of the pooled sample was oven-dried for feed analysis and part of the sample was frozen for ammonium, water soluble carbohydrate (WSC), lactate and volatile fatty acids (VFA) analyses. The concentrates were sampled once per period. Periodical samples were pooled into two samples (periods 1 and 2 and periods 3 and 4).

The digestibilities of diets were determined with eight multiparous cows using ash-insoluble ash (AIA) as an internal marker (Van Keulen and Young, 1977). For that purpose, a sample of faeces was taken by rectum twice daily (6:00 and 18:00) during the last 6 days of each period.

The dry matter contents of silages measured by oven drying (+105°C, 24 h) were corrected for volatile losses of lactic acid, volatile fatty acids (VFA) and ammonia (Porter et al., 1984). Silage, concentrate and faecal samples were subjected to proximate feed analyses and NDF, ADF and ADL were analysed according to Goering and Van Soest (1970). Ether extraction of samples was performed after hydrolysis with HCl. Sugar (Somogyi, 1945, with modifications of Salo, 1965) and ammonium N (McCullough, 1967) contents of silages were measured spectrophotometrically from the water extract of the silage sample. The total N contents of silage and faecal samples were determined from fresh samples by the Kjeldahl method.

The lactic acid content of silages was measured with the colorimetric method (Barker and Summerson, 1941). The VFA of silage were determined by gas chromatography (Hewlett Packard 5710A) as described by Huida (1973).

2.1. Calculations

Nutritional composition of feeds was calculated using the feed analyses for each period. The Finnish OIV-PVT system is a modification of the Nordic AAT-PBV system (Tuori, 1992). OIV measures amino acids (bypass protein and microbial protein) absorbable from the small intestine. PVT (protein balance value) reflects the abundance of rumen degradable protein for rumen microbial synthesis. Microbial protein synthesis is calculated from the sum of digestible carbohydrates and degraded protein in rumen. Effective protein degradability (EPD) was 85% for silage.

2.2. Statistical analyses

There were no significant interactions between square and diet. Therefore, the results of primiparous cows were analysed together with the results of multiparous cows.

Significance of treatment effects was determined using analysis of variance with SAS (1989) statistical software and the following model:

$$\begin{aligned} Y_{ijklmn} &= \mu + Q_i + A_j(Q_i) + S_k + R_l + (S \times R)_{kl} + P_m + (Q \times S)_{ik} \\ &\quad + (Q \times R)_{il} + (Q \times S \times R)_{ikl} + (Q \times P)_{im} + \varepsilon_{ijklm}, \end{aligned}$$

where Q is the effect of square, $A(Q_i)$ the effect of animal within the square and S, R and P the effects of silage, RSM and period, respectively, and ε the error.

3. Results

3.1. Feed composition and feed intake

The chemical composition of feeds as an average of all periods is given in Table 1. Wilted silage contained more ash, soluble N, ammonium N and lactic acid than direct-cut silage. Direct-cut silage, in turn, contained more crude protein, crude fat and sugars than wilted silage.

Table 1
Feed composition

	Direct-cut silage	Wilted silage	Oat	Barley	Rapeseed meal
DM (g/kg)	186	288	880	869	885
In DM (g/kg)					
Ash	84	95	33	24	79
Crude protein	164	155	135	135	361
Crude fat	54	44	65	35	78
Crude fibre	296	290	103	50	126
NDF	550	555	283	191	283
ADF	306	301	116	54	195
ADL	22	25	23	8.0	87
Sugars	108	89			
Lactic acid	3.0	21			
Acetic acid	3.9	3.1			
Unidentified VFA		3.5			
In total nitrogen (g/kg)					
Soluble N	440	501			
Ammonium N	20	56			
pH	3.88	4.14			

Table 2
Feed intake

	Direct-cut silage		Wilted silage		SEM	Significance (*p*)		
	RSM0	RSM16	RSM0	RSM16		Silage	RSM	Interaction
	(kg DM/day)							
Silage	8.4	8.8	9.8	10.2	0.19	***	*	NS
Grain	7.8	6.6	7.8	6.6				
RSM	0	1.28	0	1.28				
Total DMI	16.4	16.9	17.9	18.3	0.20	***	*	NS
CF[a] (g/day)	3065	3274	3426	3607	52.6	***	**	NS
NDF (g/day)	6436	6773	7269	7560	107.7	***	**	NS
ADF (g/day)	3212	3502	3600	3862	55.6	***	***	NS

[a] Crude fibre.
* $p<0.05$; ** $p<0.01$; *** $p<0.001$.

The feed intake is provided in Table 2. The dry matter intake (DMI) of wilted silage was greater ($p<0.001$) than that of direct-cut silage. Total DMI also increased ($p<0.001$) with wilted silage. Silage DMI and total DMI increased ($p<0.05$) with RSM supplementation.

3.2. Milk yield and milk composition

There was a slight depression ($p<0.05$) in milk yield with wilted silage although there was no significant decrease in energy-corrected milk yield (ECM) (Table 3). Silage type had no effect on milk composition. The lactose yield was greater ($p<0.05$) with direct-cut silage and there was a tendency towards greater ($p<0.10$) protein yield with direct-cut silage. Milk urea concentration increased ($p<0.01$) with direct-cut silage.

Table 3
Milk yield and milk composition

	Direct-cut silage		Wilted silage		SEM	Significance (*p*)		
	RSM0	RSM16	RSM0	RSM16		Silage	RSM	Interaction
Milk yield (kg/day)	24.0	25.1	23.0	24.7	0.34	*	***	NS
ECM (kg/day)[a]	24.3	25.7	23.4	25.3	0.41	NS	**	NS
Fat (g/day)	1007	1074	978	1059	22.9	NS	**	NS
Protein (g/day)	784	824	755	811	10.5	°	***	NS
Lactose (g/day)	1104	1158	1052	1129	16.2	*	***	NS
Fat (g/kg)	42.4	42.9	43.0	43.1	0.63	NS	NS	NS
Protein (g/kg)	33.0	33.1	33.3	33.1	0.20	NS	NS	NS
Lactose (g/kg)	45.8	46.0	45.6	45.6	0.17	NS	NS	NS
Urea (mg/100 ml)	23.9	28.9	22.1	27.3	0.44	**	***	NS

[a] Calculated according to Sjaunja et al. (1990).
° $p<0.10$; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

Table 4
Feeding values of the feeds

	Direct-cut silage	Wilted silage	Oat	Barley	Rapeseed meal
D-value	59.9	54.7	73.1	82.3	69.9
ME (MJ/kg DM)	9.58	8.75	12.52	13.47	11.99
DCP (g/kg DM)	108	91	110	99	300
OIV (g/kg DM)	78	73	94	105	149
PVT (g/kg DM)	31	27	−18	−36	133
EPD (%)	81	78	93[a]	86[a]	46[a]

[a] Particle loss-corrected EPD-values: oat 62%, barley 76% and RSM 46%.

Milk yield increased ($p<0.001$) with RSM as well as ECM ($p<0.01$), fat ($p<0.01$), protein ($p<0.001$) and lactose yields ($p<0.001$) and milk urea concentration ($p<0.001$). RSM supplementation had no effect on milk composition.

3.3. Energy and protein utilisation

The feeding value of feeds is shown in Table 4. D-value and ME and digestible crude protein (DCP) contents were higher in direct-cut silage than in wilted silage. Despite the lower ME content, ME intake was higher ($p<0.05$) with wilted silage (Table 5). The efficiency of utilisation of ME for milk production (k_l) was better ($p<0.001$) with direct-cut silage than with wilted silage disregarding live weight change. There was no difference in k_l when live weight change was taken into account. The CP and OIV intakes were higher ($p<0.01$ or better) with wilted silage (Table 6). OIV utilisation for milk production was greater ($p<0.001$) with direct-cut silage, disregarding live weight change. When live weight change was taken into account, there was no difference in OIV utilisation.

There was a tendency ($p<0.10$) towards increased ME intake with RSM (Table 5). The efficiency of utilisation of ME for milk production (k_l) was higher ($p<0.05$) with RSM

Table 5
Energy utilisation

	Direct-cut silage		Wilted silage		SEM	Significance (p)		
	RSM0	RSM16	RSM0	RSM16		Silage	RSM	Interaction
ME (MJ/day)	180.8	185.3	186.3	189.6	1.85	*	°	NS
Live weight (kg)	530	529	536	535	2.28	**	NS	NS
LW change (kg/day)	−0.15	−0.05	0.21	0.27	0.091	**	NS	NS
k_l[a]	0.59	0.61	0.62	0.66	0.024	NS	NS	NS
k_l[b]	0.60	0.62	0.56	0.59	0.008	***	*	NS

[a] LWC included, k_l=ECM×3.14/(ME intake−ME allowance for maintenance − ME of LWC×LWC), where ME of LWC is 28 MJ/kg LW loss and 34 MJ/kg LW gain and ME allowance for maintenance is calculated according to MAFF (1975) without 5% safety margin.

[b] As above, but with LWC disregarded.

° $p<0.10$; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

Table 6
Protein utilisation

	Direct-cut silage		Wilted silage		SEM	Significance (p)		
	RSM0	RSM16	RSM0	RSM16		Silage	RSM	Interact.
CP (g/day)	2421	2799	2569	2929	36.7	**	***	NS
OIV (g/day)	1419	1528	1485	1585	15.6	***	***	NS
PVT (g/day)	51	267	60	273	11.9	NS	***	*
Protein yield/CP	0.33	0.30	0.30	0.28	0.0042	***	***	NS
OIV/ECM[a]	44.3	46.0	45.9	45.9	1.02	NS	NS	NS
OIV utilisation[b]	0.74	0.71	0.72	0.71	0.016	NS	NS	NS
OIV/ECM[c]	44.0	46.2	48.3	49.2	0.64	***	*	NS
OIV utilisation[c]	0.75	0.71	0.68	0.67	0.0098	***	*	NS

[a] (OIV intake$-3.25\times W^{0.75}$)/ECM.

[b] Protein yield/(OIV intake$-3.25\times W^{0.75}$).

[c] LWC disregarded. OIV for LWC is 138 g/kg LW loss and 233 g/kg LW gain.

$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$.

than without RSM supplementation when live weight change was disregarded. CP and OIV intakes were higher ($p<0.001$) with RSM (Table 6). OIV utilisation for milk production was better without RSM, disregarding live weight change ($p<0.05$).

3.4. Digestibility

The digestibility results are shown in Table 7. The digestibility of almost all components of the diet was improved ($p<0.05$ or better) with direct-cut silage. Crude fat was the sole component where there was only a trend ($p<0.10$) towards higher digestibility. Crude fat and hemicellulose digestibility were increased ($p<0.05$) with RSM. There was also a trend ($p<0.10$) towards higher cellulose and NDF digestibility with RSM.

Table 7
Digestibility (%)

	Direct-cut silage		Wilted silage		SEM	Significance (p)		
	RSM0	RSM16	RSM0	RSM16		Silage	RSM	Interact.
Dry matter	70.7	70.4	66.9	67.6	1.03	**	NS	NS
Organic matter	72.5	72.4	68.8	69.6	1.01	**	NS	NS
Crude protein	71.2	72.4	67.1	69.0	1.26	*	NS	NS
Crude fat	63.1	67.0	56.4	64.1	2.44	°	*	NS
Crude fibre	57.0	58.7	53.6	55.6	1.39	*	NS	NS
NDF	56.8	58.7	53.1	55.6	1.21	*	°	NS
ADF	55.5	57.1	51.8	53.1	1.21	**	NS	NS
Hemicellulose	57.9	60.5	58.2	58.2	1.22	*	*	NS
Cellulose	62.1	64.9	58.7	61.3	1.29	*	°	NS

$^{\circ}p<0.10$; $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$.

4. Discussion

4.1. Silage type

4.1.1. Silage quality

Both silages were of good quality although direct-cut silage had very low lactic acid content. There was plenty of sugars left and the concentrations of volatile fatty acids were low. Low fermentation was probably due to rather high preservative administration and the late harvest time in august when the temperature was not as high as in June and July. Protein degradation during ensiling (or wilting) was reasonably low.

Direct-cut silage had lower ash content than wilted silage as in several other studies (Castle and Watson, 1982; Ettala et al., 1982; Murphy and Gleeson, 1984; Gordon and Peoples, 1986). This is due to mineral losses in effluent (Ettala et al., 1982) or contamination of wilted silage with soil (Castle and Watson, 1982). Direct-cut silage usually has a higher fibre content (Ettala et al., 1982; Murphy and Gleeson, 1984; Gordon and Peoples, 1986; Thomas and Thomas, 1988). This is due to losses of soluble components with effluent. However, the difference in fibre content between silages was negligible in our experiment. Due to low fermentation, direct-cut silage contained more sugars than wilted silage, another contrast to earlier results (Marsh, 1979; Murphy and Gleeson, 1984).

Makoni et al. (1991) suggested that effluent losses may decrease CP content of direct-cut silage, but in our experiment the CP content of direct-cut silage was higher. No apparent reason for this is seen.

In accordance with several other experiments, wilted silage had more soluble N and ammonium N than direct-cut silage (Castle and Watson, 1982; Murphy and Gleeson, 1984; Charmley et al., 1990; Makoni et al., 1991). This difference may be due to proteolysis in the field (Anderson, 1984).

4.2. Feed intake

Wilting has increased silage intake in our experiment as well as in several others (Ettala et al., 1982; Castle and Watson, 1984; Murphy and Gleeson, 1984; Bertilsson, 1987). The increase of intake was a rather high 16%. Gordon (1996) reviewed several experiments conducted in Northern Ireland where the average increase of silage intake was 6.3%.

Castle and Watson (1984) and Bertilsson (1987) concluded that the effect of wilting on silage intake is dependent on conditions during the wilting period and that wilting would appear to have a positive influence on intake, provided that wilting conditions are good. This is in agreement with our results.

Thomas and Thomas (1988) reviewed several factors affecting silage intake. Lactic acid, digestibility and nitrogen content of silage had positive correlations with silage intake, whereas acetic acid and ammonium N were negatively correlated with silage intake.

Digestibility and crude protein content of wilted silage were lower in our experiment and the differences in fermentation products were small. Thus, it seems that these factors cannot explain the difference in intake between silages. Murphy and Gleeson (1984) and (Teller et al., 1990, 1993) also reported that the small differences in fermentation products could not explain the greater voluntary intake of wilted silage. In his review, Huhtanen (1998) discussed the effect of silage fermentation quality on silage intake and suggested that modifications of nutrients during ensiling have a minor role in influencing the silage intake, provided that fermentation quality is good.

Our results (Kokkonen et al., 2000) and the results of Teller et al. (1993) suggest that the rate of particle size reduction does not explain the difference of intake between silages because wilted silage had lower OM degradability in sacco. Nevertheless, the retention time of particles small enough to leave the rumen was shorter with wilted silage (Kokkonen et al., 2000). So it seems that higher intake was facilitated by faster passage of small particles from the rumen. Possibly, this was due to an increased number of particles leaving the rumen per rumen contraction.

Another factor which could explain the higher intake with wilted silage is the ingestion rate of the silage. (Teller et al., 1989, 1990) and De Boever et al. (1993) have reported that the animals ate wilted silage faster (min/kg DM) than direct-cut silage. A more rapid ingestion of silage might be explained by differences in physical properties, for example, by fragility of the plant cell walls. Volume of plant cells decreases as a result of dehydration. Accordingly, the animal will receive more dry matter per ingested volume unit thus facilitating faster eating.

Furthermore, Teller et al. (1993) suggested that there may be a maximum period per day that animals can spend chewing (i.e. eating and ruminating) and that wilting of silage decreases time spent for eating and increases time spent for ruminating. Increased rumination may expel air and gas pockets from feed particles, thus increasing their density and facilitating faster passage through the reticulo-omasal orifice.

Yet another factor is the mass of ingested silage. The ingested fresh mass of direct-cut silage was higher than that of wilted silage. The distension caused by increased mass may have been the factor limiting the intake of direct-cut silage (Thomas and Thomas, 1988). However, the difference of ingested mass of silage was rather small, on average 8 kg per day (fresh weight).

4.3. Milk production and milk composition

Milk yield was higher with direct-cut silage than with wilted silage, which is in accordance with several other studies (Gordon, 1981, 1987; Ettala et al., 1982; Gordon and Peoples, 1986). Gordon (1996) calculated that the average depression of milk yield with wilted silage was 3.4%. This is very close to the corresponding figure of 2.9% in our experiment. Some earlier experiments have been conducted in which wilted silage has given better milk yield (Marsh, 1979), but this has been due to a better fermentation quality of wilted silage than that of direct-cut silage in those experiments. In contrast to our results, the preliminary results of Suvitie and Rinne (1996) showed slightly higher milk yield with wilted silage in a whole lactation experiment.

The high fat content of milk in our study was probably due to a high lipogenic to glucogenic ratio in rumen VFA (Kokkonen et al., 2000), which is typical with diets based on restrictively fermented silage (Huhtanen, 1998). This ratio was slightly higher with direct-cut silage (Kokkonen et al., 2000), but without any differences of milk contents between silages. Supporting our results, wilting has not had any effect on concentrations of milk fat and lactose in some experiments (Gordon, 1981; Gordon and Peoples, 1986). However, wilting did decrease fat concentration in Gordon (1980) and there was a tendency towards decreased fat concentration in Ettala et al. (1982) and Suvitie and Rinne (1996). Marsh (1979) stated that wilting often increases fat concentration, but silages were ensiled without additives in several experiments reviewed, thereby resulting in more substantial differences in silage fermentation quality and feed intake.

The effect of silage wilting on milk protein concentration has been more variable. There has been either no effect on protein concentration (Ettala et al., 1982; Gordon and Peoples, 1986), as in our experiment, or wilting has increased protein concentration (Gordon, 1981; Castle and Watson, 1984; Murphy and Gleeson, 1984; Bertilsson, 1987; Teller et al., 1990; Martinsson, 1992). Teller et al. (1993) concluded that higher milk protein content and protein yield with wilted silage was due to increased nitrogen flow in the duodenum. They also suggested that higher molar proportion of propionate in the rumen may contribute to a higher milk protein content and protein yield. Nonetheless, although the proportion of propionate was slightly elevated with wilted silage in our experiment (Kokkonen et al., 2000), there was no corresponding elevation on milk protein content.

In accordance with Gordon and Peoples (1986), wilting decreased protein and lactose yields. However, contrary to their results, there was no effect on fat yield .

4.4. Energy and protein utilisation

As pointed out by Gordon (1996), the energy content of direct-cut silage is higher than that of wilted silage; thus, the difference of digestible energy intakes between silages is smaller than could be expected from the differences of DM intake alone.

Wilting seemed to depress energy utilisation for milk production. Decreased energy utilisation with wilting is supported by other trials (Castle and Watson, 1984; Murphy and Gleeson, 1984; Peoples and Gordon, 1989). When the live weight change was taken into account, the difference in energy utilisation disappeared. Thus, wilting increased ME partitioning towards live weight gain. This could be caused by a higher molar proportion of propionate in rumen (Ørskov, 1975).

In line with our experiment, Gordon (1996) reviewed two earlier energy balance studies where ME utilisation for milk production was not decreased with wilted silage. On the other hand, Gordon (1981) reported that β-hydroxybutyrate content in blood was higher with direct-cut silage, which was probably due to increased mobilisation of body reserves. In our experiment, the animals with direct-cut silage lost weight as well.

Castle and Watson (1982) and Murphy and Gleeson (1984) have suggested that changes in protein quality during wilting would decrease silage energy utilisation. The wilted silage in our study did contain more soluble nitrogen than the direct-cut silage did, however, rumen ammonia concentration was higher in the latter. Furthermore, direct-cut silage increased milk urea concentration, thus excreting urea was not an energy cost to those animals which were given wilted silage. Taking these data, together the decreased ME utilisation with wilted silage was not related to the higher soluble nitrogen content of wilted silage.

Bertilsson (1987) suggested that wilted silage would be a better forage for early lactation high-yielding cows. Teller et al. (1990) reported that wilted silage decreased the acetate:propionate ratio. They interpreted the result in a way which supports Bertilsson (1987). The preliminary results reported by Suvitie and Rinne (1996) lend further support to this theory.

Peoples and Gordon (1989) observed a higher non-glucogenic ratio (NGR) and a lower energy utilisation with wilted silage. In contrast to this, in our study, wilted silage decreased NGR (Kokkonen et al., 2000), which has been postulated to be correlated with better energy utilisation (Ørskov, 1975). Nevertheless, NGR values were high with both silages.

In accordance with our results, wilting has been reported to decrease silage nitrogen utilisation for milk production (milk N/N intake) (Gordon and Peoples, 1986; Peoples and Gordon, 1989). It has also been reported that wilting increased the proportion of silage nitrogen excreted in urine and that this was probably due to a higher protein degradability rate in rumen (Gordon, 1980, 1987; Peoples and Gordon, 1989). As mentioned earlier, milk urea concentration was lower with wilted silage. Therefore, taking into account that milk urea and urea in urine are closely correlated to plasma urea (Gonda and Lindberg, 1994), it seems reasonable to assume that decreased protein utilisation with wilted silage was not caused by increased excretion of nitrogen in urine.

The difference in nitrogen utilisation between silages became negligible when the live weight change was taken into consideration. Thus, wilting seemed to increase silage nitrogen partitioning towards tissue gain. Lending support to this, Gordon (1980) observed more positive N balance in animals fed with wilted silage.

4.5. Digestibility

The digestibility of organic matter and fibre in diet were lower than in earlier experiments with either direct-cut or wilted silage or both (Gordon, 1980; Gordon and Peoples, 1986; Huhtanen, 1987; Peoples and Gordon, 1989; Bertilsson, 1990; Tuori, 1992). The daily concentrate ration was usually lower in those experiments ($\approx$6–8 kg per day, except Gordon (1980) 10 kg per day and Bertilsson (1990) 9.5 kg per day) than in ours.

Low rumen pH was probably the main reason for low digestibilities. Rumen pH remained below 6 for several hours (Kokkonen et al., 2000), which has been proposed to be the critical level for fibre digestion (Mould et al., 1983). Concentrate was fed only twice a day, resulting in large fluctuations in pH. The fluctuations in rumen pH and the average rumen pH were similar between silages; therefore, these were presumably not the cause of digestibility differences between silages.

In digestibility trials in sheep or cattle, the DM or OM digestibility of wilted silage without concentrate has often been lower than that of direct-cut silage (Charmley and Thomas, 1987; Narasimhalu et al., 1989; Charmley et al., 1990; Bertilsson, 1990).

Adding concentrate to the diet tends to decrease the difference in silage digestibility (Gordon and Peoples, 1986; Gordon, 1987). Gordon (1981) and Peoples and Gordon (1989) reported no difference in digestibility of diet between silages. However, in accord with our results, Bertilsson (1990) reported a tendency towards lower digestibilities of OM and CP with wilted silage, and Teller et al. (1992) reported that wilting decreased digestibilities of OM, NDF and total N. Moreover, Gordon (1980) also observed that wilted silage decreased OM digestibility, and Gordon and Peoples (1986) reported decreased fibre digestibility with wilted silage.

In our study, the shorter retention time of particles (Kokkonen et al., 2000) due to higher intake with wilted silage was probably the main reason for the decreased digestibility. The particles of wilted silage were exposed to rumen microbe digestion for a shorter period than were the particles of direct-cut silage. The lower rate of DM degradation in rumen (Kokkonen et al., 2000) may also have contributed to the lower digestibility of wilted silage.

In contrast with this Teller et al. (1992) concluded that there was no difference in ruminal digestibility of OM, but that the post-ruminal digestibility of wilted silage was lower than that of direct-cut silage. Teller et al. (1989) observed that the apparent digestibilities of wilted silage OM and NDF were lower than those of direct-cut silage and that there was a similar difference in apparent ruminal digestibility of OM. Nevertheless, they noticed that true OM digestibility in the rumen did not differ between silages and that the difference in apparent digestibility was due to a difference in bacterial OM in the duodenum, as a result of higher efficiency of bacterial protein synthesis with wilted silage. Charmley et al. (1990) reported that wilting reduced apparent digestibility of silage in steers, but the effects on ruminal digestion were marginal. However, it must be noted that the proportion of ruminal OM digestion was 74% of total apparent digestibility for both silages in Teller et al. (1989) and the proportions of ruminal NDF digestion were 93 and 101% of total apparent digestibility for direct-cut and wilted silage, respectively. Thus, with regard to fibre in particular, the role of lower tract digestion is very small.

4.6. Protein content of concentrate

Raising protein content of concentrate increased silage intake in our experiment as well as in most ad libitum feeding trials reviewed by Tuori (1992). Small and Gordon (1990) calculated that the increase of total DMI was 0.10 kg for every 100 g increase in supplementary crude protein intake (SCPI). In earlier experiments with RSM, conducted in our institute, the corresponding increase was on average 0.14 kg for every 100 g increase in SCPI (Tuori, 1992), and in this study it was 0.15 kg for every 100 g increase in SCPI. Higher intake can be a result of more efficient cell wall digestion (Oldham, 1984) when intake is limited by rumen fill, but some recent results suggest that post-ruminal metabolism may also influence DM intake (Huhtanen, 1998).

The effect of RSM on milk yield was probably largely due to higher ME intake. This is in agreement with the results reported by Aston et al. (1994). There may have also been direct effects of protein, such as increased microbial protein synthesis in the rumen, increased flow of amino acids to the duodenum and a more balanced amino acid mixture (Tuori, 1992). A more balanced amino acid mixture may lead to improved utilisation of energy for milk production (Huhtanen, 1998). There was a tendency towards higher k_l values with RSM in our experiment.

The response of milk yield to a higher protein concentration in the concentrate (0.36 kg milk for every 10 g increase in the protein concentration of concentrate) was also well in line with earlier reports. In earlier studies, the increase in milk yield has been in the range of 0–0.51 kg milk for every 10 g increase in the protein concentration of concentrate using soyabean meal (Thomas and Rae, 1988). Tuori (1992) also reviewed earlier experiments and the corresponding figure was 0.22 kg milk for every 10 g increase in the protein concentration of concentrate. In his own experiments using RSM, the response was on average 0.28 kg milk for every 10 g increase in the protein concentration of concentrate.

Huhtanen (1998) reviewed 13 recent Finnish studies. The mean response was 1.05 kg milk and 39.4 g milk protein per kilogram of RSM (fresh). Corresponding responses in our experiment were 0.97 kg milk and 33.2 g milk protein per kilogram of RSM.

As in several other experiments (Gordon, 1979, 1980; Gordon and Peoples, 1986; Peoples and Gordon, 1989; Aston et al., 1994; Huhtanen, 1998), the effect of the protein content of concentrate on milk composition was minor. Daily yields of fat, protein and lactose increased with higher protein content of concentrate. This is in agreement with Gordon and Peoples (1986) and Peoples and Gordon (1989), with the exception that in their experiments fat yield was not affected.

It has been shown that wilting of silage may increase the flow of microbial N in the duodenum (Teller et al., 1992). Consequently, one may expect a greater milk yield response to protein supplementation with direct-cut silage. Yet Gordon (1980) and Peoples and Gordon (1989) observed higher response to protein supplementation with wilted silage than with direct-cut silage. Although there were no significant interactions in our experiment between silages and RSM levels, it is noteworthy that the response to increased OIV intake was higher with wilted silage. The responses were 1.70 kg milk for every 100 g increase in OIV with wilted silage and 1.01 kg milk for every 100 g increase in OIV with direct-cut silage. It is possible that the greater response to protein supplementation with wilted silage was due to a greater increase in digestibility of diet as the protein concentration of the diet was increased (Gordon and Peoples, 1986), even though this interaction was not statistically significant in our experiment.

RSM increased only the digestibilities of crude fat and hemicellulose. Small responses to RSM supplementation in diet digestibility are in line with the results reviewed by Huhtanen (1998). As an average of 13 comparisons, RSM supplementation had no effect on total OM or NDF digestibilities. Furthermore, Aston et al. (1994) reported that CP concentration of concentrate (12–24% DM basis) had no effect on diet digestibility, excluding an improvement in nitrogen digestibility.

There was a tendency, however, towards improved NDF and cellulose digestibility. This is in agreement with the results of Peoples and Gordon (1989). Shorter FMRT with RSM (Kokkonen et al., 2000), illustrating faster particle breakdown, lends some support to this theory. The higher fibre digestibility may be due to improved ruminal digestion facilitated by improved efficiency of microbial synthesis with increased peptide supply (Nocek and Russell, 1988). The tendency towards higher ammonia concentration may not be so important for the fibre-digesting microbes (McAllan et al., 1988).

RSM improved the efficiency of ME utilisation for milk production. This is in accord with several other experiments. Improved energy utilisation has been reported by Huhtanen (1993) using fish meal as a protein source, Bertilsson et al. (1994) using RSM and Sutton et al. (1996) using high protein levels (20, 30 and 40% CP in concentrate DM) and soyabean meal as a main protein source.

The utilisation of OIV decreased with RSM. Lowered nitrogen utilisation with increasing protein supply has been observed in previous experiments (Burgess and Nicholson, 1984; Gordon and Peoples, 1986; Peoples and Gordon, 1989). However, the protein content of concentrate without RSM was, most likely, so low that amino acid supply was limiting milk production. Gordon (1979) observed that milk production improved linearly when DCP supply was 40–80 g/kg milk. DCP supply in our experiment was within that range.

5. Conclusions

Wilting of silage increased the intake of silage dry matter, but lowered the digestibility of diet. Milk production was not increased with wilted silage diets, and energy deposition into tissues was higher with wilted silage diets than with direct-cut silage diets.

Lowered diet digestibility with wilted silage can be, at least partly, explained by the shorter exposure of particles to the digestion of rumen microbes.

Consistent with results reported in earlier experiments, rapeseed meal supplementation increased silage intake and milk production with both silages.

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