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Effects of supplementation of a forage-only diet with wheat bran and sugar beet pulp in organic dairy cows

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Abstract

Although levels of concentrate supplementation are generally lower in organic as compared with conventional dairy cows, forage-only (FO) diets are not very common in organic dairy cows because of the resulting limited dry matter intake (DMI) and lower milk production. However, from the perspective of net food production, FO diets or forage diets supplemented only with by-products from the food processing industry, offer considerable potential because they do not compete with humans for food. The aim of the present study was therefore to investigate the effects of adding a mixture of wheat bran and dried sugar beet pulp [0.56:0.44 on a dry matter (DM) basis] to a FO diet on DMI, milk production, chewing activity and production efficiency. Seventeen multiparous and three primiparous mid-lactation Holstein cows were randomly assigned to one of two treatments, receiving either a FO mixture with hay and grass silage in equal proportions (FO) or the same forage mixture supplemented with a mixture of wheat bran and dried sugar beet pulp at a rate of 25% of dietary DM (25%BP). The experiment was conducted in a change-over design with two experimental periods of 7 and 6 weeks, respectively. Overall, feeding the 25%BP diet increased DMI and energy-corrected milk (ECM) yield by 1.8 kg d^{-1} as compared with cows fed FO. Feed conversion efficiency (kg ECM per kg DMI) and energy efficiency (kg ECM per 10 MJ net energy for lactation intake) were higher in FO, but cows fed FO were in a slightly negative energy balance and also tended to have a higher mobilization of body tissues as compared with cows fed 25%BP. In comparison with FO, cows receiving 25%BP showed less chewing activity per kg DMI or per kg neutral detergent fiber ingested. In conclusion, results from this feeding trial showed that adding wheat bran and dried sugar beet pulp to a FO diet increased DMI and milk yield and improved the energy balance when compared with a FO diet, although the magnitude of the milk yield response was lower than expected.

Key words: concentrate, grass-based, low input, by-product, milk, efficiency

Introduction

The tremendous increases in annual milk performance per cow over the past few decades, especially in industrialized countries, has made it necessary to increase the nutrient density of forage-based diets by increasing concentrate supplementation to meet the higher nutrient requirements (Eastridge, 2006; Knaus, 2009). In general, the amount of concentrates fed to organic dairy cows is, due to regulatory restrictions and higher concentrate prices, lower than the amount fed to conventional cows. However, feeding forage-only (FO) diets is also not very common in organic dairy production (Nicholas et al., 2004; Rosati and Aumaitre, 2004). This is probably because cows fed FO diets usually show a reduced dry matter intake (DMI), resulting in lower milk yields. Earlier studies suggest that DMI for FO diets is limited to about 17–18 kg dry matter (DM) day, and that daily milk yields do not exceed 25 kg during the winter feeding period (Gruber et al., 1999; Steinshamn and Thuen, 2008; Randby et al., 2012). Several authors showed that increasing the level of concentrates in the diet had positive effects on DMI and milk yield (Ferris et al., 2001; Steinshamn and Thuen, 2008; Randby et al., 2012). However, in these studies the concentrate components were mainly starchy grains, which are potentially edible for humans.

In order to increase overall food availability and to improve the sustainability of livestock production, the amount of such potentially human-edible feedstuffs (e.g., grains or pulses), or of feedstuffs derived from cropland should be reduced in livestock diets (Eisler et al., 2014; Schader et al., 2015; van Zanten et al., 2016). Future strategies aiming at increased sustainability in livestock production might therefore favor grassland-based ruminant systems, as these do not necessarily rely on potentially human-edible inputs (Schader et al., 2015). In addition to forage from grassland, the role of by-products from the food-processing industry as nutrient-dense feedstuffs, which are not in competition with the human food supply is often pointed out (FAO, 2011; Wilkinson, 2011; Schader et al., 2015). Ertl et al. (2016) showed that a mixture of 56% wheat bran and 44% dried sugar beet pulp (on a DM basis) could replace commonly used grains (25% of diet DM) in mid-lactating dairy cows without impairing milk performance, while strongly increasing net food production. However, only limited data are available on the potential benefits of adding these fibrous by-products to a FO diet. Therefore, the aim of the present study was to investigate the effects of adding wheat bran and dried sugar beet pulp to a diet consisting solely of conserved grass (hay and grass silage at a ratio of 0.5:0.5 on a DM basis) on DMI, milk performance, chewing activity, and efficiency parameters. In Austria, sugar beets and wheat are two of the top five produced commodities with an annual production of nearly 3 and 1.5 million tons, respectively. Presuming a yield of about 20% by-products during the processing of these two commodities (Fadel, 1999), dried sugar beet pulp and wheat bran are feedstuffs which are available in high quantities.

Material and methods

Experimental design and animals

The feeding trial was conducted in a change-over design at the organic dairy farm of the Secondary Agricultural and Forestry College Ursprung (570 m above sea level, 1250 mm annual precipitation, 8.5°C mean annual temperature) between November 2015 and February 2016. Cows were housed in a cubicle housing system with Calan gates (American Calan Inc., Northwood, NH) for individual feeding. Seventeen multiparous (2^{nd}–9th lactation) and three primiparous Holstein cows were randomly allotted to two treatment groups of ten cows each, according to their average (± standard deviation) milk yield (25.7 ± 6.2 kg), days in milk (134 ± 113), number of lactations (3.8 ± 2.3) and body weight (BW, 682 ± 63 kg) at the beginning of the trial. The experiment lasted for 14 weeks, during which week 1 was used for adaptation to the Calan gates, followed by two experimental periods lasting for 7 and 6 weeks, respectively. The first 2 weeks of each experimental period were used for adaptation to the diet, and measurements were taken in the remaining 5 and 4 weeks, respectively. Immediately after the end of the first experimental period, dietary treatments were switched between the two groups and the adaptation period for the second experimental period began. One late-lactating cow was culled during the second run (week 11) of the experiment for farm management reasons. During the trial, no invasive procedures were performed on the animals and the animals were kept according to the European regulations on organic farming (European Commission, 2008).

Feeding regime

A FO mixture and a total mixed ration (TMR) consisting of FO plus a mixture of industrial by-products (wheat bran and dried sugar beet pulp, 0.56:0.44 on DM basis) at a rate of 25% of the diet DM (25%BP), were compared in this study. The forage mixture consisted of first-cut grass silage and first-cut hay in equal proportions of the diet DM. Grass silage was derived from 8.5 ha of perennial clover–grass (approximately 55% clover and 45% grasses) and 3.5 ha of permanent grassland (about 50% grasses, 25% legumes and 25% herbs), whereas hay was derived from 6.5 ha of permanent grassland and 2 ha of perennial grassland (approximately 60% grasses, 30% legumes and 10% herbs). The mixture of wheat bran and dried sugar beet pulp was obtained premixed from a commercial feed mill in ground form (hammer milled). The ingredients, as well as the chemical composition of the diets, are shown in Table 1. Diets were prepared as TMR once a day and offered twice daily (05.00 and 15.00 h) in an amount that allowed about 5–10% feed refusals. Prior to the start of the experiment, all cows received grass silage, hay and corn silage at a ratio of about 0.55:0.30:0.15 on a DM basis for *ad libitum* intake, plus up to 4.5 kg (as fed basis) of commercial concentrates via an automatic feeding station (based on milk yield of the previous week).

Data collection and analytical procedures

Milk yield was recorded digitally during each milking (06.00 and 16.30 h) in a 2 × 3 herringbone milking parlor. Calan gates were used to determine individual feed intake during four 6-day recording periods in weeks 4, 8, 11 and 14 of the experiment. The DMI was calculated as the differences in the DM between feed provision and feed refusals. DM content of fresh diets and feed refusals was determined four times during each recording period via air-forced oven drying at 104°C for 32 h. In each of these recording periods, the following feed samples were taken for analysis of the chemical composition: two samples from the fresh mixtures and one

Table 1. Ingredients and chemical composition (± standard deviation) of diets [% of dry matter (DM), unless stated otherwise].

Item	Diet[1]	
	FO	25%BP
Ingredients		
Grass silage, first-cut	49.5	37.0
Hay, first-cut	49.5	37.0
Wheat bran	0.0	14.0
Dried sugar beet pulp	0.0	11.0
Mineral and vitamin premix[2]	1.0	1.0
Chemical composition		
DM (% of fresh matter)	41.3 ± 3.1	47.3 ± 2.4
Crude protein	14.6 ± 0.4	14.4 ± 0.6
uCP[3]	14.2 ± 0.3	15.0 ± 0.4
Ruminal N balance[4] (g kg^{-1})	0.6 ± 0.6	−0.9 ± 0.4
Ether extracts	3.1 ± 0.1	3.1 ± 0.2
Starch	–	2.4 ± 0.4
aNDFom[5]	48.0 ± 1.5	48.1 ± 2.0
Acid detergent fiber	31.0 ± 1.8	29.1 ± 1.2
Acid detergent lignin	3.9 ± 0.7	3.9 ± 0.7
Net energy for lactation (MJ kg^{-1} of DM)	5.99 ± 0.07	6.87 ± 0.12

[1] FO, Forage-only; 25%BP, forage plus 25% industrial by-products in the diet DM.
[2] Contained 16% Ca, 10% Na, 6% P, 5% Mg, 6 g of Zn/kg, 4 g of Mn/kg, 4 g of vitamin E/kg, 1 g of Cu/kg, 0.1 g of I/kg, 50 mg of Se/kg, 45 mg of |Co/kg, 1,000,000 IU of vitamin A/kg and 100,000 IU of vitamin D_3/kg.
[3] Utilizable crude protein at the duodenum; uCP = 7.84 × MJ ME + 0.43 × g crude protein (GfE, 2001).
[4] Ruminal N balance = [crude protein (g)−uCP (g)]/6.25 (GfE, 2001).
[5] Amylase-treated neutral detergent fiber expressed on an ash-free basis.

sample of feed refusals for each group (each sample was pooled over two consecutive days). Samples were immediately vacuum packed and stored at −20°C until analysis in a commercial laboratory at the end of the experiment, using the methods described in VDLUFA (1993). Content of utilizable crude protein (uCP) at the duodenum, ruminal nitrogen (N) balance, as well as net energy and uCP requirements for maintenance and lactation were calculated according to the methods of the German Society of Nutrition Physiology (GfE, 2001). During the four DMI recording periods, cows were weighed immediately after two consecutive milkings on a digital livestock platform scale and the means were taken as the cows' BW. Each week, individual milk samples were taken during two consecutive milkings and conserved with Bronysolv (ANA.LI.TIK, Vienna, Austria). Samples were then analyzed in a commercial laboratory for fat, protein, lactose and milk urea concentrations, using Milkoscan (Foss Electric, Hillerød, Denmark). Chewing activity was documented using RumiWatch noseband sensors (RumiWatch System, ITIN + HOCH GmbH, Liestal, Switzerland). During each DMI recording period, five cows per treatment were equipped with these halters, that determine the cows' chewing activity via pressure changes in an oil-filled tube at a frequency of 10 Hz. Raw data were stored on an internal storage device, downloaded onto a laptop after each 6-day recording period, and analyzed on a 24-h basis using RumiWatch converter 0.7.3.2 (ITIN + HOCH GmbH, Liestal, Switzerland).

Statistical analysis

Data were analyzed using repeated-measures mixed models (PROC MIXED) of the statistical software package SAS 9.4 (SAS Institute Inc., Cary, NY, USA), including cow within treatment (FO and 25%BP) as random component and treatment, as well as sequence of treatments as fixed effects. For analysis of milk production data, the fixed effect of lactation group (≤2 and >2) was also included. In addition, the following continuous effects were considered in the model: milk yield (except for analysis on milk yield and chewing activity), day of lactation (except for analysis on chewing behavior), BW (for feed and nutrient intake, milk performance, and chewing behavior), and DMI for daily chewing activity in minutes or beats. Average milk performance in the week before the start of the experiment was included as a covariate for milk yield. As proposed by Littell et al. (1998), the Baysian information criterion (fit statistic) value closest to zero was taken to select the best covariance structure. Results are presented as least square means for treatment and differences were taken as significant for $P \leq 0.05$ and considered as trend if $0.05 < P \leq 0.10$.

Results and Discussion

Feed and nutrient intake

Adding 25% by-products to a FO mixture increased total daily DMI and DMI as percentage of BW by about 1.8 kg and 0.26% points, respectively, but resulted in lower forage DMI (Table 2). An increased total DMI with a higher concentrate proportion is in agreement with earlier results (e.g., Waldo, 1986; Ferris et al., 2001), but the decrease in the forage DMI with the addition of concentrates was more profound than in other studies conducted with forages fed separately from concentrates. For example, when comparing DMI at concentrate levels of 0, 25 and 50% of dietary DM, fed separately from forages, Gruber et al. (1991) found a mean reduction of the forage DMI per additional kg of concentrate DM of 0.34 kg kg^{-1} for Holstein cows. Comparing different concentrate levels in a TMR, Ferris et al. (2001), however, observed a decline in the forage DMI of 0.4 kg DM when increasing the concentrate proportion in the diet DM from 0.1 to 0.3. The relatively high reduction

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Table 2. Daily dry matter (DM), nutrient, and energy intake of cows fed either a forage-only (FO) diet or a forage mixture plus 25% by-products in the diet DM (25%BP).

Item	Diet		SEM	*P*-value
	FO	25%BP		
DM intake (kg day^{-1})				
Forage	17.2	14.1	0.23	<0.001
By-product concentrates	–	4.8	0.10	
Total	17.2	19.0	0.35	0.002
Nutrient intake (kg day^{-1})				
Crude protein	2.53	2.75	0.05	0.003
Utilizable crude protein at the duodenum	2.47	2.86	0.05	<0.001
aNDFom[1]	8.34	9.20	0.17	0.001
Acid detergent fiber	5.39	5.58	0.05	0.007
Acid detergent lignin	0.65	0.73	0.01	<0.001
Starch	0.00	0.43	0.01	<0.001
Ether extracts	0.54	0.59	0.01	0.004
Non-fiber carbohydrates	3.99	4.63	0.08	<0.001
Total DM intake (% of body weight)	2.61	2.87	0.05	<0.001
aNDFom intake, (% of body weight)	1.26	1.39	0.02	<0.001
Energy (MJ of NE_L)	104	131	2.3	<0.001

[1] Amylase-treated neutral detergent fiber expressed on an ash-free basis.

in the forage DMI of the 25%BP group in the present study might be due to the high forage intake of over 17 kg DM in the FO group. Several studies showed a strong correlation between intake of forage when fed alone and reduction of forage DMI per kg additional concentrate (Dixon and Stockdale, 1999; Huhtanen et al., 2008). In addition, the high neutral detergent fiber (NDF) content of the wheat bran and dried sugar beet pulp mixture compared with grain-based concentrates did not result in a lower NDF content of the 25%BP diet compared with the FO diet (Table 1). This might also contribute to a higher reduction of forage DMI as compared with other studies because total NDF content of the diet is a limiting factor for DMI (Allen, 2000).

Due to the limited nutrient density, a high DMI presents one of the biggest challenges in FO feeding systems (Leiber et al., 2015). However, only limited recent data are available on DMI of dairy cows fed conserved grass only, as aggressive selection for high milk performance has made it necessary to include concentrates and corn silage in rations for dairy cows in order to meet the high nutritional requirements (Knaus, 2009; Zebeli et al., 2010). Forage intakes comparable with results in this study were found by Randby et al. (2012) for cows fed early-harvested grass silage only (16.9 kg) and by Gruber et al. (1999) in cows fed hay from permanent grassland with four cuttings per year (17.3 kg). Steinshamn and Thuen (2008) observed DMI of 14.8 and 13.9 kg when feeding grass–red and –white clover silages only. Conducting a meta-analysis including 497 grass silage-based diets supplemented with 0–18.4 kg concentrates, Nousiainen et al. (2009) found a maximum forage DMI of 17.4 kg. Thus, this restricted DMI for FO diets (about 17–18 kg) strongly limits potential milk performance in these systems.

Differences in DMI and in chemical composition (Table 1) resulted in a higher intake of all nutrients and energy for cows fed the 25%BP diet compared with FO (Table 2). The higher intake of energy (+26%) and uCP (+16%) for cows receiving the 25%BP diet is especially crucial, because energy and protein are the most critical factors with regard to milk yield (Brun-Lafleur et al., 2010) and the positive balances in energy and uCP are of particular relevance to cows' reproduction (Zebeli et al., 2015).

Chewing behavior

Total daily eating and ruminating time (min day^{-1}) did not differ between treatments (Table 3). The total chewing activity found in this study was very high as compared with other studies. Analyzing chewing activity of 99 dietary treatments for high-producing dairy cows, Zebeli et al. (2006) for example found a maximum chewing activity of 969 min day^{-1} and Mertens (1997) suggested that the maximum time dairy cows can spend chewing per day was about 1000 min. Thus, whereas for high-producing dairy cows the challenge is to ensure adequate provision of physically effective fiber to maintain ruminal pH and avoid milk fat depression (Zebeli et al., 2010), the high (forage) NDF contents of forage-based diets (e.g., 48% of DM in the FO diet) bring the cows to their limit with regard to daily chewing activity and hence limit their DMI and milk production.

Adding 25% by-products to a FO diet decreased eating and ruminating time per kg DMI and kg NDF ingested,

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Table 3. Chewing activity of cows fed either a forage-only diet (FO) or a forage mixture plus 25% by-products in the diet dry matter (DM; 25%BP).

	Diet			
Item	**FO**	**25%BP**	**SEM**	***P*-value**
Eating time				
min per day	417.6	398.0	12.7	0.285
min per kg of DM	24.7	21.5	0.9	0.012
min per kg of aNDFom[1]	51.3	44.5	1.8	0.010
min per kg of aNDFom from forage	51.3	59.7	2.1	0.007
Ruminating time				
min per day	586.4	579.9	9.1	0.623
min per kg of DM	35.4	31.0	1.1	0.008
min per kg of aNDFom	73.4	64.1	2.2	0.006
min per kg of aNDFom from forage	73.4	86.1	2.6	0.002
Total chewing activity (min day^{-1})	1004.3	977.4	15.0	0.217

[1] Amylase-treated neutral detergent fiber expressed on an ash-free basis.

despite the similar NDF content of the 25%BP diet as compared with the FO diet (Table 3). This lower NDF effectiveness can be explained by the lower mean particle size and higher NDF digestibility of wheat bran and dried sugar beet pulp as compared with forage (Bradford and Mullins, 2012) and is in agreement with our earlier work where we observed that providing additional NDF in a high-forage diet by replacing grain concentrates with wheat bran and dried sugar beet pulp did not increase chewing activity per kg DMI (Ertl et al., 2016).

Milk production, nutrient balances and efficiency parameters

The addition of 25% by-products to a FO diet increased milk yield (+1.7 kg or 8.5%) and there was also a trend toward increased energy-corrected milk (ECM) yield (+1.8 kg or 8.7%), whereas milk protein, fat and urea content were not affected by the treatment (Table 4). Milk lactose content was higher for cows fed 25%BP, but the magnitude of the differences (0.5 g kg^{-1}) was very small. Milk yield in cows fed the FO diet was slightly lower than observed by Steinshamn and Thuen (2008) for organic dairy cows fed white and red grass–clover silages only (22.1 and 22.0 kg). This might be explained by the advanced stage of lactation of the cows in the present study, because earlier stages of lactation physiologically support higher milk yields instead of the accumulation of body reserves. However, due to the high milk fat and protein contents in the present study, ECM yield for cows fed forage only was on the same level as in Steinshamn and Thuen (2008). Randby et al. (2012) also obtained higher milk and ECM yields for cows fed grass silage only (23.7 and 23.4 kg, respectively) compared with cows fed the FO diet in the present study, which again can be explained by the differences in the stage of lactation.

Increased milk production with increased energy supply after supplementing forage with concentrate feeds is in agreement with earlier studies (Ferris et al., 2001; Randby et al., 2012). Coulon and Remond (1991) stated that for mid-lactating dairy cows, milk production shows a curvilinear response to increased energy supply. However, looking at milk yield changes during the course of each experimental period, it can be seen that the higher milk yield for cows fed the 25%BP diet was mainly due their ability to support and maintain their level of milk production during the first weeks of the first experimental period. Between the week before feeding the experimental diets (week 0) and the first week after the 2-week adaptation period (week 3), cows fed 25%BP kept their milk production nearly constant, whereas the milk production of the cows fed the FO diet decreased strongly during this time (Fig. 1), because of the lowered DMI and a slight energy deficit observed in these animals. However, providing additional energy by switching from the FO diet to the 25%BP diet in the second experimental period (right diagram in Fig. 1) did not increase milk yield as would have been expected from the curvilinear response in milk production to increased energy supply (Coulon and Remond, 1991). One possible explanation could be that during experimental period 2, cows were in a later lactation stage, when the energy excretion through the milk becomes less responsive compared with the energy deposition in adipose tissues. On the other hand, the cows fed the 25%BP diet might have compensated for the energy deficit and BW loss during restricted feeding conditions when fed FO in experimental period 1. Garnsworthy (1988) argued that cows try to keep a target level of energy reserves, which would result in increased partitioning of nutrients toward body reserves when energy supply is increased after a period of lower energy supply. It has been shown that cows fed a high-concentrate diet after a low-concentrate diet tend to have a lower milk yield compared with

Table 4. Milk production traits, body weight (BW) change, nutrient balances, and efficiency parameters of cows fed either a forage-only (FO) diet or a forage mixture plus 25% by-products in the diet dry matter (DM; 25%BP).

	Diet			
Item	**FO**	**25%BP**	**SEM**	***P*-value**
Milk parameters				
Milk yield (kg day^{-1})	19.8	21.5	0.5	0.020
Energy-corrected milk (ECM) yield (kg day^{-1})	20.8	22.6	0.7	0.066
Protein (g kg^{-1})	31.7	32.7	0.7	0.307
Fat (g kg^{-1})	45.3	45.3	1.2	0.986
Urea (mg/100 mL)	18.5	18.9	0.5	0.626
Lactose (g kg^{-1})	46.3	46.8	0.2	0.021
BW change (kg day^{-1})	−0.44	−0.05	0.16	0.095
Energy balance (%)	98.1	122.3	2.1	<0.001
uCP[1] balance (%)	126	140	2.6	0.002
Ruminal nitrogen balance (g day^{-1})	9.7	−16.9	0.4	<0.001
Feed conversion efficiency (kg ECM/kg DM intake)	1.21	1.13	0.01	<0.001
Energy efficiency (kg ECM/10 MJ NE_L intake)	2.03	1.63	0.04	<0.001
Nitrogen efficiency (milk N in % of N intake)	24.2	24.1	0.7	0.916

[1] Utilizable crude protein at the duodenum (GfE, 2001).

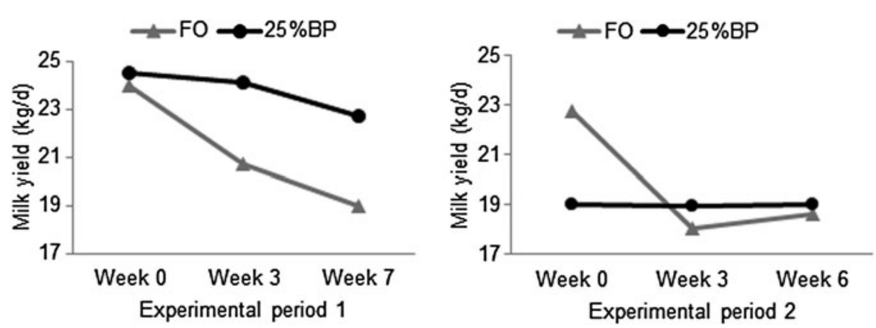

Figure 1. Changes in average daily milk yield of cows fed a forage-only diet (FO) or a forage mixture plus 25% by-products in the diet dry matter (DM) (25%BP) during experimental periods 1 (left) and 2 (right), with week 0 as the week before feeding experimental diets (in period 1) or before changing experimental diets (period 2).

cows continuously fed a high-concentrate diet (Friggens et al., 1998). However, whereas cows fed the FO diet in the present study tended to have a higher mobilization of body reserves, cows fed the 25%BP diet did not show a significant gain in BW (Table 4). Thus, regaining body reserves is unlikely to be the explanation for the absence of the milk yield response with increased feeding level for cows fed the 25%BP diet in experimental period 2. However, it should be pointed out that BW changes might not adequately reflect changes in the body energy balance and that for change-over designs with short experimental periods, changes in BW need to be interpreted with care (Huhtanen and Hetta, 2012).

Considering the highly positive energy balance for cows fed the 25%BP diet (122%), it remains unclear why these cows did not show any BW gain. The strong mobilization of body reserves under the FO diet indicates that, although their calculated energy balance was close to 100%, these cows were not fed according to their respective requirements, because under adequate feeding conditions, mid-lactating dairy cows already start regaining BW (Roche et al., 2009). Normally, a negative energy balance occurs especially in early lactation when it can have strongly negative effects on animal health (Collard et al., 2000). Although it is unlikely that a mobilization of body reserves at this stage of lactation is associated with effects similar to those of a negative energy balance at the beginning of lactation, no conclusions on potential long-term effects of feeding a FO diet can be drawn from the results of this study. The higher energy balance for the 25%BP diet resulted in decreased energy efficiency (kg ECM/10 MJ NE_L intake) as compared with the FO diet. However, this energy efficiency does not take the mobilization of body reserves for cows fed FO into consideration.

Due to the higher uCP content of the 25%BP diet in combination with the higher DMI, the uCP balance was higher for the 25%BP diet as compared to the FO diet,

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but the balance was clearly above 100% for both treatments. As a result of the relatively high N supply, the efficiency of nitrogen use (milk N in % of N intake) was at about 24% somewhat low (Powell et al., 2010). Supplementing a FO diet with a mixture of wheat bran and dried sugar beet pulp to at a rate of 25% resulted in a decreased feed conversion efficiency (FCE, kg ECM per kg DMI). This was mainly because of the low milk yield response to the increased DMI from the 25%BP diet. The FCE has considerable effects on the profitability of dairy production, because feed costs account for a high percentage of the total costs in dairy businesses (Beever and Doyle, 2007). Thus, although the 25%BP diet did slightly increase milk yield as compared to the FO diet, it did not increase profitability under the current feed prices. This is in agreement with on-farm results, where the lower milk performance of farms where little or no concentrates are fed did not lead to a reduced marginal income per cow (Ertl et al., 2014). Not considering the potential negative long-term effects of the mobilization of body reserves under the FO diet, results of this study suggest that feeding mid-lactating dairy cows a FO diet might economically be at least competitive to a diet including 25% industrial by-products. However, long-term studies would be needed to draw clear conclusions, because it has been shown that short-term change-over trials might lead to misleading conclusions on long-term responses of milk production to increased concentrate proportions (Huhtanen and Hetta, 2012). In addition, the profitability of different feeding strategies also strongly depends on the farm's circumstances (e.g., availability of land for home-grown forages and climatic conditions), which makes it difficult to draw conclusions on the economic impacts of different feeding strategies for individual farms based on the results of this feeding trial. The overall level of FCE observed in this study (1.13–1.21) was low as compared with results reported in other studies, which can be explained mainly by the high-forage percentage (75 and 100%, respectively), the high dietary NDF content, and the relatively low milk yield as compared with other studies summarized in Britt et al. (2003).

Conclusions

Results from this study showed that a reasonably high milk yield can be obtained from feeding only forage to mid-lactating dairy cows. However, cows fed FO tended to have a higher mobilization of body tissue, which in the long-term might have negative consequences for cows' reproductive traits. Adding a mixture of wheat bran and dried sugar beet pulp at a rate of 25% of dietary DM to a FO diet increased DMI and milk yield in a short run, and helped to maintain a positive energy balance in mid-lactating cows. Cows fed the FO diet seemed to reach the upper limit of potential chewing activity per day (>1000 min), suggesting that this is a limiting factor for DMI in cows fed FO. Chewing activity per kg DMI as well as per kg NDF ingested was lower in the 25%BP diet as compared to the FO diet. The levels for FCE and nitrogen efficiency were generally low for both diets, highlighting a critical issue in forage-based and fiber-rich diets for dairy cows.

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References

Allen, M.S. 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. Journal of Dairy Science 83: 1598–1624.

Beever, D.E. and Doyle, P.T. 2007. Feed conversion efficiency as a key determinant of dairy herd performance: A review. Australian Journal of Experimental Agriculture 47:645–657.

Bradford, B.J. and Mullins, C.R. 2012. Invited review: Strategies for promoting productivity and health of dairy cattle by feeding nonforage fiber sources. Journal of Dairy Science 95:4735–4746.

Britt, J.S., Thomas, R.C., Speer, N.C., and Hall, M.B. 2003. Efficiency of converting nutrient dry matter to milk in Holstein herds. Journal of Dairy Science 86:3796–3801.

Brun-Lafleur, L., Delaby, L., Husson, F., and Faverdin, P. 2010. Predicting energy × protein interaction on milk yield and milk composition in dairy cows. Journal of Dairy Science 93:4128–4143.

Collard, B.L., Boettcher, P.J., Dekkers, J.C.M., Petitclerc, D., and Schaeffer, L.R. 2000. Relationships between energy balance and health traits of dairy cattle in early lactation. Journal of Dairy Science 83:2683–2690.

Coulon, J.B. and Remond, B. 1991. Variations in milk output and milk protein-content in response to the level of energy supply to the dairy-cow – a review. Livestock Production Science 29: 31–47.

Dixon, R.M. and Stockdale, C.R. 1999. Associative effects between forages and grains: Consequences for feed utilisation. Australian Journal of Experimental Agriculture 50: 757–773.

Eastridge, M.L. 2006. Major advances in applied dairy cattle nutrition. Journal of Dairy Science 89:1311–1323.

Eisler, M.C., Lee, M.R.F., Tarlton, J.F., Martin, G.B., Beddington, J., Dungait, J.A.J., Greathead, H., Liu, J.X., Mathew, S., Miller, H., Misselbrook, T., Murray, P., Vinod, V.K., Van Saun, R., and Winter, M. 2014. Steps to sustainable livestock. Nature 507:32–34.

Ertl, P., Knaus, W., and Steinwidder, A. 2014. Comparison of zero concentrate supplementation with different quantities of concentrates in terms of production, animal health, and profitability of organic dairy farms in Austria. Organic Agriculture 4:233–242.

Ertl, P., Zebeli, Q., Zollitsch, W., and Knaus, W. 2016. Feeding of wheat bran and sugar beet pulp as sole supplements in high-forage diets emphasizes the potential of dairy cattle for human food supply. Journal of Dairy Science 99:1228–1236.

European Commission 2008. Commission Regulation (EC) No 889/2008 of 5 September 2008. Available at Web site http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=OJ%3AL%3A2008%3A250%3ATOC (verified 30 April 2016).

Fadel, J.G. 1999. Quantitative analyses of selected plant by-product feedstuffs. A Global perspective. Animal Feed Science and Technology 79:1225–1233.

FAO 2011. World Livestock 2011 – Livestock in Food Security. FAO, Rome.

Ferris, C.P., Gordon, F.J., Patterson, D.C., Kilpatrick, D.J., Mayne, C.S., and McCoy, M.A. 2001. The response of dairy cows of high genetic merit to increasing proportion of concentrate in the diet with a high and medium feed value silage. Journal of Agricultural Science 136:319–329.

Friggens, N.C., Emmans, G.C., Kyriazakis, I., Oldham, J.D., and Lewis, M. 1998. Feed intake relative to stage of lactation for dairy cows consuming total mixed diets with a high or low ratio of concentrate to forage. Journal of Dairy Science 81:2228–2239.

Garnsworthy, P.C. 1988. The effect of energy reserves at calving on performance of dairy cows. In P.C. Garnsworthy (ed.). Nutrition and Lactation in the Dairy Cow. Butterworths, London/Boston. p. 157–170.

GfE 2001. Empfehlungen zur Energie- und Nährstoffversorgung der Milchkühe und Aufzuchtrinder. DLG-Verlag, Frankfurt/Main.

Gruber, L., Steinwender, R., Krimberger, K., and Solkner, J. 1991. Roughage intake of simmental, brown Swiss and Holstein Friesian cows fed rations with 0-percent, 25-percent and 50-percent concentrates. Livestock Production Science 27:123–136.

Gruber, L., Steinwidder, A., Stefanon, B., Steiner, B., and Steinwender, R. 1999. Influence of grassland management in Alpine regions and concentrate level on N excretion and milk yield of dairy cows. Livestock Production Science 61:155–170.

Huhtanen, P. and Hetta, M. 2012. Comparison of feed intake and milk production responses in continuous and change-over design dairy cow experiments. Livestock Science 143:184–194.

Huhtanen, P., Rinne, M., and Nousiainen, J. 2008. Evaluation of concentrate factors affecting silage intake of dairy cows: A development of the relative total diet intake index. Animal 2:942–953.

Knaus, W. 2009. Dairy cows trapped between performance demands and adaptability. Journal of the Science of Food and Agriculture 89:1107–1114 and 1163.

Leiber, F., Dorn, K., Probst, J.K., Isensee, A., Ackermann, N., Kuhn, A., and Neff, A.S. 2015. Concentrate reduction and sequential roughage offer to dairy cows: Effects on milk protein yield, protein efficiency and milk quality. Journal of Dairy Research 82:272–278.

Littell, R.C., Henry, P.R., and Ammerman, C.B. 1998. Statistical analysis of repeated measures data using SAS procedures. Journal of Animal Science 76:1216–1231.

Mertens, D.R. 1997. Creating a system for meeting the fiber requirements of dairy cows. Journal of Dairy Science 80:1463–1481.

Nicholas, P.K., Padel, S., Cuttle, S.P., Fowler, S.M., Hovi, M., Lampkin, N.H., and Weller, R.F. 2004. Organic dairy production: A review. Biological Agriculture and Horticulture 22:217–249.

Nousiainen, J., Rinne, M., and Huhtanen, P. 2009. A meta-analysis of feed digestion in dairy cows. 1. The effects of forage and concentrate factors on total diet digestibility. Journal of Dairy Science 92:5019–5030.

Powell, J.M., Gourley, C.J.P., Rotz, C.A., and Weaver, D.M. 2010. Nitrogen use efficiency: A potential performance indicator and policy tool for dairy farms. Environmental Science and Policy 13:217–228.

Randby, A.T., Weisbjerg, M.R., Norgaard, P., and Heringstad, B. 2012. Early lactation feed intake and milk yield responses of dairy cows offered grass silages harvested at early maturity stages. Journal of Dairy Science 95:304–317.

Roche, J.R., Friggens, N.C., Kay, J.K., Fisher, M.W., Stafford, K.J., and Berry, D.P. 2009. Invited review: Body condition score and its association with dairy cow productivity, health, and welfare. Journal of Dairy Science 92:5769–5801.

Rosati, A. and Aumaitre, A. 2004. Organic dairy farming in Europe. Livestock Production Science 90:41–51.

Schader, C., Muller, A., Scialabba, N.E., Hecht, J., Isensee, A., Erb, K.H., Smith, P., Makkar, H.P.S., Klocke, P., Leiber, F., Schwegler, P., Stolze, M., and Niggli, U. 2015. Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability. Journal of the Royal Society Interface 12: 20150891.

Steinshamn, H. and Thuen, E. 2008. White or red clover-grass silage in organic dairy milk production: Grassland productivity and milk production responses with different levels of concentrate. Livestock Science 119:202–215.

van Zanten, H.H., Meerburg, B.G., Bikker, P., Herrero, M., and de Boer, I.J. 2016. Opinion paper: The role of livestock in a sustainable diet: A land-use perspective. Animal 10:547–549.

VDLUFA 1993. Handbuch der Landwirtschaftlichen Versuchs- und Untersuchungsmethodik (VDLUFA-Methodenbuch), Bd. III: Die Chemische Untersuchung von Futtermitteln. VDLUFA-Verlag, Darmstadt.

Waldo, D.R. 1986. Effect of forage quality on intake and forage-concentrate interactions. Journal of Dairy Science 69:617–631.

Wilkinson, J.M. 2011. Re-defining efficiency of feed use by livestock. Animal 5:1014–1022.

Zebeli, Q., Tafaj, M., Steingass, H., Metzler, B., and Drochner, W. 2006. Effects of physically effective fiber on digestive processes and milk fat content in early lactating dairy cows fed total mixed rations. Journal of Dairy Science 89:651–668.

Zebeli, Q., Mansmann, D., Steingass, H., and Ametaj, B.N. 2010. Balancing diets for physically effective fibre and ruminally degradable starch: A key to lower the risk of sub-acute rumen acidosis and improve productivity of dairy cattle. Livestock Science 127:1–10.

Zebeli, Q., Ghareeb, K., Humer, E., Metzler-Zebeli, B.U. and Besenfelder, U. 2015. Nutrition, rumen health and inflammation in the transition period and their role on overall health and fertility in dairy cows. Research in Veterinary Science 103:126–136.