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Maize silage as an energy supplement in organic dairy cow rations

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Abstract

The literature implicates strongly that including energy supplements in dairy rations based on protein-rich forages increases performance and feed efficiency due to an improved and more balanced ruminal energy and protein supply. Therefore, both conventional and organic dairy farms primarily supplement roughages with concentrates, containing high proportions of cereal grains. However, considering the main principles of sustainable agricultural systems and nutrient cycles, the question of alternatives is raised. Therefore, the present study was conducted to compare grain and maize silage as energy sources in organic dairy cow rations. Two grass–clover silage-based diets, offered on an *ad libitum* basis, were supplemented either with 1 kg grain mixture plus 0.5 kg hay (treatment group G) or 2.1 kg maize silage (treatment group M) on a dry matter (DM) basis. The trial was carried out as a change-over design and lasted for 15 weeks. Intake of concentrates, DM and utilizable crude protein in the duodenum (uCP) were similar in both treatments. However, significant differences between treatments G and M were found for grass–clover silage dry matter intake (DMI) (13.4 versus 12.9 kg), forage DMI (14.6 versus 15.7 kg), crude protein (CP) intake (2885 versus 2801 g), ruminal nitrogen balance (RNB) (40 versus 29 g) and intake of neutral detergent fiber (NDF) (7630 versus 7900 g). Milk yield was not affected by treatment, but in treatment M, milk fat content was at 42.4 g kg^{-1}, significantly higher, and milk urea concentration at 19.7 mg 100 ml^{-1}, significantly lower, as compared with treatment G. Efficiency of N use (N in milk in % of N intake) tended to be improved in treatment M. Balances of energy and uCP (intake as a percentage of requirements) were unaffected by treatment.

Key words: dairy cow, organic farming, energy supplement, maize silage, protein, milk composition

Introduction

In organic dairy farming systems, grass, legumes and their ensiled conserves represent the main feedstuffs and major protein sources. In ruminant nutrition, ruminal microbes contribute considerably to the protein supply of the animal. For an optimal growth of rumen microbes and synthesis of microbial protein, a balanced and simultaneous ruminal protein and carbohydrate supply is crucial[1]. Carbohydrates can be divided into non-structural carbohydrates (starch, sugar and pectins), which are readily fermentable in the rumen, and structural carbohydrates (cell wall constituents consisting of cellulose, hemicellulose and lignin), which are potentially degradable in the rumen. Both determine the energy value of a feedstuff. From grass, legumes and their silages, rumen protein supply is usually higher than energy supply and, most notably, protein degradation occurs more rapidly than carbohydrate fermentation. Therefore, slow ruminal carbohydrate degradation rate in relation to rapid nitrogen release is claimed as one of the main factors for high environmental nitrogen losses, low microbial protein synthesis and low feed efficiency[2].

Traditionally, protein-rich dairy diets are supplemented with cereal grains, which are high in starch and low in protein content. However, in sustainable agriculture systems, feeding grain must be viewed critically with regard to amount of forage utilization, intact nutrient cycles and the use of potential human food in animal feeding. Therefore, in the past decade, several studies examined alternatives to grain such as fodder beets, beet pulp, whole crop silages, maize silage or energy-rich by-products[3–7]. A nutritional consequence when substituting cereals is that starch is replaced by other carbohydrate sources.

The general aim of organic dairy farming is to reach a high level of self-sufficiency. This can be achieved by minimizing purchased concentrate use and focusing on milk production from forage. Therefore, on organic dairy farms, maize silage could be an attractive crop instead of

Table 1. Chemical composition and calculated nutritive values of feeds (g kg^{-1} dry matter (DM) unless stated).

Component	Grass–clover silage	Hay	Concentrate mixture	Maize silage	Grain mixture
DM	466	870	863	300	869
Crude protein	160	110	171	76	107
Crude ash	119	72	61	40	21
Crude fiber	220	283	82	200	33
Crude fat	29	22	26	31	24
Starch	ND[1]	ND	414	304	673
NDF_{org}	430	586	309	452	171
ADF_{org}	279	336	118	232	45
NEL (MJ kg^{-1} DM)	6.0	5.4	7.5	6.5	8.5
uCP[2]	136	121	171	130	165
Ruminal N balance	3.8	−1.7	0.0	−8.7	−9.3

[1] Not determined.
[2] Utilizable crude protein in the duodenum.

cereal grains. Maize silage is a reliable forage supplement that can be grown in most grassland regions of moderate altitude. It supplies ruminally digestible fiber, but also noteworthy amounts of ruminally degradable starch[8]. Therefore, the objective of this experiment was to evaluate whether grain and maize silage are interchangeable energy sources in grass–clover silage-based diets in terms of feed and nutrient intake, milk yield, milk constituents and feed efficiency.

Animals, Materials and Methods

Experimental design and animals

The experiment was conducted as a repeated change-over design at the organic farm of the Agricultural High School Ursprung in the province of Salzburg, Austria (570 m NN, 1250 mm precipitation, 8.5°C average annual temperature) from November 2005 to February 2006. The experiment was carried out with 13 Holstein Friesian dairy cows, housed in a cubicle housing system with Calan gates for individual feeding. Cows were allotted to two treatment groups (six cows in treatment G and seven cows in treatment M) according to milk yield, days in milk and number of lactations. At the beginning of the experiment, average (± standard deviation) milk yield, days in milk and number of lactations were 25.9 ± 6.16 kg per day, 105 ± 59.0 days in milk and 2.9 ± 1.82, respectively. The experiment lasted for 15 weeks with a 3-week adaptation period to Calan gates and feeding regimen at the beginning of the experiment and a change-over period of 2 weeks in weeks 9 and 10.

Feeding regimen

In the experiment, two grass–clover silage-based rations, intended to be equal in dietary energy content, were compared. The chemical composition and nutritional values of the feeds are listed in Table 1. Grass–clover silage was a mixture of first and third cut and derived from approximately 50% grassland and 50% perennial clover–grass leys. Hay was harvested from second cut. Maize silage was harvested in mid-October, chopped to lengths of approximately 10 mm and ensiled as bales. The grain mixture consisted of equal amounts of barley, wheat, rye and maize, which represent commonly used energy sources in concentrates for dairy cows. Furthermore, 50 g of a commercial mineral and vitamin mixture were given to each cow daily.

Both diets were based upon *ad libitum* allowance of grass–clover silage, which was fed at 5 : 00 and 15 : 30. At 14 : 00, approximately 1.5 kg hay was provided for each cow. All feeds were removed and weighed before the next feeding. Treatment group G received 1 kg of the grain mixture and treatment group E 2.1 kg maize silage on a dry matter (DM) basis. Grain mixture and maize silage were fed on top of grass–clover silage in two equal portions at morning and evening feeding. Additionally, cows in treatment G were fed 1 kg hay in addition to grass–clover silage at morning feeding to decrease grass–clover silage intake. It was assumed that the grain mixture and the maize silage were consumed completely. Refusals of morning-fed hay in treatment G were manually collected and weighed before removing grass–clover silage. In the present paper, maize silage, the grain mixture and morning-fed hay are referred to as supplements. In both treatments, cows exceeding a daily milk production of 17 kg were fed a purchased, pelleted concentrate mixture at a rate of 1 kg DM per 2 kg additional milk yield via an automatic feeding station.

Data collection and analytical procedures

Individual forage intake was recorded during four 6-day recording periods in weeks 4, 8, 11 and 15 of the experiment using Calan gates. Grass–clover silage was offered twice a day to ensure refusals in amounts of 5–10%. Orts were weighed before next feeding. Intake of the concentrate mixture was recorded daily during the whole experiment. In each recording period, DM content of all used feeds and

Table 2. Effect of maize silage versus grain-mixture on daily feed and nutrient intake.

	Lsmeans			
Item	**Treatment G**	**Treatment M**	s_e	***P***
Hay DMI (kg)	1.2	0.7	0.37	< 0.001
Hay DMI morning feeding (kg)	0.5	–		
Concentrate DMI (kg)	3.0	3.0	0.45	0.916
Total DMI (kg)	18.6	18.7	2.19	0.599
Total DMI kg body weight$^{-0.75}$ (g)	145	145	16.6	0.910
Forage DMI (kg)	14.6	15.7	1.70	< 0.001
Grass-clover silage DMI (kg)	13.4	12.9	1.67	0.005
NEL intake (MJ)	118	117	10.7	0.726
CP intake (g)	2885	2801	277.3	0.011
uCP intake (g)	2637	2618	240.7	0.506
Ruminal N-balance (g)	39.5	29.1	6.83	< 0.001
Crude fiber intake (g)	3551	3691	375.7	0.002
NDF_{org} intake (g)	7630	7900	763.6	0.003
ADF_{org} intake (g)	4532	4672	483.6	0.014
Crude fat intake (g)	522	541	52.0	0.003

feed refusals (grass–clover silage and hay) was determined at least three times by oven drying at 105°C for 24 h. Furthermore, in each recording period, one sample of each dietary component and feed refusal (for each treatment separately), pooled over 3 days, was collected and analyzed using methods described by ALVA[9] and VDLUFA[10]. Contents of utilizable crude protein in the duodenum (uCP) and energy were calculated according to GfE[11]. Cows were milked twice daily at 6 : 00 and 16 : 30 in a herring milking parlor and milk yields were recorded automatically at each milking. In each recording period, three pooled samples from morning and evening milk were collected from each cow and analyzed for fat, protein, lactose, urea and somatic cell counts. Between recording periods, individual milk samples were collected once a week. Body weights and body condition scores (BCSs) (1–5 points, 0.25 interval, 1: very lean, 5: very fat) were determined once in each recording period.

Statistical analysis

Data were analyzed with the statistical program package SAS[12] according to the model developed by Kaps and Lamberson[13]. However, only parameters which were statistically significant were included in the final reduced model. Statistical differences were considered to be significant when $P < 0.05$ and trending towards significance when $P < 0.10$.

$$Y_{ijklmn} = \mu + \alpha_i + \beta_k + \gamma_l + \delta_m + \mathrm{SUB}(\beta)_{jk} + \varepsilon_{ijklmn},$$

where Y_{ijklmn} = observation on cow j with treatment i, order of treatment k and period l, μ = overall mean, α_i = fixed effect of treatment i (G, M), β_k = effect of order k (I, II) of applying treatments, γ_l = fixed effect of period l (1, 2, 3, 4), δ_m = continuous covariate day of experiment m, $\mathrm{SUB}(\beta)_{jk}$ = random effect of cow j within order k, ε_{ijklmn} = random residual error.

Results and Discussion

Several studies have examined the supplementation of protein-rich forages (pasture, grass silage and legume silage) with maize silage[14–16]. Other trials have compared different carbohydrate sources in dairy cow diets[3,4,17–19]. However, surveys comparing grain and maize silage as supplements are rare. In the present study, cows were fed grass–clover silage-based diets, which were supplemented either with 1 kg of a grain mixture plus 0.5 kg hay (treatment G) or 2.1 kg maize silage (treatment M) on a DM basis. Dietary energy content was similar in both treatments (6.4 and 6.3 MJ net energy for lactation (NEL) kg^{-1} DM in treatments G and M, respectively). Generally, it is assumed that at low levels of supplementation, the energy source has only little effect on feed intake, milk yield and milk composition[20]. Hence, most studies cited in the present paper used much higher supplementation rates than the study at hand.

Feed and nutrient intake

Maize silage and grain differ in their nutritional characteristics, especially in their contents of starch and fiber (Table 1). Generally in maize silage, the B1 fraction (starch) of the CNCPS (Cornell net carbohydrate and protein system) is lower as compared with cereal grain (40 versus 70% of carbohydrates) and the B2 fraction (hemicellulose and cellulose) higher (45 versus 20% of carbohydrates)[21,22].

Daily forage dry matter intake (DMI) (grass–clover silage, hay and maize silage) was significantly higher in treatment M (15.7 versus 14.6 kg DM). Grass–clover silage intake was 0.5 kg DM lower in treatment M as compared with treatment G (Table 2). However, in the present study, DMI and energy content of supplements were different and no data for a treatment group without supplementation were

Table 3. Effect of maize silage versus grain-mixture on daily milk yield and milk composition.

Item	Lsmeans		s_e	*P*
	Treatment G	Treatment M		
Milk (kg)	23.3	23.1	1.57	0.360
ECM (kg)	23.1	23.3	1.86	0.431
Protein ($g\,kg^{-1}$ milk)	32.0	31.8	1.25	0.197
Fat ($g\,kg^{-1}$ milk)	40.9	42.4	4.10	0.012
Lactose ($g\,kg^{-1}$ milk)	47.2	47.9	11.38	0.617
Fat protein ratio	1.28	1.33	0.124	0.004
Protein yield (g)	733	729	54.9	0.559
Fat yield (g)	949	974	109.5	0.094
Somatic cell counts ($\times 10^3\,ml^{-1}$)	98	106	107.2	0.611
Urea ($mg\,100\,ml^{-1}$)	20.8	19.7	3.74	0.035

Table 4. Effect of maize silage versus grain-mixture on feed utilization.

Item	Lsmeans		s_e	*P*
	Treatment G	Treatment M		
Concentrate mixture[1] (g DM kg^{-1} milk)	164	115	22.6	< 0.001
N efficiency[2] (%)	25.5	26.1	16.39	0.075
Milk from forage[3] (%)	70	82	2.8	< 0.001
uCP balance[4] (%)	113	113	6.5	0.788
NEL balance[4] (%)	105	104	8.8	0.264

[1] Concentrate mixture and grain mixture.
[2] N in milk in % of N intake.
[3] (NEL $intake_{forage}$ − NEL $requirement_{maintenance}$)/NEL requirement kg^{-1} milk.
[4] Intake as a percentage of requirements for maintenance and milk production.

available. Hence, with the present results, no reliable statement for substitution rates can be made. Intake of the concentrate mixture averaged 3.0 kg DM in both treatments. Therefore, percentage of dietary forage intake was rather high ($P < 0.01$) at 79% of total daily DMI in treatment G and 85% in treatment M, taking into account an average milk yield of 23.2 kg per day.

No difference between treatments was observed for total daily DMI, estimated intake of NEL and uCP (Table 2). Contrary to uCP intake, intake of CP was significantly lower in treatment M, which resulted in different dietary CP concentrations (15.7 and 14.9% of DM in treatments G and M, respectively, $P < 0.01$). RNB is an estimated value for the protein supply of the ruminal microbes and is calculated as CP minus uCP divided by 6.25[11]. RNB was significantly lower in treatment M (29 versus 40 g), which reflected the lower CP intake in treatment M (Table 2).

In the study in question, protein balance, defined as uCP intake as percentage of requirements for maintenance and observed milk production[11], was markedly positive (+13%) in both treatments. Reasons for the positive protein balance could be the following: provision of grass–clover silage *ad libitum* for the whole day, a slight overestimation of the uCP feed value as well as discrepancies in the estimation of the protein and energy requirements of the GfE[11].

Overall hay intake was, according to plan, significantly higher in treatment G (1.2 versus 0.7 kg DMI); however, intake was considerably lower in both groups (6 and 4% of total daily DMI in treatments G and M, respectively) than initially planned and expected. Although treatment G was supplemented with hay at morning feeding, daily intake of crude fiber, NDF_{org} and ADF_{org} was on average 3–4% higher in treatment M, which was statistically significant (Table 2). This reflected mainly differences in the fiber content of the two energy supplements (fiber intake from maize silage was 50% higher than fiber intake from grain mixture plus hay consumed at morning feeding).

Milk production and feed efficiency

Several authors have dealt with the effect of different carbohydrate supplements on milk yield and milk composition. Inconsistency in the results is often attributed to differences in the source of carbohydrate, the quantity of supplementation and the forage quality. Generally, it is assumed that good roughage quality is likely to increase substitution rates and reduce production responses to supplements[23,24].

Results of the present study concerning milk performance and feed efficiency are shown in Tables 3 and 4, respectively. In the present study, daily milk yield was unaffected by energy supplementation, which is in agreement with results of Castillo et al.[17] and Visser et al.[25], who fed concentrate mixtures with different structural and non-structural carbohydrates and did not observe any difference in DMI, energy intake or milk yield. Contrary to this, Moran and Croke[7] fed different amounts of maize silage or wheat to pasture-fed dairy cows at the same level of supplemental energy and observed numerically higher milk yields when feeding wheat. However, this might have resulted from the trend for higher supplemental ME intake and lower calculated pasture substitution in the wheat-fed treatment.

In the study at hand, milk protein content was unaffected by treatment, which agrees with results of Huhtanen et al.[6], but is contrary to those of Moran and Croke[7]. The present study showed a significantly higher milk fat content in treatment M ($P = 0.01$). However, this difference was only a trend for milk fat yield ($P = 0.09$). It is commonly agreed that the amount of ruminally fermentable fiber and consequently the production of acetic acids have a major impact on milk fat content. Nevertheless, several studies comparing fibrous versus starchy supplements did not report any effect on milk fat percentage[6,7,17], although NDF intake was significantly higher with fibrous carbohydrates.

In the present study, milk urea concentration was within the recommended range of 15–30 mg $100\,ml^{-1}$ in both treatments[26]. However, in treatment M, urea concentration was slightly but significantly lower (19.7 versus 20.8 g, $P = 0.04$). Hristov and Ropp[27] fed two diets supplemented either with ruminally fermentable non-structural carbohydrates (barley and molasses) or ruminally fermentable fiber (beet pulp, brewer's grain and corn) and found a significantly lower milk urea concentration for the ruminally fermentable fiber diet. However, whether the reduced urea content observed in the present study resulted from reduced protein intake, increased ruminally fermentable energy or improved ruminal N capture is unclear.

In general, the efficiency with which dietary N is utilized by dairy cows (N in milk in % of N intake) is low, ranging from 22 to 39%[2,28,29]. It is generally agreed that low dietary N efficiency is partly related to high dietary CP content and an unbalanced ruminal energy and protein supply, and that it can be improved through the supplementation of feedstuffs rich in carbohydrates[30,31]. The present study showed a slight tendency (26.1 versus 25.5%, $P = 0.08$) for an improved dietary N efficiency in treatment M. Unfortunately, in the present study, herd size was too small to allow for a third, non-supplemented treatment group; hence no statement for a diet without supplementation can be made.

With the data at hand, it is difficult to make a reliable statement on changes in body weight and BCS, because cows were in different stages of lactation and cows were not kept separated from water troughs and grass–clover silage before weighing. Generally, treatment did not show a significant effect on body weight, which averaged 649 kg ($P = 0.56$), and BCS, which averaged 3.2 points in both treatments ($P = 0.83$). The lack of differences in body weight and BCS between treatments may be partly because of the rather low amount of supplements fed and partly because of the lack of difference in DMI and NEL intake.

Conclusions

The present study gives an indication that with even small amounts of supplemental energy nutrient intake, protein supply and milk composition can be influenced. Although only 11% of total DMI was fed as maize silage, CP intake was significantly reduced, RNB and milk urea concentration significantly decreased, and dietary N efficiency slightly improved as compared with the grain-supplemented treatment. However, with the present trial, no reliable statement can be made whether these improvements are due to reduced CP intake, improved ruminal energy supply or greater ruminal N capture. Milk yield was not negatively influenced by feeding maize silage instead of grain; however, the dietary proportion of supplements was probably too small to observe responses in milk production. It is concluded that inclusion of small amounts of maize silage instead of grain did not seem to have any negative effects. However, higher supplementation rates and lower dietary CP contents might lead to greater differences.

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