Maize silage and Italian ryegrass silage as high-energy forages in organic dairy cow diets: Differences in feed intake, milk yield and quality, and nitrogen efficiency

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Research Paper

Abstract

During the winter feeding period in organic dairy production systems in the alpine and pre-alpine regions of Austria and its neighboring countries, maize silage is an energy-rich forage that is regularly included in grass-silage-based diets to improve the energy supply of the cows. Italian ryegrass (*Lolium multiflorum* Lam.) is also a high-energy fodder grass popular as forage for dairy cows, but it is rarely cultivated in Austrian organic agriculture. The two crops differ in their cultivation demands and characteristics. Italian ryegrass establishes rapidly and may reduce the risk of soil erosion. Italian ryegrass would be a beneficial addition to crop rotation, which is an essential tool in successful organic farming. In a 15-week feeding trial, Italian ryegrass silage and maize silage were fed to 22 lactating Holstein dairy cows. Organically produced Italian ryegrass silage and maize silage were included at a rate of 40% [of dry matter (DM)] in grass-silage-based mixed basal diets. The mixed basal diets were supplemented with modest amounts of additional concentrates (2.7–3.0 kg DM day^{-1}). Owing to the higher energy content of maize silage as compared to Italian ryegrass silage, the maize diet provided more energy [6.3 MJ net energy for lactation (NEL) kg^{-1} DM] than the ryegrass diet (6.15 MJ NEL kg^{-1} DM). The protein supply of the maize diet and the ryegrass diet was intended to be equal, but in fact the protein content of the maize diet was significantly lower (122 g crude protein kg^{-1} DM) than that of the ryegrass diet (141 g kg^{-1} DM). When the maize diet was fed, feed intake, milk yield and milk protein content were significantly higher as compared to the ryegrass diet. Also, intake of crude protein was significantly lower when feeding the maize diet, and in combination with the higher milk protein yield, this enabled an efficiency of gross nitrogen (N) utilization as high as 0.304. This level of N efficiency can be considered as above average and was significantly and considerably higher than the level of 0.259 observed when the ryegrass diet was fed. Therefore, maize silage upholds its reputation as an ideal energy-rich component in grass-silage-based dairy cow diets.

Key words: Italian ryegrass, maize silage, organic, dairy cow, nitrogen efficiency

Introduction

In the alpine and pre-alpine regions of Austria and its neighboring countries, ruminant production plays a vital role in organic agriculture, mostly due to the high proportion of total farm land that is permanent grassland. In Austria, 51.2% of the utilized agricultural area is permanent grassland[1]. Owing to ruminants' ability to digest fibrous materials, dairy production systems are well suited for utilizing grassland for the production of foods. As a consequence, organic milk production is commonly based on fresh and conserved forages from permanent grassland and perennial clover–grass leys. The latter are an essential component of crop rotation, which is of particular importance in organic farming systems. In organic crop rotations, nitrogen (N)-demanding and N-fixing crops are balanced in order to optimize yields. On an organic dairy farm, sufficient forage for cows has to be produced while still maintaining soil fertility[2]. Clover–grass provides both N for the next crop in the rotation as well as forage for the dairy cows. Ley farming also prevents soil erosion and provides carbon-rich crop residues as feed for soil

organisms. Apart from feeding forages, most Austrian farmers supplement with concentrates to improve milk yield. Common home-grown concentrates are barley and triticale, whereas in commercial concentrates, industrial by-products (e.g., bran, press cake) are used as well. Where local growing conditions allow maize production, maize silage is valued as a high-energy forage. Including it in the diet increases the supply of ruminally fermentable carbohydrates from forage and thereby improves the capture of dietary N, a precious and scarce resource in organic agriculture. Studies in which perennial ryegrass silage is replaced with maize silage have shown that increasing inclusion of maize silage positively affects dry matter (DM) intake, milk yield, and milk protein content, while milk fat concentration is either not affected or decreases[3–5].

Italian ryegrass (*Lolium multiflorum* Lam.) is a fodder grass that has been grown in northern Italy since the 12th century[6], making it the oldest fodder grass cultivated by humans. Today, Italian ryegrass can be found in temperate regions all around the world. In Austria, it can be found in natural grassland, but is rarely cultivated due to its low frost resistance, although using it for annual (or bi-annual, depending on the winter losses) leys would avoid this problem.

Among the fodder grasses, Italian ryegrass has one of the highest energy contents, and due to its favorable composition of structural carbohydrates, it is easily digestible[7]. Reports about its positive effects on the forage intake of dairy cows are frequent[8,9], and some researchers even report better feed efficiency than when feeding maize silage[10].

In Austrian areas where the cultivation of both maize and Italian ryegrass is possible, Italian ryegrass may be an alternative to forage maize, resulting in longer rotation breaks between maize and therefore a more diverse crop rotation. In areas where conditions are not optimal for maize production, Italian ryegrass might be a valuable high-energy forage in addition to the usual clover–grass. Italian ryegrass and maize differ in their cultivation demands and characteristics: whereas maize only requires an annual precipitation of 500–800 mm[11], the annual water demand of Italian ryegrass is much higher, about 900–1200 mm[12]. Both forage crops are sensitive to low temperatures: for successful cultivation of Italian ryegrass, an average annual temperature of about 8.5°C is needed[12]. Maize for silage production requires an average temperature between 10 and 15°C between May and September[11]. Italian ryegrass is either sown in fall or in spring, establishes quickly, and covers the ground effectively. Under Austrian conditions it rarely survives more than one winter. Maize is sown in April/May and harvested for silage in September/October, and especially under organic cultivation, establishment is slow. Owing to its high nutrient demand, maize is commonly planted after clover–grass or other legumes[13]. Italian ryegrass has no special demands with regard to the preceding crop,

although it thrives when planted after legumes. Possible succeeding crops after Italian ryegrass are grain legumes or summer cereals[13]. Special attention must be paid to the N supply of succeeding crops, because the crop residues left behind by Italian ryegrass are rich in carbon but poor in N. Italian ryegrass itself requires regular, moderate fertilization with manure in order to realize its potential. Thus, both maize and Italian ryegrass can be considered intensive forage crops under the conditions of organic agriculture.

The objective of this study was to compare Italian ryegrass silage and maize silage as forage for dairy cows under the conditions of Austrian organic agriculture. Therefore, a feeding trial was conducted in which Italian ryegrass silage and maize silage were included in grass-silage-based mixed basal diets for dairy cows during the winter feeding period. The main questions were how intake of DM, milk yield, and quality and production efficiency, especially gross N efficiency, would differ depending on the forages used. The milk fatty acid profile was chosen as an additional parameter to describe milk quality.

Materials and Methods

Italian ryegrass harvest

Italian ryegrass (*L. multiflorum* Lam. var. *italicum*, cultivar: TIGRIS) was grown in a field belonging to the Secondary Agriculture and Forestry College at Ursprung (HLFS Ursprung) in the province of Salzburg, Austria (570 m NN, 1250 mm precipitation, 8.5°C average annual temperature). The preceding crop was clover–grass. After seeding on April 16, 2010, the first cut on May 11 was a cleaning cut due to weeds, and the second (June 24) and third cuts (July 19) were ensiled without additives as round bales. After the second and third cut, liquid manure was applied at a rate of 40 kg N (10 kg of which were NH_4-N) per hectare. The two ensiled cuts combined yielded 2.9 t DM ha^{-1}.

Experimental design and animals

The feeding trial was conducted with the organically managed HLFS Ursprung dairy herd, which is housed in a cubicle housing system equipped with Calan gates for individual feeding. Milking takes place in a 2×3 herringbone milking parlor twice a day, at 6:00 and 16:30. A total of 22 lactating Holstein cows were included in the feeding trial between November 2010 and February 2011, but only 19 cows were included for the whole trial. The remaining three cows were included belatedly because of delayed calving or were eliminated prematurely because they were dried off. At the beginning of the experiment, the cows were divided into two treatment groups of 11 cows each, based on number of lactation (2.5 ± 1.7 versus 3.0 ± 1.5), days in milk (110 ± 65 versus 141 ± 109),

Table 1. Nutrient content and fermentation traits of silages, g kg^{-1} DM unless stated otherwise.

| | | | Italian ryegrass silage | | | | |
	Grass silage *n* = 2	Maize silage *n* = 2	2nd cut *n* = 2	3rd cut *n* = 2	Hay *n* = 2	Barley *n* = 2	Soybean cake *n* = 2
Nutrients							
DM (g kg^{-1} fresh weight)	338	388	356	225	942	867	921
Crude protein	99	75	160	118	85	123	460
uCP	130	133	136	121	115	162	299
Ether extracts	28	31	40	38	24	26	93
NDF	426	403	491	527	646	.	.
ADF	243	219	282	309	382	.	.
Lignin (sa)	31	31	49	45	63	.	.
Starch	.	375	.	.	.	533	87
Sugar	21	9	23	13	146	.	108
Ash	98	33	127	117	63	28	76
NEL (MJ kg^{-1} DM)	6.33	6.77	6.14	5.55	5.38	8.00	8.93
Fermentation traits							
pH	4.5	4.3	5.2	5.2			
Lactic acid	30.1	22.0	16.3	7.9			
Acetic acid	14.8	8.1	2.6	3.1			
Butyric acid	8.9	0.5	5.7	23.4			
Ammonia-N (g kg^{-1} of total N)	53	65	57	100			

DM, dry matter; uCP, utilizable crude protein at the duodenum; NDF, neutral detergent fiber;
ADF, acid detergent fiber; and NEL, net energy lactation.

milk yield (27.4 ± 9.5 versus 23.9 ± 5.1 kg), and live weight (654 ± 62 versus 665 ± 47 kg). After an initial 3-week adaptation period to the Calan gates and the feeding regimen, data were collected over 12 weeks. Treatments were switched after week 6 to ensure that every cow received every treatment. The feeding trial was conducted according to the EU Directive 2010/63/EU for animal experiments[14] and the Austrian Act on Animal Experiments[15]. No invasive procedures were performed on the cows.

Feeding regimen

Two mixed basal diets based on grass silage and hay and supplemented with additional concentrates were compared. The nutrient content and fermentation traits of the feeds included in mixed basal diets are summarized in Table 1. Grass silage consisted of a mixture of a first cut from permanent grassland and a third cut from a perennial clover–grass ley in its third year; therefore, clover proportion was already low. Hay was produced from a first cut of permanent grassland, and residual drying was performed in the barn by a ventilation system. Owing to a crop failure at HLFS Ursprung, maize silage produced according to the regulations of Austrian organic agriculture was purchased from a farmer in the Austrian province Lower Austria. The DM content of the silages ranged between 338 and 388 g kg^{-1} fresh matter, except for the third cut of Italian ryegrass, which was poorly fermented and numerically lower in energy and DM (225 g kg^{-1} fresh weight) than the other silages. The crude protein content of the silages varied greatly, from as low as 75 g kg^{-1} DM in the maize silage to 99 g kg^{-1} DM in the grass silage, and up to 160 g kg^{-1} DM in the ensiled second cut of Italian ryegrass.

Table 2 shows the ingredients and nutrient content of the mixed basal diets. Considerable amounts of maize silage and Italian ryegrass were included in diet M (maize diet) and diet R (ryegrass diet), respectively, to make the effects of and differences between the two forages clearly visible. In order to avoid the negative effects of protein deficiency in the maize diet, differing amounts of barley and soybean cake were added to the forages. The resulting mixed basal diets were meant to be isonitrogenous with a calculated crude protein content of 142 g kg^{-1} DM, but not isoenergetic. However, in fact, the crude protein content of mixed basal diet R turned out to be significantly higher than in mixed basal diet M. Regarding the content of utilizable crude protein at the duodenum (uCP), which is influenced by the energy content of the feed, the reverse was true. Regarding carbohydrate composition, only neutral detergent fiber (NDF) content was significantly higher in mixed basal diet R, whereas starch content was considerably and significantly higher in mixed basal diet M. Owing to the third cut of Italian ryegrass silage being considerably wetter than the other silages, mixed basal diet R had a significantly lower content of DM than mixed basal diet M.

The mixed basal diets were prepared daily and offered twice a day in amounts to ensure feed refusals of 5–10%.

Table 2. Ingredients and nutrient content of mixed basal diets, g kg^{-1} DM unless stated otherwise.

	Mixed basal diet		R^2	P value
	Maize $n=8$	Ryegrass $n=8$		
Ingredients				
Grass silage	380	380		
Maize silage	400	–		
Italian ryegrass silage, 2nd cut	–	200		
Italian ryegrass silage, 3rd cut	–	200		
Hay	100	100		
Barley	20	100		
Soybean cake	100	20		
Nutrients				
DM (g kg^{-1} fresh weight)	370	352	0.29	**0.032**
Crude protein	122	141	0.60	**< 0.001**
uCP	136	133	0.27	**0.041**
Ether extracts	31	32	0.35	**0.015**
NDF	449	468	0.33	**0.020**
ADF	267	287	0.24	0.055
Lignin (sa)	50	51	0.00	0.962
Starch	183	44	0.95	**0.027**
Sugar	35	41	0.73	0.143
Ash	82	110	0.82	**< 0.001**
NEL (MJ kg^{-1} DM)	6.30	6.15	0.37	**0.012**

DM, dry matter; uCP, utilizable crude protein at the duodenum; NDF, neutral detergent fiber; ADF, acid detergent fiber; NEL, net energy lactation.

The herd included cows in different stages of lactation and therefore a wide range of milk yields. In order to enable cows to maintain their production level, additional concentrates were supplemented according to milk yield: Cows exceeding a daily milk yield of 15 kg received a commercial concentrate mixture (166 g crude protein, 7.79 MJ net energy for lactation (NEL) kg^{-1} DM; $n=2$) at a rate of 0.5 kg DM for each additional kg of milk yield, up to a maximum of 6 kg DM concentrates. Concentrates were fed via an automatic feeding station, and quantities were adjusted weekly. Furthermore, all cows received 50 g of a commercial mineral and vitamin mixture per day.

Data collection and analytical procedures

Throughout the experiment, milk yield and intake of additional concentrates were documented continuously, while individual intake of mixed basal diets was recorded manually only during four 6-day recording periods in weeks 3, 6, 9 and 12. For feed analysis, the following samples (each pooled over two consecutive days) were taken for each recording period: one sample of each dietary component (only during weeks 3 and 9), two samples of both freshly mixed basal diets, and one sample of each treatment's feed refusals. The feed samples were analyzed according to the German Handbook of Agricultural Experimental and Analytical Methods[16] and method numbers are given. The DM content of feed offered and feed refusals was determined by oven-drying at 105°C (3.1). Ash, ether extracts, and sugar and starch content were analyzed using methods 8.1, 5.1.1, 7.1.1, and 7.2.1, respectively. Content of crude protein was assayed with Dumas combustion (4.1.2). NDF (6.5.1) in grass and ryegrass silages was determined without a heat stable amylase, while for analysis in maize silage and mixed basal diets alpha-amylase was added. Both NDF and acid detergent fiber (ADF, 6.5.2) are expressed inclusive of residual ash. Lignin was determined by solubilization of cellulose with sulfuric acid (6.5.3). Content of NEL and utilizable crude protein at the duodenum (uCP[17]) were calculated according to GfE[18].

A total of 16 milk samples (each pooled over two consecutive milkings) per cow were taken and conserved with Bronopol® until analysis for fat, protein, lactose and urea concentrations were conducted. An additional set of individual milk samples from the 19 cows that were included in the whole trial was taken for analysis of milk fatty acid profile during weeks 6 and 12. These samples were stored at −20°C until gas chromatographic analysis of fatty acid composition was performed at the laboratory and quality service center Muva, Kempten, Germany. Once a week, cows' live weights were determined by weighing them twice immediately after milking and calculating the mean. Nutrient balances and efficiency calculations were computed according to GfE[18].

Statistical analysis

For statistical analysis, the program package SAS[19] was used. The nutrient content of the mixed basal diets was analyzed using proc GLM, with a model including only the fixed effect of treatment. All other data were analyzed using proc MIXED, using the following model:

$$Y_{klmnopqr} = \mu + \text{treatment}_k + \text{day}_l + \text{order}_m + LN_n$$
$$+ LS_o + ECM_p + LW_q + \text{treatment} \times LN$$
$$+ \text{treatment} \times LS + \text{cow(order)}_{rm} + \varepsilon_{klmnopqrs}$$

where Y = variable studied; μ = overall mean; treatment = fixed effect of treatment k (M, R); day = fixed effect of day l in the feeding trial (1, 2, … , 83); order = fixed effect of order m (1, 2); LN = fixed effect of number of lactation n (1, 2, …, 6); LS = fixed effect of stage of lactation o, expressed as thirds (1st and 2nd 100 days, >200 days in milk); ECM = continuous effect of daily ECM yield p of cow r (only for parameters of feed intake); LW = continuous effect of live weight q of cow r (only for parameters of feed intake and milk fat, protein and lactose content); treatment × LN = interaction between treatment k and lactation number n; treatment × LS = interaction between treatment k and stage of lactation o; cow(order) = random effect of cow r within order m; ε = random error.

Table 3. Daily intake of DM, nutrients and energy of organically managed dairy cows fed diets containing either maize silage or Italian ryegrass silage.

	Treatment		SD	*P* value	CovS
	Maize	**Ryegrass**			
DM (kg)					
Mixed basal diet	15.3	14.2	1.51	**< 0.001**[1]	SP(POW)
Concentrate	3.0	2.7	1.73	**0.007**	SP(POW)
Total	18.4	17.0	1.58	**< 0.001**	SP(POW)
Nutrients (g)					
Crude protein	2380	2459	241.3	**0.017**	SP(POW)
uCP	2598	2364	231.7	**< 0.001**	SP(POW)
Ether extracts	591	566	55.3	**< 0.001**	SP(POW)
NDF from mixed basal diet	6968	6738	746.5	**0.002**	SP(POW)
ADF from mixed basal diet	4108	4134	468.0	0.635	SP(POW)
Lignin(sa) from mixed basal diet	686	708	180.0	**0.018**	CSH
Energy, MJ NEL	120	109	10.7	**< 0.001**	SP(POW)

uCP, utilizable crude protein at the duodenum; NDF, neutral detergent fiber;
ADF, acid detergent fiber; NEL, net energy lactation.
CovS, covariance structure: CSH, heterogeneous compound symmetry; SP(POW), spatial power law.
[1] *P* value of interaction treatment × number of lactations = 0.008.

Except for the main effects of treatment and day, fixed effects and interactions which were not statistically significant were excluded from the individual models. This did not result in any changes in the interpretation of results. Tables 3 and 4 include information on significant interactions, which have a marked influence on the interpretation of results. Seven covariance structures possibly suitable for the data at hand were tested: unstructured (UN), antedependence (ANTE[1]), compound symmetry (CS), heterogeneous compound symmetry (CSH), spatial power law (SP[POW]), spatial Gaussian (SP[GAU]), and spatial spherical (SP[SPH]). The covariance structure with the Bayesian information criterion value closest to zero, which indicates the best fit of the model to the data, was selected[20]. For analysis of milk fatty acids, only the covariance structure CS was used. Statistical differences were considered to be significant when *P* < 0.05. Table 1 shows the arithmetic means of the nutrients content and fermentation traits of the feeds, Table 2 shows the least-squares means of the nutrient content of mixed basal diets, the pertaining probability values (*P* value) and the coefficients of determination (R^2). Tables 3–5 show least-squares means for treatment, the residual standard deviation (SD), the *P* values, and the covariance structure used (CovS).

Results

Feed and nutrient intake

Feeding the maize diet resulted in a significantly higher intake of mixed basal diet (+ 1.1 kg DM) and also of total energy (+ 11 MJ NEL, see Table 3). Even though a significant interaction between treatment and number of lactation was observed, treatment M led to an increase in every lactation. Feeding the ryegrass diet significantly increased crude protein intake by 3.3%, but due to the significantly higher energy content of mixed basal diet M, intake of uCP was 10% higher when feeding the maize diet. Although the mixed basal diet R contained significantly more NDF than the mixed basal diet M, intake of NDF was significantly higher (+ 3.4%) in treatment M due to the resulting higher intake of DM. Lignin determined by solubilization of cellulose with sulfuric acid [Lignin (sa)] intake was 3.2% higher in cows fed the ryegrass diet, whereas intake of ether extracts was significantly higher (+ 4.4%) in treatment M.

Milk production, nutrient balances, and feed efficiency

Feeding the maize diet significantly increased milk yield (+ 2.3 kg) as well as milk protein content (+ 1.2 g kg^{-1}), whereas milk fat content was significantly lower (2.9 g kg^{-1}, see Table 4). Despite lower milk fat content, both milk fat yield (+ 13.2%) and milk protein yield (+ 17.2%) were significantly higher in treatment M. Milk urea content was significantly lower when the maize diet was fed. Even though significant interactions between treatment and number of lactation and treatment and stage of lactation were observed, feeding the maize diet always decreased milk urea content. On average, cows fed the maize diet produced milk with a urea content of 78 mg l^{-1}, whereas cows fed the ryegrass diet had a milk urea content of 137 mg l^{-1}.

Nutrient balances and calculated parameters of production efficiency are given in Table 4. The uCP and NEL balances were positive in both treatments, but only NEL

Table 4. Milk production traits, nutrient balances and efficiency of milk production of organically managed dairy cows fed diets containing either maize silage or Italian ryegrass silage.

| | Treatment | | | | |
	Maize	Ryegrass	SD	*P* value	CovS
Milk production					
Milk yield (kg)	22.7	20.4	5.72	**< 0.001**	SP(POW)
ECM (kg)	23.3	21.3	7.03	**< 0.001**	CSH
Fat content (g kg^{-1})	40.8	43.7	6.61	**< 0.001**	SP(POW)
Protein content (g kg^{-1})	33.0	31.8	2.61	**< 0.001**	CSH
Lactose content (g kg^{-1})	47.0	47.2	1.92	0.198[1]	CSH
Urea content (mg l^{-1})	78.1	137.0	28.4	**< 0.001**[2]	SP(POW)
Fat yield (g)	970	857	256.3	**< 0.001**	SP(POW)
Protein yield (g)	737	629	155.2	**< 0.001**	SP(POW)
Nutrient balances					
Ruminal N balance (g)	− 29.4	9.4	12.45	**< 0.001**	ANTE(1)
uCP balance (%)	119	120	13.2	0.512	SP(POW)
Live weight change (kg day^{-1})	0.20	0.10	1.403	0.509	SP(POW)
NEL balance (%)	109	104	10.9	**< 0.001**	SP(POW)
Efficiency of milk production					
Feed efficiency[3]	1.23	1.19	0.210	0.486	SP(SPH)
Gross N efficiency[4]	0.304	0.259	0.0457	**< 0.001**	SP(POW)

ECM, energy corrected milk; uCP, utilizable crude protein at the duodenum;

NEL, net energy lactation; N, nitrogen;

CovS, covariance structure: ANTE(1), first-order antedependence structure;

CSH, heterogenous compound symmetry; SP(POW), spatial power law; SP(SPH), spatial spherical.

[1] *P* value of interaction treatment × stage of lactation = 0.004.

[2] *P* value of interaction treatment × stage of lactation = 0.002 and treatment × number of lactation = 0.005.

[3] g ECM kg^{-1} total intake of DM.

[4] g N milk kg^{-1} N consumed.

balance was significantly higher (+ 5 percentage points) in treatment M. Live weight change was slightly positive as well and did not differ. Ruminal N balance was significantly lower when the maize diet was fed. Feeding the ryegrass diet resulted in a gross N efficiency of 0.259, whereas feeding the maize diet resulted in a significantly higher gross N efficiency of 0.304.

Milk fatty acid profile

The effect of dietary treatment on milk fatty acid profile is summarized in Table 5. Of the main milk fatty acids palmitic, stearic, oleic and myristic acids, which together comprised approximately 700 g kg^{-1} total fat, only palmitic and myristic acids were affected by treatment. While myristic acid was significantly higher when the maize diet was fed, palmitic acid was significantly lower. Feeding the maize diet also resulted in a higher proportion of the *de novo* fatty acids C8:0-C14:0, as well as a higher proportion of linoleic acid, $n-6$ fatty acids and consequently a higher $n-6/n-3$ ratio. Proportions of vaccenic and rumenic acid and the sum of trans fatty acids were higher when the ryegrass diet was fed. Despite these differences in individual milk fatty acids, neither saturated fatty acids (SFA) nor mono-unsaturated fatty acid (MUFA) were influenced by treatment, only the poly-unsaturated fatty acids (PUFA) content was significantly increased when the maize diet was fed.

Discussion

This study was conducted to compare maize silage and Italian ryegrass silage as forage components in mixed basal diets for dairy cows under the conditions of Austrian organic agriculture. Despite the addition of adjusted amounts of barley and soybean cake to achieve isonitrogenous mixed basal diets, crude protein content was significantly higher in mixed basal diet R (including Italian ryegrass silage), while contents of uCP were slightly, but significantly higher in mixed basal diet M (including maize silage).

Feed composition, feed and nutrient intake

The DM content, fermentation quality and energy values of the silages ranged between good and ideal, except for the third cut of Italian ryegrass (see Table 1). Ash content of all samples of both ensiled cuts of Italian ryegrass (raw data not shown) was higher than 100 g kg^{-1} DM, indicating some contamination with soil particles during harvest. However, only in the third cut did this lead to higher levels of butyric acid and degradation of protein

Table 5. Fatty acid profile and groups of fatty acids of milk fat ($g\,kg^{-1}$ total fat) of organically managed dairy cows fed diets containing either maize silage or Italian ryegrass silage.

		Treatment			
		Maize	**Ryegrass**	**SD**	**P value**
Fatty acid					
Butyric acid	C4:0	42.6	44.3	3.62	**0.031**
Caproic acid	C6:0	24.8	24.1	10.18	0.204
Caprylic acid	C8:0	14.4	13.3	1.85	**0.006**
Capric acid	C10:0	31.0	28.0	5.25	**0.003**
Lauric acid	C12:0	35.1	31.3	5.56	**<0.001**
Myristic acid	C14:0	116	111	6.2	**0.008**
Palmitic acid	C16:0	313	332	34.1	**0.002**
Stearic acid	C18:0	95.7	91.5	14.68	0.358
Arachidic acid	C20:0	1.5	1.5	0.21	0.694
Behenic acid	C22:0	0.46	0.51	0.101	0.066
Oleic acid	C18:1 c9	182	178	25.3	0.246
Vaccenic acid	C18:1 t11	13.9	19.3	3.53	**<0.001**
Linoleic acid	C18:2 c9c12	14.8	11.6	2.68	**<0.001**
Rumenic acid	C18:2 c9t11	6.0	8.4	2.14	**<0.001**
α-linolenic acid	C18:3c9c12c15	4.8	5.5	1.05	**0.011**
γ-linolenic acid	C18:3 c6c9c12	0.35	0.32	0.162	0.384
Fatty acid groups					
SFA		698	696	33.6	0.688
MUFA		221	215	29.8	0.121
PUFA		23.5	21.1	2.78	**<0.001**
trans fatty acids		34.5	39.4	5.87	**<0.001**
$n-3$ fatty acids		6.8	7.5	1.19	**0.009**
$n-6$ fatty acids		17.0	13.5	2.78	**<0.001**
$n-6/n-3$ ratio		2.52	1.84	0.233	**<0.001**

SFA, saturated fatty acids; MUFA, mono-unsaturated fatty acids; PUFA, poly-unsaturated fatty acids.

to ammonia-N, probably due to the fact that the butyric-acid-producing clostridia prefer wet conditions[21]. The unusually low crude protein content of grass silage probably resulted from low amounts of clover in the grass-clover leys that provided part of the substrate.

The general level of intake of DM (17.0–18.4 kg, see Table 3) is in accordance with the average of 18.5 kg (13.0 kg forage plus 5.5 kg concentrates) observed by Gruber et al.[22] based on the analysis of an extensive database of 2151 lactating dairy cows. Important factors influencing forage intake are DM and energy content, and fermentation quality of the forage[23,24]. The ryegrass diet had the disadvantage of containing a wet, suboptimally fermented and low-energy third cut of Italian ryegrass, and consequently almost all parameters of feed intake were improved when the maize diet was fed. However, even the energy content of the well-preserved second cut of Italian ryegrass was numerically lower than the maize silage, therefore, the ryegrass diet would have had a lower energy content than the maize diet even without the added disadvantage of the suboptimally fermented third cut. When substituting parts of a maize-silage-based diet (312 g DM kg^{-1}) with Italian ryegrass silage (264 g DM kg^{-1}), Cooke et al.[25] found a significant positive relationship between the proportion of maize

silage and intake of DM, which is in accordance with the findings of the present study. However, Bernard et al.[9] report quite the reverse. In this study, cows showed numerically but not significantly, higher intakes of DM when Italian ryegrass was the sole forage as compared to maize silage (44.5% concentrates of total feed DM).

Milk yield and composition

There are frequent reports of a positive correlation between starch intake and milk yield, while milk fat content decreases[26–28]. Since the maize diet contained significantly more starch than the ryegrass diet, the difference in starch intake explains the higher milk yield and lower milk fat content when the maize diet was fed. Feeding trials comparing maize silage and Italian ryegrass silage as forage for high-yielding dairy cows (44–54% concentrates of total feed DM) do not give a consistent picture of the effect on milk yield. Neither Calabro et al.[29] nor Cooke et al.[10,25] report an effect when comparing Italian ryegrass silage as the sole forage to a mixture with maize silage, and when comparing total mixed rations with maize silage or Italian ryegrass silage, respectively. Bernard et al.[9], however, report higher intake of DM as well as higher milk yield when feeding Italian ryegrass silage as the sole

forage. Apart from severe undersupply with energy, milk lactose content is hardly ever influenced by feeding[30]; therefore, the lack of treatment effect on milk lactose content was to be expected.

Some of the most important dietary factors influencing milk fatty acid composition are fat intake, energy balance and proportion of starch in the diet.

Intake of ether extracts was significantly higher in treatment M. Although not measured in this experiment and although variation in the content of individual fatty acids is considerable, maize oil is generally higher in linoleic acid and lower in alpha-linolenic acid than grass silage[31]. As a result, cows fed the maize diet produced milk with significantly higher content of linoleic acid, $n-6$ fatty acids in general, and consequently a higher $n-6/n-3$ ratio. On the other hand, milk from cows fed the ryegrass diet contained significantly higher proportions of trans fatty acids in general and of vaccenic and rumenic acid specifically. Vaccenic and rumenic acid are intermediates of the biohydrogenation of dietary alpha-linolenic and linoleic acids in the rumen, and as the major conjugated linoleic acid isomers in milk fat they seem to be associated with positive effects on human health[32]. The $n-6/n-3$ ratio of 1.84 observed in treatment R is in accordance with levels reported by Fall and Emanuelson[33] for organically managed dairy cows during the indoor season, whereas the ratio of 2.52 observed in treatment M is considerably higher. In general, a lower ratio of $n-6/n-3$ fatty acids is more desirable for human consumption, but still the milk produced from all cows was well below the recommendations (5:1) given by DACH[34].

According to Walker et al.[28], the higher proportion of de novo fatty acids observed when the maize diet was fed can be explained by the fact that both energy intake and energy balance were significantly higher in treatment M. When substituting increasing parts of a grass silage based diet with maize silage, Kliem et al.[5] found an increasing proportion of de novo fatty acids as well. Usually, increasing starch intake at the expense of fiber is known to result in higher ruminal propionate and less acetate production. However, the slowly degradable starch in maize has also been shown to increase ruminal butyrate production[35], which, together with acetate, is a precursor of the de novo synthesized milk fatty acids. Therefore, the higher starch intake when the maize diet was fed had a positive effect on the proportion of the short and middle-chain fatty acids C8:0–C14:0. Also, both diets were based on grass silage and hay and therefore fiber was not a limiting factor. A higher proportion of myristic acid, but lower proportion of palmitic acid in milk fat when feeding maize silage has also been found by Nielsen et al.[27] who compared maize silage and grass silage as the sole forage for dairy cows. To summarize, even though the milk fatty acid profile showed some beneficial characteristics when the ryegrass diet was fed, the overall differences were small and are not expected to substantially influence human health.

Nutrient balances and efficiency of milk production

Positive nutrient balances and live weight change indicate an adequate supply of uCP and energy for all cows (see Table 4). Cows fed the maize diet had higher uCP intakes but also higher milk protein yields, therefore no difference in uCP balance was observed. Unlike uCP balance both ruminal N balance and milk urea content were significantly lower in treatment M; while the ruminal N balance observed in treatment R (9.4 g) indicates an adequate protein supply, the negative value of −29.4 g found in treatment M can be interpreted as a protein undersupply to ruminal microbes, according to the recommendations of GfE[18]. Milk urea content is used as a tool to monitor protein nutrition of dairy cows, because it reflects the N surplus for microbial synthesis in the rumen[36]. Nousiainen et al.[37] even report an adequate protein supply to microbes only at $251\,\mathrm{mg\,l^{-1}}$ milk urea content, without regarding N-recycling via the ruminohepatic circle. Compared to these results, the values measured in the experiment in question indicate that the protein supply to ruminal microbes was scarce when the ryegrass diet was fed (average milk urea content $137\,\mathrm{mg\,l^{-1}}$), and very scarce when the maize diet was fed (average milk urea content $78\,\mathrm{mg\,l^{-1}}$). When dairy cows are not adequately supplied with protein, at least part of the protein deficit can be mobilized from body tissue, before milk yield eventually starts to decline[38,39]. However, the fact that the protein-scarce maize diet resulted in significantly higher milk yields and did not cause negative live weight changes allows for the conclusion that scarce protein supply to the ruminal microbes did not (yet) harm the cows and their performance.

The observed feed efficiencies of $1.19–1.23\,\mathrm{kg}$ $\mathrm{ECM\,kg^{-1}}$ intake of DM lie within the range of previous reports about organically managed dairy cows, ranging from $1.11\,\mathrm{kg}$ $\mathrm{milk\,kg^{-1}}$ intake of DM when only $1.3\,\mathrm{kg}$ DM of concentrates were supplemented[40] (forage base consisted of grass–clover silage and maize silage) to $1.35–1.37\,\mathrm{kg}$ $\mathrm{ECM\,kg^{-1}}$ intake of DM when $10\,\mathrm{kg}$ DM of concentrates were supplemented[41] (forage base grass–clover silage). The gross N efficiency of 0.259 observed when feeding the ryegrass diet is similar to the level of 0.255 observed by Velik et al.[42] (forage-base grass–clover silage, supplemented with $3\,\mathrm{kg}$ DM of concentrates), but at the lower end of the range of 0.25–0.30 that according to Chase[43] can be considered as average, while the level of 0.304 achieved with the maize diet is already slightly above average. Although the biological potential of cows to convert feed N into milk N is limited, N efficiency can be improved by reducing feed N intake and thereby optimizing the use of microbial protein synthesis in the rumen[44]. Accordingly, the positive effect of the maize diet can be attributed to the fact that cows fed the maize diet had a lower intake of crude protein but a higher milk protein yield than cows fed the ryegrass diet. A positive

effect of including maize silage in grass-silage-based diets on N efficiency has also been found by Givens and Rulquin[45], who reviewed numerous feeding trials. They attributed the effect to a better energy supply to the ruminal microbes and therefore enhanced synthesis of microbial protein, whereas in the experiment in question the effect of lower crude protein intake might have been more important.

Conclusions

Including maize silage at a rate of 40% (of DM) in a grass-silage-based diet for dairy cows and the conditions of Austrian organic agriculture was found to result in a significantly higher intake of DM and milk yield than including Italian ryegrass silage. The significantly lower intake of crude protein when feeding the maize diet as compared to the ryegrass diet, in combination with a higher milk protein yield, enabled an efficiency of gross N utilization as high as 0.304 when the maize diet was fed. This was significantly and considerably higher than the level of 0.259 observed when the ryegrass diet was fed. Therefore, maize silage upholds its reputation as an ideal energy-rich component in grass-silage-based dairy cow diets, and as long as it can be easily incorporated into crop rotation, its cultivation is recommended.

References

1 Statistik Austria. 2010. Agrarstrukturerhebung 2010 [Agricultural Structure Survey 2010]. Self-publishing, Vienna, Austria. p. 33.

2 Weller, R.F. and Bowling, P.J. 2007. The importance of nutrient balance, cropping strategy and quality of dairy cow diets in sustainable organic systems. Journal of the Science of Food and Agriculture 87:2768–2773.

3 Burke, F., Murphy, J.J., O`Donovan, M.A., O`Mara, F.P., Kavanagh, S., and Mulligan, F.J. 2007. Comparative evaluation of alternative forages to grass silage in the diet of early lactation dairy cows. Journal of Dairy Science 90:908–917.

4 Keady, T.W.J., Kilpatrick, D.J., Mayne, C.S., and Gordon, F.J. 2008. Effects of replacing grass silage with maize silages, differing in maturity, on performance and potential concentrate sparing effect of dairy cows offered two feed value grass silages. Livestock Science 119:1–11.

5 Kliem, K.E., Morgan, R., Humphries, D.J., Shingfield, K.J., and Givens, D.I. 2008. Effect of replacing grass silage with maize silage in the diet on bovine milk fatty acid composition. Animal 2(12):1850–1858.

6 George, R.A.T. 2011. Agricultural Seed Production. CAB International, Wallingford, UK.

7 Tamburini, A., Rapetti, L., Crovetto, G.M., and Succi, G. 1995. Rumen degradability of dry matter, NDF and ADF in Italian ryegrass (*Lolium multiflorum*) and winter cereal silages. Zootecnica e Nutrizione Animale 21(Suppl.):75–80.

8 Baldinger, L., Baumung, R., Zollitsch, W., and Knaus, W.F. 2011. Italian ryegrass silage in winter feeding of organic dairy cows: Forage intake, milk yield and composition. Journal of the Science of Food and Agriculture 91 (3):435–442.

9 Bernard, J.K., West, J.W., and Trammell, D.S. 2002. Effect of replacing corn silage with annual ryegrass silage on nutrient digestibility, intake, and milk yield for lactating dairy cows. Journal of Dairy Science 85(9):2277–2282.

10 Cooke, K.M., Bernard, J.K., and West, J.W. 2008. Performance of dairy cows fed annual ryegrass silage and corn silage with steam-flaked or ground corn. Journal of Dairy Science 91(6):2417–2422.

11 FAO [Food and Agriculture Organization of the United Nations]. 2009. Crop Water Information: Maize. Available at Web site http://www.fao.org/nr/water/cropinfo_maize.html (verified May 21, 2013).

12 Dietl, W. and Lehmann, J. 2004. Ökologischer Wiesenbau [Organic Grassland Production]. Österreichischer Agrarverlag, Leopoldsdorf, Austria.

13 Freyer, B. 2003. Fruchtfolgen—Konventionell, Integriert, Biologisch [Crop Rotations—Conventional, Integrated, Organic]. Eugen Ulmer, Stuttgart, Germany.

14 The European Parliament and the Council of the European Union. 2010. Directive 2010/63/EU of the European Parliament and of the Council of 22 September 2010 on the protection of animals used for scientific purposes. Official Journal of the European Union 276:33–79.

15 Federal Law Gazette 198/2000 for the Austrian republic of 30 June 2000 on the Act of Animal Experiments. Available at Web site http://www.bmwf.gv.at/fileadmin/user_upload/forschung/recht/tierversuche/tvvo.pdf (accessed July 28, 2013).

16 VDLUFA [Association of German Agricultural Analytic and Research Institutes] (ed.). 1993. Handbuch der Landwirtschaftlichen Versuchs- und Untersuchungsmethodik (VDLUFA-Methodenbuch), Band III: Die chemische Untersuchung von Futtermitteln [Handbook of Agricultural Experimental and Analytical Methods, Volume III: The chemical analysis of feedstuffs]. VDLUFA-Verlag, Darmstadt, Germany.

17 Lebzien, P. and Voigt, J. 1999. Calculation of utilizable crude protein at the duodenum of cattle by two different approaches. Archives of Animal Nutrition 52(4):363–369.

18 GfE [Society of Nutrition Physiology]. 2001. Empfehlungen zur Energie- und Nährstoffversorgung der Milchkühe und Aufzuchtrinder [Recommendations on the energy and nutrient supply for dairy cows and heifers]. DLG-Verlag, Frankfurt am Main, Germany.

19 SAS. 2002. Software, Release 9.1.3. SAS Institute Inc., Cary, NC, USA.

20 Wang, Z. and Goonewardene, L.A. 2004. The use of MIXED models in the analysis of animal experiments

with repeated measures data. Canadian Journal of Animal Science 84(1):1–11.

21 Wilkinson, J.M. 2005. Silage. Chalcombe Publications, Lincoln, UK.

22 Gruber, L., Schwarz, F.J., Erdin, D., Fischer, B., Spiekers, H., Steingaß, H., Meyer, U., Chassot, A., Jilg, T., Obermaier, A., and Guggenberger, T. 2005. Prediction equations for feed intake of lactating dairy cows. Proceedings of the Society of Nutrition Physiology 14:42.

23 Huhtanen, P., Khalili, H., Nousiainen, J.I., Rinne, M., Jaakkola, S., Heikkilä, T., and Nousiainen, J. 2002. Prediction of the relative intake potential of grass silage by dairy cows. Livestock Production Science 73(2–3):111–130.

24 Krizsan, S.J., Westad, F., Ådnøy, T., Odden, E., Aakre, S.E., and Randby, Å.T. 2007. Effect of volatile compounds in grass silage on voluntary intake by growing cattle. Animal 1(2):283–292.

25 Cooke, K.M., Bernard, J.K., and West, J.W. 2009. Performance of lactating dairy cows fed ryegrass silage and corn silage with ground corn, steam-flaked corn, or hominy feed. Journal of Dairy Science 92(3):1117–1123.

26 Murphy, J.J. and O´Mara, F. 1993. Nutritional manipulation of milk protein concentration and its impact on the dairy industry. Livestock Production Science 35(1–2):117–134.

27 Nielsen, T.S., Straarup, E.M., Vestergaard, M., and Sejrsen, K. 2006. Effect of silage type and concentrate level on conjugated linoleic acids, trans-C18:1 isomers and fat content in milk from dairy cows. Reproduction Nutrition Development 46(6):699–712.

28 Walker, G.P., Dunshea, F.R., and Doyle, P.T. 2004. Effects of nutrition and management on the production and composition of milk fat and protein: A review. Australian Journal of Agricultural Research 55(10):1009–1028.

29 Calabro, S., Caligiuri, A., Piccolo, V., and Infascelli, F. 2004. Insilato di loiessa e silomais nell'alimentazione della vacca [Italian ryegrass silage and maize silage as feed for cows]. Informatore Agrario 60(32):37–44.

30 Chalupa, W. and Sniffen, C.J. 2000. Balancing rations for milk components. Asian-Australasian Journal of Animal Sciences 13(Suppl.):388–396.

31 Khan, N.A., Cone, J.W., Fievez, V., and Hendriks, W.H. 2012. Causes of variation in fatty acid content and composition in grass and maize silages. Animal Feed Science and Technology 174(1–2):36–45.

32 Bauman, D.E., Lock, A.L., Corl, B.A., Ip, C., Salter, A.M., and Parodi, P.W. 2006. Milk fatty acids and human health: Potential role of conjugated linoleic acids and trans fatty acids. In K. Sejrsen, T. Hvelplund, and M.O. Nielsen (eds). Ruminant Physiology—Digestion, Metabolism and Impact of Nutrition on Gene Expression, Immunology and Stress. Wageningen Academic Publishers, Netherlands. p. 529–561.

33 Fall, N. and Emanuelson, U. 2011. Fatty acid content, vitamins and selenium in bulk tank milk from organic and conventional Swedish dairy herds during the indoor season. Journal of Dairy Research 78(3):287–292.

34 DACH. 2008. Referenzwerte für die Nährstoffzufuhr [Reference Values for the Nutrient Supply]. Umschau Braus, Frankfurt am Main, Deutschland.

35 Chilliard, Y., Ferlay, A., Mansbridge, R.M., and Doreau, M. 2000. Ruminant milk fat plasticity: Nutritional control of saturated, polyunsaturated, trans and conjugated fatty acids. Annales de Zootechnie 49(3):181–205.

36 Hof, G., Vervoorn, M.D., Lenaers, P.J., and Tamminga, S. 1997. Milk urea nitrogen as a tool to monitor the protein nutrition of dairy cows. Journal of Dairy Science 80 (12):3333–3340.

37 Nousiainen, J., Shingfield, K.J., and Huhtanen, P. 2004. Evaluation of milk urea nitrogen as a diagnostic of protein feeding. Journal of Dairy Science 87(2):386–398.

38 National Research Council. 2001. Nutrient Requirements of Dairy Cattle. 7th ed. National Academy Press, Washington, DC, USA.

39 Van Soest, P.J. 1994. Nutritional Ecology of the Ruminant. 2nd ed. Cornell University Press, Ithaca, New York, USA.

40 Velik, M., Baumung, R., Zollitsch, W., and Knaus, W.F. 2007. Effects of partial substitution of concentrates by maize silage on performance and feed efficiency in organic dairy cow rations. Journal of the Science of Food and Agriculture 87(14):2657–2664.

41 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(1–3):202–215.

42 Velik, M., Baumung, R., and Knaus, W.F. 2007. Maize silage as an energy supplement in organic dairy cow rations. Renewable Agriculture and Food Systems 23(2):155–160.

43 Chase, L.E. 2003. Nitrogen utilization in dairy cows—what are the limits of efficiency? In Proceedings of the Cornell Nutrition Conference for Feed Manufacturers, Syracuse, New York, October 21–23, 2003. Cornell University Press, Ithaca, NY, USA. p. 233–245.

44 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(3):217–228.

45 Givens, D.I. and Rulquin, H. 2004. Utilisation by ruminants of nitrogen compounds in silage-based diets. Animal Feed Science and Technology 114(1–4):1–18.