Effects of Increasing the Proportion of High-Quality Grass Silage in the Diet of Dairy Cows

Mikaela Patel
Faculty of Veterinary Medicine and Animal Science
Department of Animal Nutrition and Management
Uppsala

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Cover: 1369 Ada, eating grass silage at Kungsängen Research Centre in 2009.
(photo: M. Patel)

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Abstract

The Swedish dairy cow has almost doubled its annual milk yield over a few decades. This has simultaneously led to an increase in the dietary proportion of concentrate in order to meet the increased nutritional requirement of dairy cows. The proportion of forage is often below 50% of dry matter (DM) intake in conventional dairy production on an annual basis. However, the regulations for organic dairy production stipulate a minimum of 60% DM of forage in the diet, with a permissible decrease to 50% in early lactation. The price of concentrate is currently high, so feed is a large expense for dairy farmers and has a large impact on total farm profits. Since the techniques for forage preservation have improved, enabling earlier harvesting, the nutritional quality of grass silage has increased. This may allow partial replacement of concentrate by high-quality grass silage without any adverse effects on milk production. This thesis examined the effects of replacing concentrate with grass silage of high nutritional quality over the entire lactation. The effects were examined for milk production, enteric methane emissions, milk fatty acid composition and profitability.

Over two consecutive years, a total of 92 dairy cows were randomly assigned to one of three diets that differed in the proportion of forage. After peak lactation, from lactation month four, the proportion of forage was gradually increased over the entire lactation up to a maximum in late lactation of 50%, 70% or 90% on a DM basis.

Overall, increasing the dietary proportion of silage up to 70% in late lactation did not significantly affect milk yield compared with feeding 50% silage. Positive effects were shown in terms of milk fatty acid composition and profitability. Increasing in the dietary proportion up to 90% silage in late lactation significantly decreased milk production, but the positive effects on milk fatty acids persisted. Enteric methane emissions showed a tendency to increase with increasing proportion of silage in the diet. The overall conclusion was that there is great potential for increasing the proportion of high-quality grass silage in the diet of high-yielding dairy cows after peak lactation, up to 70% silage in late lactation.

Keywords: milk yield, forage-to-concentrate ratio, feed utilisation, greenhouse gas, sulphur hexafluoride, fatty acid, economy, milk income over feed cost

Author's address: Mikaela Patel, SLU, Department of Animal Nutrition and Management, Kungsängen Research Centre, SE-753 23 Uppsala, Sweden
E-mail: Mikaela.Patel@slu.se

The friendly cow all red and white,
I love with all my heart:
She gives me cream with all her might,
To eat with apple-tart.

“The Cow” by Robert Louis Stevenson, 1885

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Patel, M., E. Wredle, E. Spörndly and J. Bertilsson. Replacing concentrate with high-quality grass silage in diets for dairy cows after peak lactation. (manuscript, submitted to *Livestock Science*).

II Patel, M., G. Börjesson, R. Danielsson, A.D. Iwaasa, E. Spörndly, E. Wredle and J. Bertilsson. (2011). Enteric methane emissions from dairy cows fed different proportions of highly digestible grass silage. *Acta Agriculturae Scandinavica, Section A - Animal Science* 61:3, 128-136.

III Patel, M., E. Wredle and J. Bertilsson. (*In press*). Effect of dietary proportion of grass silage on milk fat with emphasis on odd- and branched-chain fatty acids in dairy cows. *Journal of Dairy Science* (2012), doi:10.3168/jds.2012-5441.

IV Patel, M., E. Wredle, E. Spörndly, J. Bertilsson and K.-I. Kumm. Profitability of organic and conventional dairy production with different dietary proportions of high-quality grass silage. (manuscript, submitted to *Organic Agriculture*).

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Abbreviations

AIA	acid insoluble ash
BCS	body condition score
BW	body weight
CH_4	methane
CLA	conjugated linoleic acid
CO_2	carbon dioxide
CP	crude protein
DM	dry matter
DMI	dry matter intake
ECM	energy corrected milk
FA	fatty acid/fatty acids
GC	gas chromatography
GHG	greenhouse gases
INDF	indigestible neutral detergent fibre
k_l	apparent efficiency of ME utilisation for milk production
LCA	life cycle assessment
ME	metabolisable energy
ME_m	metabolisable energy for maintenance
MIOFC	milk income over feed cost
MJ	megajoule
NDF	neutral detergent fibre
OBCFA	odd- and branched chain fatty acids
OM	organic matter
OMD	organic matter digestibility
SF_6	sulphur hexafluoride
VFA	volatile fatty acids
Y_m	methane conversion factor from gross energy

1 Introduction

In a few decades, the structure of Swedish dairy production has undergone major changes, from 688,000 cows and 77,300 herds in 1974 to 346,000 cows and 5,300 herds in 2011 (Swedish Board of Agriculture, 2007a; Swedish Board of Agriculture, 2012c). During the same period, the average annual milk yield of a Swedish dairy cow in the official milk recording scheme has increased from 5,500 kg to 9,500 kg energy corrected milk (ECM) (Swedish Dairy Association, 2012a). Similar changes have occurred in other countries with intensive dairy production. The change in milk yield is due to several improvements in dairy farming over the years, *e.g.* feeding routines, feed quality and management, as well as genetic improvement of the cows (Lindgren *et al.*, 1983). The enhanced milk yield has simultaneously led to an increase in the proportion of concentrates in the diet of dairy cows in order to achieve more energy-dense diets. The low price of cereal grain over periods of time may have contributed to the increased use of concentrates in dairy cow diets. However, the techniques for harvesting and forage preservation have improved since the 1970s, and it is now possible to cut and preserve large quantities of forage at an early stage of maturity, as silage instead of hay. Early harvesting enhances the possibilities for high nutritional value in forage, which makes it an interesting alternative to concentrates in the dairy cow diet.

The price of concentrates has been fluctuating during the last few years, and is at present high. The current situation makes the dairy cow diet, which consists of 50-60% concentrate on an annual basis in conventional Swedish production (Emanuelson *et al.*, 2006), very expensive for the farmer. In contrast, the regulations for organic dairy production stipulate at least 60% forage in the diet (EC, 2008), and consumer demand for organic milk has grown rapidly during the last decade. However, feed is a large expense item for dairy farmers regardless of production system, and measures for lowering the costs of feed will have an impact on the total profitability of the farm.

The impact of animal production on the environment was highlighted in the report “Livestock’s Long Shadow” (Steinfeld *et al.*, 2006) published by the United Nations Food and Agriculture Organization. Since then, the role of livestock in global warming has been thoroughly discussed world-wide. Particular focus has been on mitigation of methane (CH_4) emissions from ruminants, since these contribute substantially to the total emissions of greenhouse gases from livestock.

The public’s interest in, and the supply of, so-called “functional foods” has increased during the past few years. In dairy products, components having health benefits may be attributed to *e.g.* proteins, vitamins, minerals and certain fatty acids (FA) (Lock & Bauman, 2003). The possibilities to study milk components in detail have been facilitated through the improvement of methods, *e.g.* analyses of milk FA. The nutrient supply of the cow may to some degree be reflected in the milk FA composition, which possibly makes it useful as a future farm management tool.

The conditions for dairy farming have changed in many ways during recent decades, as briefly described above. Therefore, the main objective of the present work was to investigate the possibility of using high-quality grass silage to a larger extent in dairy cow diets, as a sustainable alternative for the future. The term ‘sustainable’ is used in a variety of disciplines and can have different meanings. However, a general definition was adopted by the United Nations in 1987:

> “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” (World Commission on Environment and Development, 1987)

Sustainability in the farmers’ perspective, if concentrates are to be replaced with high-quality grass silage, may include: maintained or improved milk production and milk composition, increased profitability and unaltered or mitigated CH_4 production. These issues were thus investigated in the present thesis.

2 Background

2.1 High-Quality Grass Silage

Cows are grazers and physically designed to eat forage, which is thus an essential part of the dairy cow ration. Forage contains fibrous material which stimulates rumination and maintains the normal function of the rumen. The unique ability and necessity of ruminants to utilise fibre as feed depends on their symbiosis with rumen microbiota. During rumen fermentation, volatile fatty acids (VFA), which are utilised by the ruminants as nutrients, are produced by the microbes.

The characteristics of forages depend on *e.g.* plant species, climate conditions, fertilisation regime, stage of maturity at harvest, dry matter (DM) content, method of preservation and hygienic quality. While the plant matures, the proportions of protein and lipid decrease and the neutral detergent fibre (NDF) content, *i.e.* hemicellulose, cellulose and lignin, increases (Beever *et al.*, 2000). The composition of the plant changes particularly at the time of stem elongation. The digestibility of the fibre is related to the lignin content, since lignin is indigestible to the ruminant. Thus, concurrently with increased lignification, the proportion of organic matter digestibility (OMD) decreases over time. In general, grasses have a higher proportion of NDF compared with legumes, but the proportion of lignin in total NDF is higher in legumes (Beever *et al.*, 2000). Several studies have shown increased intake and higher milk yields with legume silages compared with grass silages (Bertilsson & Murphy, 2003; Dewhurst *et al.*, 2003b). However, the cultivation and preservation of pure legume silages may be difficult due to losses of leaf material during handling and high buffer capacity during ensiling (Merry *et al.*, 2000). If proper ensiling and low pH are not achieved, the hygienic quality of the silage may be impaired, resulting in *e.g.* high levels of butyric and acetic acids and ammonia. Deteriorated silage will be less nutritious and will discourage intake by the animals.

The lipid content of grass and legumes is low, approximately 2-3% of DM, and the lipids consist of glycolipids, phospholipids, waxes, sterol esters and free FA. Most of the lipids are found in the leaf chloroplasts and they contain high proportions of α-linolenic acid (C18:3n-3) and linoleic acid (C18:2n-6). These essential FA can be transferred from feeds to milk and meat. The concentrations of FA in grass are highest in the spring and autumn, but FA concentrations can be maintained through harvest of regrowth before flowering (Dewhurst *et al.*, 2001). Some studies have shown that processes associated with ensiling, such as field wilting, decrease the concentration of C18:3n-3 (Boufaïed *et al.*, 2003; Dewhurst *et al.*, 2003c). However, Arvidsson *et al.* (2009) did not detect any such decrease in grass silage of timothy (*Phelum pratense* L.) with short-term wilting to 33-35% DM.

2.2 Enteric Methane

Methane is a potent greenhouse gas, with approximately 25 times the effect of carbon dioxide (CO_2) (Forster *et al.*, 2007). Enteric CH_4 is produced during the fermentation of feeds, and most of it originates from the rumen. Through oxidative fermentation in the rumen, hydrogen is released and to avoid accumulation and an associated decrease in pH, CO_2 is reduced to CH_4 by methanogens. The production of CH_4 represents a 2-12% loss of ingested gross energy for the animal. There is large variability in CH_4 losses and the more digestible the diet, the more variable the CH_4 production. The CH_4 production is influenced by *e.g.* the amount of feed consumed, the rate of digestion and the production of different VFA. Energy losses decrease when feed intake increases, especially when highly digestible feeds are used (Johnson & Johnson, 1995). Starch-rich diets increase propionate production in the rumen, and fermentation of fibrous feeds increases the production of acetate and butyrate (Moe & Tyrrell, 1979). The production of acetate and butyrate results in surplus hydrogen, which favours CH_4 formation. The production of propionic acid requires hydrogen and is therefore an alternative hydrogen sink to the formation of CH_4 (McAllister *et al.*, 1996; Beauchemin *et al.*, 2008).

Several dietary strategies to mitigate enteric CH_4 from ruminants have been investigated, such as changes in dietary composition and inclusion of additives. A well-known strategy is to increase the proportion of concentrate in the diet. The effect is most pronounced when the dietary proportion of concentrate exceeds 80% in the diet of beef cattle. The decrease in acetate:propionate ratio and decrease in pH associated with starch-rich diets cause a decrease in CH_4

production (Beauchemin *et al.*, 2008). However, a starch-rich diet is not an option for dairy cows, since it would jeopardise health and welfare, in addition to having adverse effects on milk fat. Other dietary means to decrease CH_4 emissions include changing from grass to legume forages or including tannin-rich legumes. Addition of lipids to the diet decreases CH_4 emissions, but the effects seems transitory, and high levels of dietary lipid can have adverse effects on milk fat (Beauchemin *et al.*, 2008).

2.3 Milk Fatty Acids

Milk fat consists of approximately 98% triacylglycerol, *i.e.* three FA chains esterified to a glycerol molecule. The remaining 2% consists of phospholipids, cholesterol, 1,2-diacylglycerol, monoacylglycerol and free FA (Jensen, 2002). A typical characteristic of bovine milk is the presence of the short-chain FA C4:0 and C6:0, and a large proportion of even-numbered and saturated FA. There are approximately 400 different FA in cow milk and the approximate distribution is 70% saturated FA, 25% monounsaturated FA and 5% polyunsaturated FA (Grummer, 1991).

The FA composition can be altered by dietary changes, *e.g.* through different forage-to-concentrate ratios, or by addition of lipid supplements. When the feeds are fermented in the rumen, VFA are produced. Of these, acetate and butyrate (converted to β-hydroxybutyrate in the rumen wall) are precursors of short- and medium-chain milk FA in the *de novo* synthesis which occurs in the mammary gland. When feed lipids (mainly triacylglycerides from seeds and galactolipids from plant leaves) enter the rumen, the first step is hydrolysis by microbial lipases, which means that the FA are released from the glycerol or the galactose. The next step is biohydrogenation by rumen bacteria, a process where unsaturated FA are saturated through the addition of hydrogen to the double bonds. The feed FA are absorbed by the intestines and transported to the mammary gland. During periods of body fat mobilisation, non-esterified FA from adipose tissue are released in the plasma and taken up by the mammary gland. The FA originating from feed and from body fat are so-called preformed FA and are precursors for the long-chain FA in milk. In contrast to biohydrogenation, FA can be desaturated in the mammary gland by the enzyme Δ^9-desaturase, mainly C18:0 to C18:1 or C18:1 to C18:2, in order to decrease the melting point, and thus facilitate milk secretion (Dils, 1986; Chilliard *et al.*, 2000).

Of the total amount of FA, 2-3% are odd- and branched-chain FA (OBCFA) derived from the membrane lipids of rumen microbes. It has been shown that certain OBCFA are correlated to cellulolytic bacteria while others are correlated to amylolytic bacteria. The correlation between milk OBCFA and rumen VFA (Vlaeminck *et al.*, 2006b) and the correlation with duodenal flow of microbial protein (Cabrita *et al.*, 2003; Vlaeminck *et al.*, 2005) make the OBCFA possible markers and a non-invasive tool to assess nutrient supply to cows. The correlation with rumen VFA also means that the OBCFA can be useful as predictors of ruminal acidosis (Colman *et al.*, 2010; AlZahal *et al.*, 2011).

Unsaturated FA are considered more healthy for humans than saturated FA, which are regarded as inducers of cardiovascular disease (especially C12:0, C14:0 and C16:0) (Ohlsson, 2010). Different dairy cow diets have been investigated in order to increase the proportion of unsaturated FA at the expense of saturated FA in milk fat. It has been shown that inclusion of plant or marine oil supplements has the greatest effects on FA composition in terms of changing towards an increased proportion of unsaturated FA in milk (Chilliard *et al.*, 2007). The major unsaturated FA in cow milk are: C18:1*c*-9, C18:2n-6, C18:3n-3 and conjugated linoleic acid C18:2*c*-9, *t*-11 (CLA). The conjugated linoleic acids consist of several isomers, of which C18:2*c*-9, *t*-11 dominates in cow milk. Hence, in this thesis CLA refers to C18:2*c*-9, *t*-11. Another measure of healthy fat composition is the ratio between C18:2n-6 and C18:3n-3 (n-6:n-3). The lower the ratio, the healthier the composition of the fat (Simopoulos, 2002). Comparisons of the effect of conventional vs. organic dairy cow diets on milk FA composition show that the concentrations of beneficial FA and lower n-6:n-3 ratio are higher in organic milk (Butler *et al.*, 2011; Fall & Emanuelson, 2011).

2.4 Dairy Farm Profitability

The profitability of Swedish dairy farms has fluctuated over the past decade, and is currently low in both conventional and organic production systems (Swedish Dairy Association, 2012b). The high feed costs and currently low milk price in combination with high costs of farm buildings, energy and labour are possible causes of the present situation. The farm buildings used in the past are often not suitable for extension or conversion to free-stall houses. Thus, an expanded herd size often implies large investments. Approximately 50% of Swedish dairy cows are housed in free-stall buildings, and free-stalls are mandatory in newly built houses and in all organic dairy herds of ≥45 cows (KRAV, 2012). Planning for large investments requires thorough economic analysis to ensure that these are sustainable, although a simplified key figure often used is milk income over feed cost (MIOFC). The MIOFC can be useful as a short-term tool, to decide when to purchase feeds or make changes to the ration. The Swedish milk price is dependent on prices on the global dairy market, which are currently low, mainly due to overproduction of milk in the major milk producing countries: the European Union (EU), USA, Australia and New Zealand (Swedish Board of Agriculture, 2012a). Organic dairy herds have higher MIOFC than conventional herds (Swedish Dairy Association, 2012b), despite 8-10% less milk per 305-d lactation (Sundberg *et al.*, 2009). Although the price paid for organic milk is higher, organic concentrate is much more expensive than conventional concentrate, and organic production relies more on forage than conventional production.

Grain prices are currently high, mainly due to drought in the USA, southern Europe and Russia. In a future perspective, the prices may increase even more due to the increasing use of grains in *e.g.* biofuels (Swedish Board of Agriculture, 2009). The economic advantage of using high-quality forage compared with grain in the diet of dairy cows is the lower production costs due to the environmental payments from the EU in the production of leys. Another important advantage is that farmers are less dependent on the global feed market when using home-grown feeds.

3 Aims of the Thesis

The general aim of this thesis was to study the effects of feeding three different dietary proportions of high-quality grass silage to dairy cows. The diets corresponded to a common conventional diet and two diets with higher proportions of forage. The latter diets followed the standards set for organic production regarding proportion of forage. The experimental strategy adopted was to increase the proportion of silage to different degrees after peak lactation and then study the effects on milk production, feed utilisation and enteric methane production in dairy cows. Furthermore, the fatty acid composition in milk fat was studied, with the emphasis on the OBCFA, and the economic profitability when using the different diets was evaluated.

The hypotheses tested in Papers I-IV were that:

I Increasing the dietary proportion of silage would decrease milk production over the lactation, and would result in lowered feed utilisation even with a moderate increase in silage proportion, from 50% to 60%.

II An increased dietary proportion of silage would increase the enteric CH_4 emissions.

III Increasing the dietary proportion of silage would be reflected in the milk FA composition and the OBCFA could be correlated to the fibre content of the diet, and could thus be used as a marker for forage intake.

IV Increasing the dietary proportion of silage from 50% to 60% over the lactation would increase the economic profitability due to lower feed costs, despite assumed lower milk yield.

4 Materials and Methods

The main component of the work was a large two-year study on milk production using 92 dairy cows over the entire lactation (Paper I). The design of the experiment was to feed grass silage *ad libitum* and adjust concentrate to a pre-determined forage proportion of 40% or 50% of DM intake (DMI) during the first 12 weeks of lactation. After peak lactation, when feed intake was established, the proportion of grass silage was gradually increased over the entire lactation. Complementary experiments were performed to investigate interesting side-effects of the different diets (Papers II and III). Furthermore, calculations of profitability of these diets under different farm management situations were performed (Paper IV). A short description of the methods used in Papers I-IV follows below. For Paper IV, only the methods used for calculations of profitability are described, as the calculations were based on the results from the animal experiment in Paper I.

4.1 Animals, Housing and Experimental Design

All cows were of the Swedish Red Breed, and the experiments were performed at the Kungsängen Research Centre of the Swedish University of Agricultural Sciences, Uppsala, Sweden. In total, during two subsequent years, 92 cows (60 multiparous and 32 primiparous) were included in the experiment described in Paper I. The cows were completely randomised into three groups to be fed different diets over the entire lactation (see Table 1 and the description in the next section). The cows calved in autumn or early in the winter season, entered the experiment during the first week after calving, and remained until week 44 of lactation. Of the cows used in Paper I, 50 cows (34 multiparous and 16 primiparous) were used in Paper III. These were cows that had reached lactation week 25, in order to have as large differences as possible in dietary proportion of silage between the groups (see Table 1). The cows were housed indoors in a free-stall building with an automatic milking system (VMS™, DeLaval International AB, Tumba, Sweden). Body weight (BW) and body condition score (BCS) were recorded on two consecutive days at calving, and then every fourth week throughout the lactation. Milking permissions were set to every sixth hour with a maximum of 12 hours between milkings. During the experimental period in Paper III, the milking permission was set to 12 hours to obtain regular intervals. During the summer season the cows had access to pasture in accordance with the Swedish Animal Welfare Act and the Animal Welfare Ordinance (SFS 1988:534, 1988; SFS 1988:539, 1988).

In Paper II, six rumen-fistulated lactating cows were used in a duplicated 3×3 Latin square change-over design. The study consisted of three trial periods of 25 days, including 20 days of adaptation to the diet and five days of measurements. The cows were housed indoors and tied up in individual stalls. Milking was performed twice daily, in the morning at 06.00 and in the evening at 16.30 h.

The cows were managed according to the Swedish Animal Welfare Act (SFS 1988:534, 1988), the Animal Welfare Ordinance (SFS 1988:539, 1988) and the European Communities Council directive 86/609/EEC. The experiments were approved by the Uppsala Local Ethics Committee C/173/6 and C/29/8.

Table 1. *Experimental design of the study described in Paper I, with gradually increasing dietary proportions of silage in the three treatment groups, over the entire 44 weeks of lactation*

	Forage proportion % of DMI		
Diet	Week 1 to 12[1]	Week 13 to 24[1,2]	Week 25 to 44[1,2]
Low (L)	40	40	50
Medium (M)	50	60	70
High (H)	50	70	90

1. Grass silage *ad libitum* and the amount of concentrate adjusted to achieve the pre-determined forage %.
2. Intake was restricted if it exceeded 110% of the cow's energy requirement, according to the Swedish feeding recommendations (Spörndly, 2003).

4.2 Experimental Diets, Feeds and Feeding

The three treatments, low (L), medium (M) and high (H), differed in the dietary proportion of silage on a DM basis in terms of mean total and of different degrees of increase over the entire lactation. During the first 12 weeks of lactation, the cows were fed grass silage *ad libitum* and concentrate was adjusted weekly to the intake of silage, to maintain the pre-determined forage proportions. From lactation week 13 until drying off, the proportion of silage was gradually increased, see Table 1. Intake was restricted if it exceeded 110% of the cow's calculated energy requirement according to the Swedish feeding recommendations (Spörndly, 2003). Minimum daily individual amount of silage was set to 8 kg DM. The feed rations were adjusted when needed, at most by 10% (DM basis), once a week according to calculated energy requirements.

In Paper II, it was decided to examine the effects of dietary proportions of silage using the diets with the largest differences. Thus, the treatments were 50%, 70% and 90% silage in the diet (DM basis). Due to the experimental design, the feeding level was fixed from the start of the experiment and left unchanged until terminated.

Since the cows were simultaneously part of the experiments described in Papers I and III, the dietary proportion of silage in Paper III was dependent on days in milk of the individual cow. The average dietary proportion of silage (DM basis) on diet L, M and H was 49%, 69% and 86%, respectively, in Paper III.

The same types of feeds were used in all experiments. The silage was made from leys dominated by timothy (*Phelum pratense* L.), meadow fescue (*Festuca pratensis* L.) and some (<10%) red clover (*Trifolium pratense* L.). The ingredients in the pelleted concentrate were (% of feed): oats (23.4), barley (23.2), peas (20.0), rapeseed cake (12.5), beet fibre (9.0), wheat bran (7.0), whole crushed rapeseed (2.5), minerals and vitamins (2.4). During the pasture season, the cows on diet L had access to exercise pasture and they were fed their rations of silage and concentrate indoors. The cows on diets M and H had access to pasture with an estimated allowance of >25 kg DM/cow per day, and were only fed concentrate indoors during the pasture period. The cows had free access to water cups, salt licks and minerals. The cows in the free-stall house in Papers I and III had access to feeding stations for concentrate and forage mangers placed on weighing cells, for control and recording of individual feed intake. The feeds were accessible directly or via the milking unit throughout 24-h. The tied cows in Paper II were fed silage and concentrate simultaneously in individual feed troughs four times per day.

4.3 Sample Collections and Analyses

4.3.1 Feeds

In Papers I and III, samples of silage were collected five days per week, immediately frozen at -20 ^{o}C and pooled into one sample over a 14-day period. Concentrate was sampled twice a week and pooled into one sample per 28-day period in Papers I and IV. In Paper III, concentrate was pooled into one sample over a 14-day period. In Paper III, the pooled samples were divided into two, one for chemical analyses and one for FA analyses. In Paper II, the two feeds were sampled daily during the measurement periods and pooled into one sample per period. Conventional chemical analyses and calculations of metabolisable energy (ME) were performed as described by Bertilsson & Murphy (2003). Indigestible NDF (INDF) of the silage in Papers I and II was determined according to Åkerlind *et al*. (2011). Crude fat in Paper III was determined according to EC (2009). In Paper II, gross energy content was determined on fresh samples of silage using an isoperibol calorimeter and acid-insoluble ash (AIA) was analysed according to Van Keulen & Young (1977). Extraction of feed lipids was performed using the method described by Folch *et al.* (1957) and the extracts were methylated according to Appelqvist (1968) and analysed by gas chromatography (GC).

4.3.2 Milk

Milk yield was recorded automatically at each milking in Papers I and III. Milk samples were withdrawn from the VMS™ every 14 days during a 24-h milking in Paper I. In Paper III, milk samples were withdrawn from the VMS™ during morning and evening milking, see also section 4.1. In Paper II, milk yield was weighed at each milking during the measurement periods, and samples for analysis of milk composition were collected morning and evening on two consecutive days. In Papers I-III, samples for analysis of milk composition were preserved with Bronopol and stored at +4^{o}C until time of analysis. The concentrations of milk components were determined by infrared spectroscopy. Energy corrected milk was calculated from milk yield and milk composition according to Sjaunja *et al*. (1990). The results were weighed to daily mean composition except in Paper II, where the results were pooled into a mean value per cow and period.

Milk samples for analysis of FA in Paper III were frozen without preservative immediately after collection, and stored at -80 ^{o}C. On the day of lipid extraction, the milk was thawed and pooled according to total milk yield into one sample per cow and day. Milk lipids were extracted by a modification of the method described by Nourooz-Zadeh & Appelqvist (1988). After extraction, the lipids were weighed and stored at -80 ^{o}C until methylation. Prior to analysis, the lipids were methylated using methanolic sodium methoxide and then analysed by GC according to Shingfield *et al*. (2003).

4.3.3 Enteric Methane

Six rumen-fistulated animals were used in Paper II to facilitate concurrent measurements of CH_4, ruminal pH and sampling of rumen fluid. Ten days prior to the first experimental period, a permeation tube containing sulphur hexafluoride (SF_6) gas was placed in the rumen of each cow via the rumen fistula. The cows were equipped with a PVC 2-L U-shaped yoke that was placed on the neck of the cow and attached to a halter. The yoke had an air-tight connection to a capillary tube (Ø 0.127 mm) which regulated the air inlet. Above the nostrils of the cow, an inlet tube was attached to the capillary tube and thus breath samples were collected. The equipment was manufactured at the Agriculture and Agri-Food Canada, Semiarid Prairie Agricultural Research Centre, Swift Current, Saskatchewan, Canada by Dr Alan Iwaasa and technician Ed Birkedal. The yokes were replaced every 24-h on five consecutive days. Background emissions were collected in order to adjust for ambient concentrations of CH_4 and SF_6. Gas samples were collected daily from the yokes and analysed by GC. From the results of the analyses, daily CH_4 production was calculated using the equation developed by Johnson *et al.* (1994):

$$\mathrm{CH_4(g/day) = SF_6\ (mg/day) \times [CH_4]/[SF_6]}$$

where $[\mathrm{CH_4}]$ and $[\mathrm{SF_6}]$ are concentrations adjusted for ambient concentrations.

4.3.4 Rumen Fluid

Rumen fluid was studied in Paper II, and sampling via the rumen fistula was performed every hour from 05.30 to 22.30 h distributed over four days to cover for the diurnal variation in VFA concentrations and pH. In all, 18 samples from each cow and period were collected. The rumen fluid was immediately analysed for pH, then frozen and stored at -20 ^{o}C. Ruminal VFA were analysed by high-performance liquid chromatography according to Andersson & Hedlund (1983), and ammonia-N was analysed by a commercial laboratory by flow injection analysis in water.

4.3.5 Digestibility

Digestibility of the feeds was determined in Paper II by collection of spot samples of faeces twice daily on five consecutive days during the measurement period. The samples were stored at -20 ^{o}C until time of analysis, then thawed and pooled into one sample per cow and period. The samples were freeze-dried, milled and analysed for DM, ash, NDF, crude protein (CP) and AIA. Apparent OMD was calculated from estimated intake of organic matter (OM) in the feed and estimated OM excreted in faeces:

$$\mathrm{OMD = (OM_{feed} - OM_{faeces})/OM_{feed}}$$

Apparent digestibility of NDF and CP was calculated similarly.

4.4 Statistical Analysis

All statistical analyses were performed using SAS software (version 9.1, SAS Institute Inc., Cary NC, USA) and PROC MIXED was used to analyse the effects of dietary proportion of grass silage.

In Paper I, milk production variables, BW and BCS were analysed using the repeated statement and a model which included diet, parity and lactation week as fixed factors and cow as random factor. All fixed effect interactions were also included in the model. The analysis of feed intake variables included the same factors, with the addition of year as fixed factor, due to some differences in feed intake between the years.

In Paper II, when analysing CH_4, the fixed effect of replicate was included in the model as the measurements were repeated over five days. The analyses of milk, ruminal VFA and pH were based on mean values for each cow and period. The model included the fixed effects of period and diet and the random effect of cow. In the linear regression analysis, the same model was used, but treatments were transformed to percentage proportions of silage. Simple correlations were estimated by Pearson correlation coefficients. No significant carry-over effects from the previous diet were found.

The model used in Paper III included the fixed effects of year and diet, while cow was the random variable. Since 10 cows (out of 50) were present in both years (randomly allocated to new diets), carry-over effects from the previous diet were tested, but found to be non-significant. Differences between the milk production variables were determined using orthogonal polynomial contrasts. A multiple regression analysis on diet composition and OBCFA was performed using PROC STEPWISE.

4.5 Calculations of Profitability

The calculations of profitability were performed on production data from Paper I and simulation of farms located in three districts with different natural conditions for milk production and cultivation of leys. The calculations were performed on herd sizes of 80 and 160 cows, and on conventional and organic production systems. In addition, calculations on profitability were performed both with and without economic support from the EU. The economic support forms used in the calculations were: environmental payment for cultivation of leys, payment for organic production, support for less favoured areas and national support (Swedish Board of Agriculture, 2012b), and are referred to hereafter as “support”. The districts were described as: a plains district in the south of Sweden (SP), a district dominated by forest fragmented by larger or smaller agricultural areas with farms in the south-eastern part of Sweden (SF) and a similar forest-dominated district in the north of Sweden (NF), where farms are mainly situated along river valleys and along the coast. The estimations of harvest yields were based on experimental trials and field data (Spörndly & Kumm, 2010). Farm layout on typical farms within the three districts was based on information from the Swedish Board of Agriculture (2007c) and opportunity costs of arable land used in the calculations were based on regional enterprise budgets from the Swedish University of Agricultural Sciences (Agriwise, 2012). The supports and opportunity cost values relate to the levels in 2011–2012. The profitability was expressed as incomes minus expenses per cow and year and as MIOFC which was calculated as total income from milk minus total cost of feeds expressed per kg milk.

5 Results

The results presented in Papers I-IV are briefly summarised in this chapter. See the individual papers for complete information on the results.

5.1 Paper I

In Paper I, the hypothesis that even a moderate increase of 10% silage would decrease milk production or feed utilisation was not confirmed. There were no significant differences in average daily feed DMI among the dietary treatments. The average silage proportion over the entire lactation was 51%, 62% and 69% on diet L, M and H, respectively. The average ECM yield in kg/d over the entire lactation did not differ significantly between diets L and M, whereas it was significantly lower on diet H compared with the other two diets (Table 2). The slope of the lactation curve after lactation week 40 was significantly steeper on diet H compared with diet L (Figure 1), and the calculations on milk yield persistency showed significantly decreased persistency with increased dietary proportion of forage, particularly in primiparous cows.

Table 2. *Milk production and milk composition over the entire lactation of cows fed a low (51%), medium (62%) or high (69%) proportion of grass silage in the diet, LSmeans*

	Low	Medium	High	SEM[1]	*P*-value
Milk, kg/d	30.7^{a}	30.2^{a}	27.9^{b}	0.72	0.013
ECM[2], kg/d	32.1^{a}	32.0^{a}	29.7^{b}	0.65	0.014
ECM, 305-d	9796^{a}	9747^{a}	9053^{b}	199	0.014
Milk fat, %	4.32^{b}	4.45^{ab}	4.55^{a}	0.055	0.014
Milk protein, %	3.51	3.51	3.49	0.030	0.84
Lactose, %	4.81	4.78	4.76	0.015	0.06

$^{a-b}$Means within rows with different superscripts differ significantly ($P < 0.05$).
[1]Standard error of means.
[2]Energy corrected milk yield.

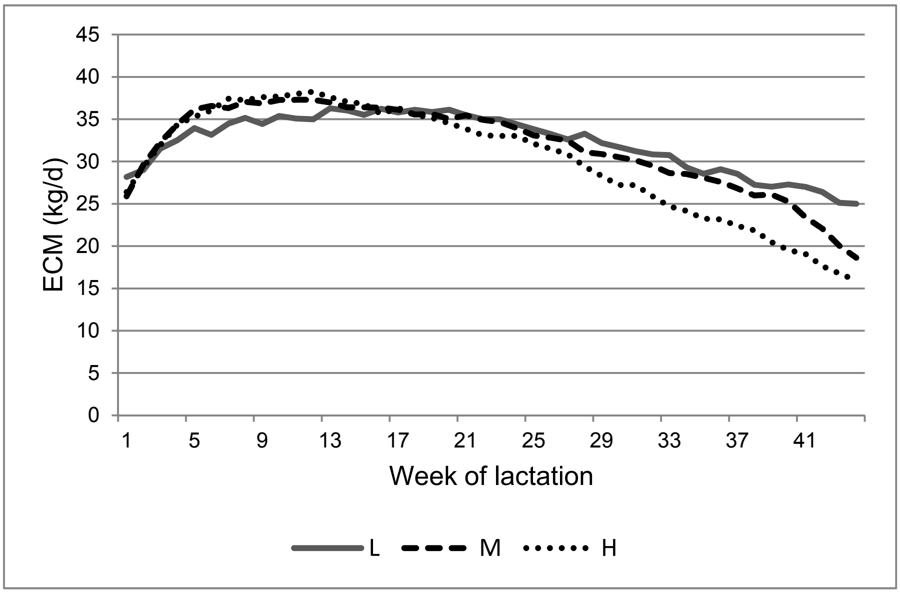

Figure 1. Mean values of energy corrected milk (ECM) yield of cows fed a low (L, 51%), medium (M, 62%) or high (H, 69%) dietary proportion of high-quality grass silage, data from two years, n=92.

Milk fat yield was significantly lower on diet H compared with diet M, whereas diet L did not differ from the other two diets in this regard. Milk protein yield did not differ between diets L and M, but was significantly lower on diet H compared with the other two diets. Milk fat concentration was significantly lower on diet L compared with diet H, whereas diet M did not differ from the other two diets. There were no differences in milk protein or lactose concentration between the diets.

The apparent efficiency of ME utilisation for milk production was calculated for the different diets, denoted k_l. The values of k_l over the lactation did not differ significantly among dietary treatments. However, k_l was significantly higher in primiparous cows compared with second parity and multiparous cows, irrespective of dietary treatment.

Body weight and BCS did not differ significantly among the dietary treatments, but there were significant differences between all three ages (primiparous, second parity and multiparous cows). Body weight increased with increased age and BCS was significantly higher in multiparous cows compared with younger cows. A significant increase in BW in primiparous cows over the lactation was only shown on diet L. In second parity and multiparous cows, there were no significant effects of dietary treatment on BCS or BW over the lactation.

5.2 Paper II

In Paper II, the hypothesis that an increased dietary proportion of silage would increase the enteric CH_4 emissions was not completely confirmed. The analysis of variance did not show any significant differences in enteric CH_4 production between the dietary treatments, but a tendency (P=0.08) for increased CH_4 production with increased proportion of silage was shown by regression analysis.

Ruminal pH increased with increasing proportion of silage, as indicated by a significant difference between diet H and the other diets. The mean concentration of total VFA did not differ between diets, but the molar proportion of butyric acid was higher on diet L compared with the other diets. Coefficients of correlation between VFA and CH_4 and between VFA and the CH_4 conversion factor from gross energy (Y_m) showed similar results: total VFA, acetic acid, isobutyric acid and isovaleric acid showed highly significant and strong positive correlations to both CH_4 and Y_m. Mean values of ammonia-N, which is an indicator of normal rumen function and sufficient nitrogen supply, did not differ between diets.

5.3 Paper III

In Paper III, the hypothesis that the dietary proportion of silage would be reflected in the milk FA composition, and that the OBCFA could be correlated to the fibre content of the diet was confirmed. The concentration of C15:0, *iso* C15:0, C16:0, C16:1 *cis-9*, C17:0, CLA, C18:3n-3 and total OBCFA increased as the dietary proportion of silage increased. A decrease was shown in the concentration of C10:0, C18:0, C18:2n-6, C20:3n-6 and in the n-6:n-3 ratio when the dietary proportion of silage increased. Increasing the silage proportion decreased milk yield, ECM, fat and protein yield in terms of kg/cow per day during the time of the experiment. However, no significant effects were shown on fat, protein or lactose concentrations. Multiple regression analysis showed that the dietary content of NDF had the strongest positive correlation with total OBCFA, followed by C15:0 and *iso* C15:0. Starch had a strong negative correlation with C17:0.

5.4 Paper IV

In Paper IV, the hypothesis that a moderate increase in the dietary proportion of silage would increase the economic profitability was confirmed. Maximum profitability was shown on a herd size of 160 cows in organic production with economic support in district NF. The differences in profitability between using diet M or H were small in organic production when support was included. However, in organic production without support, diet M performed slightly better than diet H. In conventional production, diet M showed maximum profitability in all districts and herd sizes, whereas diet L showed minimum profitability, both with and without support. Maximum profitability in conventional production was shown for a herd size of 160 cows in district NF with support and a herd size of 160 cows in district SP without support.

Milk income over feed cost was highest in organic production, both with and without support. Using a high dietary proportion of grass silage had a profitable impact on the MIOFC in all districts and on both herd sizes studied, regardless of production system.

6 General Discussion

6.1 Milk Production and Feeding

Milk is an important food in Sweden and there are protests by the public when the offer of fresh milk for lunch at the nurseries or schools is threatened. While cheese and butter have been basic feed commodities since farming started, fresh milk as a beverage only became popular in the 1930s, once knowledge of pasteurisation and refrigeration became available. The consumption of fresh milk per capita has been decreasing continuously since the 1950s, while the consumption of cheese and fermented dairy products has increased, so total milk production has remained relatively constant over the years. The proportion of milk from organic dairy cows has increased rapidly in Sweden during recent years, from 5.2% in 2006 to 11.6% in 2011 (Swedish Dairy Association, 2012a). The regulations for organic dairy production stipulate free access to forage and a maximum of 40% concentrate on a daily DM basis, with a permissible increase to 50% during the first three months of lactation (EC, 2008; KRAV, 2012). In contrast, the recommendation in conventional production allows a maximum of 65% concentrate on a daily DM basis (Spörndly, 2003). Cows are herbivores and grazers by nature, and have a unique ability to convert fibrous material to VFA to utilise as nutrients. Forage is necessary for the cow's welfare and health: A low amount of forage decreases the duration of feeding and this may induce disturbances, *e.g.* stereotypic behaviours (Redbo *et al.*, 1996). A low forage intake also decreases the time spent chewing and ruminating and thus decreases the amount of saliva produced to buffer the ruminal VFA (Van Soest, 1994). Despite the fact that the cow is evolutionarily designed to eat forage, the average diet of Swedish cows in conventional production has changed over recent decades and constitutes at present >50 % concentrate on an annual DM basis (Emanuelson *et al.*, 2006).

It was hypothesised in Paper I that milk yield would decrease when the dietary proportion of forage increased. However, no significant differences were shown in ECM yield between diets L and M, although milk yield was significantly lower on diet H. In general, Swedish dairy cows in organic production produce 8-10% less milk per 305-d lactation than cows in conventional production. The difference in milk yield is often ascribed to the increased proportion of forage (Sundberg *et al.*, 2009). Johansson & Holtenius (2008) reported from a long-term study on Swedish Holstein cows, using forage-only diets, annual milk yields of 6000 kg ECM per cow. In that particular study, the cows remained healthy, but lost BW and became very lean during the housing period. However, milk yields of 6000 kg ECM/cow and year are generally not an option for Swedish dairy farmers, due to their high variable costs.

The design of the study in Paper I was intended to combine the positive biological effects of feeding large proportions of forage with sufficient nutrient supply in early lactation in order to exploit the cows' genetic potential. The average ME value in the silage used in the study was 11.3 megajoule (MJ) ME/kg DM, which is 0.4 MJ higher than the average ME value of grass silage used in Sweden (NorFor, 2012). In addition, the variation in grass silages used in commercial herds is probably very large. This variation has of course a large impact on milk yield, especially in organic production, when as much as 60% of DMI consists of silage. Based on the results in Paper I, it is debatable whether it is reasonable to feed high amounts of concentrate to animals that are grazers by nature. Feeding concentrates to maintain high milk yields is obviously not a valid argument according to the results in milk yield on diet M compared with diet L. However, it must be stressed that the results obtained on diet M would not have been possible using grass silage of lower nutritional quality. Other studies on grass/clover silages have shown similar DMI and milk yields over the first four to five months of lactation (Bertilsson & Murphy, 2003; Randby *et al.*, 2012). Differences in nutritional quality of silages of the same species are dependent not only on the stage of maturity at harvest, but also on whether the herbage is primary growth or regrowth. Silage from regrowth has a higher proportion of INDF and thus lower digestibility at the same NDF concentration, compared with primary growth (Huhtanen *et al.*, 2006). Approximately 75% of the silage used in Papers I-III was from primary growth and the rest from regrowth. The silage contained <10% red clover, which thus probably only had a very small effect on the results. In general, clover silages result in higher intakes compared with grass silages of similar digestibility, due to differences in rate of fermentation, particle breakdown and rumen passage rate (Dewhurst *et al.*, 2003a).

World grain prices are currently high (International Grains Council, 2012) compared with the cost of silage, and the prices may increase further in the future, not least due to the increasing demand for grain for use in biofuels and food for the growing global population. The calculations on profitability in Paper IV, based on data from Paper I, showed a difference in concentrate use per cow and year of 900 kg between diets L and M and 750 kg between diets M and H. Applied to all Swedish cows in conventional production, a change from diet L to diet M would result in a reduction of approximately 270,000 tonnes concentrate per year (for comparison, this is equivalent to half the volume processed annually at the Swedish ethanol plant). Thus, high-quality forage is likely to have large economic potential in future milk production systems. The average yield of leys is low in Sweden and there is room for substantial improvements.

The climate conditions in Sweden are favourable for cultivation of leys. Of approximately 2,600,000 ha arable land, 1,200,000 ha are currently used for leys, and an additional 450,000 ha are permanent grassland and meadow (Swedish Board of Agriculture, 2011). In a future perspective, the impact of climate change on agriculture is difficult to predict, but the average annual temperature and precipitation are predicted to increase, with summer droughts in the south (SMHI, 2012). According to the Swedish Board of Agriculture (2007b), cultivation of forages may gain from these climate changes, with increased yields due to increased CO_2 concentrations in the air. However, this prediction includes increased cultivation of maize. The use of maize in Swedish dairy cow diets has increased during the past decade, mainly in the south of Sweden. Maize silage has a high starch content and ME per kg DM, but is relatively low in protein, which increases the need for protein feeds in maize silage-based diets. The limited supply of local protein feeds means increased dependency on imported protein feeds, *e.g.* soybean meal, associated with increased use of maize silage. The production of soybean meal has a large impact on global warming, as shown by life cycle assessment (LCA) (Flysjö *et al.*, 2008), which argues against increased use of maize silage in combination with imported soybean meal in Swedish dairy cow diets.

In contrast, there are several benefits of cultivation of ley, which is a perennial crop and therefore needs less tillage. Life cycle assessment has shown that the cultivation of leys requires less energy, has less impact on global warming, gives rise to less pesticide use and contributes less to eutrophication compared with cultivation of grain (Flysjö *et al.*, 2008). In addition, leys contribute to the diversity of fauna, since the year-round vegetation provides shelter for different species. Mixing grass and legumes reduces the need for nitrogen fertilisation and increases the biomass compared with pure grass leys or monocultures of grass, especially if species-rich seed mixtures are used (Weigelt *et al.*, 2009). The biodiversity can be enhanced *e.g.* if the field margins are left free uncut. However, crop rotation and field layout (*e.g.* habitat islands between fields) appear to have greater positive impacts on biodiversity than whether the farm is organic or conventionally managed (Weibull *et al.*, 2000; Hole *et al.*, 2005).

In Paper I, all cows were out to pasture for at least three months in accordance with Swedish animal welfare legislation (SFS 1988:534, 1988; SFS 1988:539, 1988). One of the advantages with pasture is that it is a low-cost feed since the cow can "harvest and feed itself", thus reducing the time and cost of machinery, labour and storage of feed. The cows on diets M and H had to rely on pasture to achieve their intake of forage (except during periods of transition and low allowance due to pasture shortage, when supplementary silage was fed in the paddocks). Pasture turnout is associated with a decrease in DMI and supplements are necessary to meet the energy requirement in high-yielding cows. On a grass-only diet, the maximum DMI is an estimated 110-120 g per kg $BW^{0.75}$ (Van Vuuren & Van den Pol-van Dasselaar, 2006). Pasture intake was not measured in this thesis, but was calculated from the energy requirement for milk production and maintenance and the known intake of concentrate. There was a significant decline in milk yield of cows on diet H compared with cows on diet L from lactation week 40. However, it is difficult to distinguish whether this difference was an effect of grazing or of dietary proportion of forage, since the latter part of the lactation coincided with the grazing period for most of the cows. The lower yield persistency in milk production was particularly pronounced in the primiparous cows. The decline in milk yield could be regarded as a weakness, but it can also be argued that a moderate decline, such as on diet M, in late lactation, can benefit the cow at drying off. The drying off process is easier at low yields and has been shown to reduce the risk of mastitis (Newman *et al.*, 2010). However, the average value of ME in the pasture grass was lower than that in the silage, which further decreased the nutritional supply to the cows on diets M and H during the grazing period. The leys (mainly *Poa pratensis* L.) used in the experiment were >10 years old, and the diversity and quality of the pasture are often impaired over the years. This is mainly due to the degree of utilisation of pasture, with species that are more resistant to trampling outcompeting other species. If more intensively managed leys had been available, the results during the grazing period might have been different. Grazing management can be difficult in large herds due to limited pasture areas within walking distance of the farm buildings. Grazing in combination with automatic milking, such as in the present study, requires well-designed infrastructure and pastures relatively close to the houses, which may be a challenge in large herds in certain areas, as discussed in Paper IV. However, positive effects of grazing on lameness (Haskell *et al.*, 2006) and mortality (Burow *et al.*, 2011) have been reported. Part-time grazing has been suggested as a successful strategy (Sairanen *et al.*, 2006) in order to combine the positive effects of grazing with sufficient nutrient supply in high-yielding dairy cows.

Overall, the dietary treatments tested did not affect BW or BCS, but primiparous cows on diets M and H did not significantly increase in BW over the lactation, as they did on diet L. Thus it is interesting to consider whether diets M and H actually affected growth in the young cows. The average ME intake in primiparous cows over the lactation was not significantly different among the diets, but decreased numerically with increased forage proportion. The energy requirements of the primiparous cows in Paper I was calculated from $0.507 \times BW^{0.75}$ and ECM yield, and additions were made for growth and gestation, according to the Swedish feeding recommendations (Spörndly, 2003). However, feed intake was restricted from lactation month four, and the average milk yield was numerically lower in primiparous cows on diets M and H compared with diet L, which was reflected in the lower ME intake. The lack of BW gain may be an effect of diet or an effect of the restriction of ME intake due to milk yield. This would be interesting to examine further in a larger group of animals on *ad libitum* intake. Mäntysaari *et al*. (2003) compared constant (53%) or increased forage proportion (43% to 63% forage) in total mixed ration fed *ad libitum* over the lactation, and found no difference in BW or BCS in primiparous Ayrshire cows (closely related to the Swedish Red Breed). The BW in their study was calculated from heart girth measurements and the average BW increase over the lactation was small (<15 kg) on both treatments. However, the forage proportion was lower compared with diets M and H in Paper I, and the results are therefore not completely comparable. Yan *et al.* (2006) showed that there was large variation between primiparous cows cows in the partitioning of energy for milk production or for body tissues. Body weight gain and BCS were found to be higher in Norwegian Red cows (closely related to the Swedish Red Breed) compared with Holstein-Friesian cows, on both high- and low concentrate diets. The ability of ruminants to efficiently use the ingested energy is a widely discussed topic, both in terms of milk production, growth and CH_4 emissions. Mäntysaari *et al.* (2012) concluded that the variation in energy efficiency among Nordic Red dairy cows was sufficient to be used in selection of animals for breeding. In Paper I, there was no effect of diet on the calculated efficiency of ME utilisation for lactation, k_l, between the diets. This was in line with the summarised results reviewed by Agnew & Yan (2000), where it was concluded that forage proportion does not affect k_l. However, it was suggested that increasing the dietary fibre concentration increases the requirement of ME for maintenance (ME_m), due to increased metabolic rate. This higher requirement of ME_m would result in less energy for milk production. In Paper I, the values of k_l were significantly higher in primiparous cows than in second and multiparous cows irrespective of diet, indicating mobilisation of body tissue in primiparous cows.

Due to the inevitable variations in chemical composition of forages compared with concentrates, it is important to be observant regarding feed quality and feed intake when using high dietary proportions of forage. Furthermore, it may be difficult to achieve adequate ME intake in primiparous cows on a high dietary proportion of forage. This may be due to limitations in intake capacity due to smaller rumen size of young animals or due to competition for feed. Keeping cows in free-stall houses has become more common in Sweden during the past decade, and limited access to the feed bins or feed bunks may decrease feed intake and negatively affect the feeding behaviour of lower social ranked cows (Olofsson, 1999), which often applies to primiparous cows.

6.2 Greenhouse Gases

The experiment described in Paper II was the first measurements of enteric CH_4 emissions from individual cows ever conducted in Sweden. The fact that the experiment was performed on high-yielding dairy cows was also quite unique. Earlier experiments conducted in other countries were on cows of lower milk yield, using respiration chambers. More recent experiments have often been performed on dairy cows or beef cattle in pasture-based systems using the SF_6 tracer technique. The results of Paper II did not show any statistically significant differences in CH_4, although emissions increased numerically with increasing silage proportion. The linear regression analysis of CH_4 g/d and proportion of silage in the diet showed a tendency for higher emissions with increasing dietary proportion of silage, which agreed with other reports (*e.g.* Lovett *et al.*, 2003; Ellis *et al.*, 2007). However, there is large within- and between-animal variation in CH_4 emissions (Grainger *et al.*, 2007; Vlaming *et al.*, 2008; Garnsworthy *et al.*, 2012). In addition, the SF_6 tracer technique used in Paper II seems to further increase variation (Grainger *et al.*, 2007; Pinares-Patiño *et al.*, 2008), and Beauchemin *et al.* (2012) suggested that the variation increases even more when rumen-fistulated animals are used. This may have contributed to the non-significant results obtained here. The Latin square change-over design of the experiment using five days of repeated measurements was chosen to minimise variance, and a higher number of animals would of course have been desirable. Rumen-fistulated cows were required in order to correlate rumen VFA and CH_4 emissions. Sampling of VFA is facilitated, especially for frequent sampling as performed in Paper II, if rumen-fistulated cows are used, compared with probing the animals orally for VFA. The results showed no significant difference in total ruminal VFA, but a significant increase in butyric acid on diet L compared with the other diets. This increase may be associated with an increased population of protozoa with increased proportion of concentrate (Jaakkola & Huhtanen, 1993). Higher proportions of acetic acid were expected on the increased proportions of forage (McAllister *et al.*, 1996) in diets M and H, but no such differences were found. In contrast, the proportions of acetic and propionic acids were similar between the diets. According to previous studies, propionate is the end product of rumen fermentation of lactic acid (Chamberlain *et al.*, 1983; Jaakkola & Huhtanen, 1993), and in this process propionate is produced at the expense of acetate. Thus, the fermentation of the silage lactic acid may be a reason for the results obtained here.

The three diets used in the experiment were highly digestible, even on a dietary proportion of silage of 90%. Earlier studies showed increased emissons of CH_4 per unit feed when digestibility of the feeds increased at maintenance feeding, but decreased per unit feed as feeding level increased (Blaxter & Clapperton, 1965). In Paper II, the feeding level was approximately three times maintenance, which increases the rate of passage through the rumen compared with lower feeding levels. Fast passage rate enables high feed intake, but results in less time for the microbes to digest the feeds and thus decreased CH_4 formation (McAllister *et al.*, 1996). However, no correlation between digestibility and CH_4 production has been found in more recent studies feeding beef cattle diets on maintenance level or up to slightly more than two times maintenance (Pinares-Patiño *et al.*, 2003; Hart *et al.*, 2009). Pinares-Patiño *et al.* (2003) concluded from a grazing study on beef cattle that CH_4 production was correlated with daily NDF intake, but no such correlation was obtained in Paper II. However, daily DMI was higher, and the NDF intake lower, in Paper II in comparison with the intakes in the study by Pinares-Patiño *et al.* (2003). Furthermore, recent analyses of data from dairy cows fed typical Scandinavian diets showed two significant predictors of CH_4: DMI, which was positively correlated, and feed FA content, which was negatively correlated to CH_4 (Åkerlind[1], pers. comm., 2012). There was no significant effect of DMI on CH_4 in Paper II, probably due to the small variation in DMI among cows. However, one can speculate whether the FA content affected the results, since there was a

1. Åkerlind, M. Swedish Dairy Association, Stockholm, Sweden.

tendency for increased CH_4 with increased forage proportion. No analysis of FA was made in Paper II, but similar feeds and similar dietary proportions of silage were used in Paper III, when feed FA content was analysed. According to the results of Paper III, the daily intake of FA was significantly decreased with increased proportion of silage. Thus, there may have been a lower intake of FA on diets M and H in Paper II, which may have affected the results. Several experimental studies have shown significant effects of lowering CH_4 by dietary inclusion of vegetable oils, but the long-term effects are not clear (Beauchemin *et al*., 2008).

The enteric CH_4 emissions constitute a substantial part of the total greenhouse gas (GHG) emissions from ruminants. Nevertheless, the environmental impact of livestock production has several sources, *e.g.* use of fossil fuels, production and utilisation of fertilisers, storage and spreading of manure (Sommer *et al.*, 2009). Since the amount of enteric CH_4 depends on the diet composition, it is important to take into account the emissions from producing the different feeds and from handling the manure. As mentioned in the previous section, the production of grass silage has been shown to contribute less to environmental degradation than cultivation of grain in terms of energy use, impact on global warming, use of pesticides and mineral fertilisers (Flysjö *et al.*, 2008). A common suggestion in the debate on CH_4 emissions from dairy cows is to increase milk yield as a means of reducing the emissions per kg milk. However, if both beef meat and milk are to be produced, Flysjö *et al.* (2012) showed that total GHG emissions are not reduced by increased milk yield per cow in intensive production, since less beef is produced per kg milk in high-yielding (conventional) cows compared with cows in more extensive (organic) systems. Those authors stressed the importance of integrating milk and beef production in analyses of total GHG emissions from ruminants, due to the increasing global demand for animal products.

6.3 Milk Fatty Acids

The different proportions of forage in the present study were chosen to represent different diets used in conventional and organic dairy production. Milk fatty acid profiles from different production systems have been previously examined in screening studies, with the focus on FA considered to be beneficial to human health. Organic and conventional retail milk samples produced in the United Kingdom were compared by Butler *et al.* (2011), who found higher concentrations of beneficial FA and lower n-6:n-3 ratio in organic milk. Fall & Emanuelson (2011) compared organic and conventional milk from commercial Swedish herds during the housing period, and reported similar results, whereas Toledo *et al*. (2002) concluded that there were no differences in milk FA profiles between organic and conventional dairy herds in Sweden. However, little information on diet composition is provided in the studies mentioned above, although some reported feed intakes based on farm surveys. The accuracy of feed data obtained from surveys cannot be compared with data from experiments where intake has actually been measured, as in Paper III, which makes the results of Paper III an interesting complement to studies on larger data sets.

6.3.1 Milk Fatty Acids of Interest for Human Health

In a human health perspective, the essential C18:2n-6 and C18:3n-3 are particularly interesting (Ohlsson, 2010). A low ratio of n-6:n-3 is associated with reduced risk of many diseases. The typical diet in the Western world is often rich in n-6 FA and thus has a high n-6:n-3 ratio (Simopoulos 2002). Conjugated linoleic acid has been reported to have several positive effects on human health, *e.g.* anti-carcinogenic and anti-inflammatory properties. This FA is found mainly in the body fat and milk fat of ruminants. However, studies of the effects on cardiovascular disease have been inconsistent (Park, 2009; Ohlsson, 2010). Reduced risk of cardiovascular disease is associated with replacement of saturated FA, mainly C12:0, C14:0 and C16:0, with unsaturated FA in the diet (Ohlsson, 2010).

In Paper III, increasing the dietary proportion of silage increased the intake of C18:3n-3 and decreased the intake of C18:2n-6, and these relationships were reflected in milk FA. Similar results were reported by *e.g.* Dewhurst *et al.* (2003b) using different silages and levels of concentrate, and by Shingfield *et al.* (2005) who compared different silages and concentrate levels with addition of an equal amount of oil in each diet. Consequently, the n-6:n-3 ratio in milk decreased with increased silage proportion and milk from cows on the high forage diets had a healthier composition in that respect (Simopoulos, 2002). The concentration of C18:3n-3 is higher and the transfer efficiency from feed to milk is also higher for clover silage compared with grass silage (Chilliard *et al.*, 2007). In the silage used in Paper III there was only a small inclusion of red clover, but this may have positively affected the results with respect to C18:3n-3. Increased concentration of C18:3n-3 in milk is also a common effect of grazing. This effect is enhanced if the dietary proportion of pasture grass is increased (Chilliard *et al.*, 2007). In Paper III, the concentration of CLA in milk increased with increased dietary proportion of silage. Increased concentration of CLA is typically shown when cows are on pasture or fed diets with a high concentration of C18:2n-6 (Griinari *et al.*, 2000; Chilliard *et al.*, 2007). The large variation in NDF content in forages influences the rumen passage rate, and Dewhurst *et al.* (2003a) suggested that high passage rate was one cause of reduced biohydrogenation in legume silages. Here the C16:0 increased with increased forage proportion, which is consistent with results by Dewhurst *et al.* (2003b). This effect may be explained by increased *de novo* synthesis from acetate and β-hydroxybutyrate with increased fibre inclusion in the diet. The overall effect of increasing the dietary proportions of high quality grass silage seems to be increased concentrations of milk FA that are considered healthy for humans. However, the contribution of these FA from milk to the total human diet is low.

6.3.2 Odd- and Branched-Chain Fatty Acids

The results of Paper III showed increased concentrations of C15:0, *iso* C15:0, C17:0 and total OBCFA in milk with increased silage proportion. Increased levels of NDF are associated with increased efficiency of rumen microbial growth (Bas *et al.*, 2003). Shingfield *et al.* (2005) reported higher concentration of C17:0 and *iso* C14:0 associated with increased dietary proportion of grass silage. The increased levels of total OBCFA and *iso* C15:0 with increased silage-to-concentrate ratio obtained in Paper III, were in line with the results from several studies reviewed by Vlaeminck *et al.* (2006a). The multiple regression analysis in Paper III showed that NDF was the component that affected the total OBCFA composition the most. The major differences between the diets used in Paper III were the different proportions of NDF and starch. Vlaeminck *et al.* (2006a) reported an influence of NDF on the concentrations of milk *iso* C14:0 and *iso* C15:0. These relationships may reflect the proportion of cellulolytic bacteria in the rumen with different silage-to-concentrate ratios. In contrast, Dewhurst *et al.* (2007) compared a wide range of silage-to-concentrate ratios, but did not find any significant relationship between OBCFA in the duodenum and the corresponding FA in milk. However, since earlier experiments (Vlaeminck *et al.*, 2005) showed promising results in the field, more studies are required to increase our knowledge of the OBCFA. Furthermore, recent research has indicated the potential of using OBCFA as predictors of ruminal acidosis at an early stage, before any clinical signs appear (Colman *et al.*, 2010; AlZahal *et al.*, 2011). The relationship between rumen VFA and milk OBCFA has also been proved to be useful in prediction models of CH_4 emissions from dairy cows (Dijkstra *et al.*, 2011; Montoya *et al.*, 2011).

Milk OBCFA is a potential indicator of rumen function and it may be used as a non-invasive tool further on. However, more research is needed to increase the knowledge of the transfer from duodenum to milk and the synthesis of the linear odd-chain FA in body tissue. There is also a need for improvements to methods for rapid and simple analysis of milk OBCFA in order to make it a routine management tool to monitor *e.g.* forage intake on farm level in the future.

6.4 Profitability

The results of Paper IV showed that diet M was the most profitable option in all three districts and in both conventional and organic production without economic support. This option was also shown to be the most profitable when support was included except for organic production in district NF, where diet H was the most profitable alternative. Overall, it was only the organic production system that reached full cost coverage. However, a herd size of 160 cows was required in organic production in order to reach full cost coverage, except in district NF, where this was achieved with support on a herd size of 80 cows. Without support in organic production, full cost coverage was only achieved in district SP on a herd size of 160 cows. The benefits of larger herds are associated with less labour hours and lower building costs per cow and year and higher milk price because of large volumes of milk delivered.

Organic dairy farms with a herd size of 160 cows in districts with relatively low-yielding organic production of leys and pasture require large areas of agricultural land. In most forest-dominated areas there are difficulties in finding such large areas within a few kilometres of the farm buildings. For example, in district NF, 160 cows in organic production on the M diet require 60 ha of pasture. In the south of Sweden and in conventional dairy production, the pasture yields are higher and thus the need for agricultural land is considerably lower. On some farms in forest-dominated districts the amount of land available for pasture is so limited that only exercise pasture (as for cows on diet L) is possible in large herds. However, this strategy is of course not permitted in organic production. It was shown in Paper IV that diet L did not achieve full cost coverage even with support. As a measure to increase profitability, increasing the amount of available land for pasture and leys, and thereby using diets similar to diet M, may be an alternative. In forest-dominated areas, increasing the areas of ley and pasture may be possible by transforming forest to grassland after clear-cutting. Planning the infrastructure around new animal houses should include possibilities for intensive grazing. The current high price of concentrates and grain had a great influence on the results of the present study. However, results from sensitivity analysis (± 0.06 €/kg concentrate, not reported) showed similar results as in Paper IV. The price of concentrate, combined with small differences in milk income, resulted in the lowest MIOFC when using 50% forage in the diet in conventional production, regardless of district or herd size. In contrast, MIOFC in the organic production system was ~0.08 € higher/kg milk compared with in the conventional production system, and diet H showed the highest MIOFC of all three options. However, it should be stressed that the MIOFC is only one of several indicators of profitability; the overall costs must be considered, such as in the calculations of farm profitability. The results in Paper IV clearly show the advantage of feeding diet M (an average of 62% grass silage over the lactation), regardless of production system or geographical location. However, in organic production in the north of Sweden, it may even be more profitable to use diet H (69% grass silage). In addition, the overall low profitability in Swedish dairy farming is due to the high costs of animal housing, labour and fuels. The dependency on economic support, especially in the north, is also reflected in the results.

7 Conclusions

Overall, positive results were obtained from a gradual increase in the dietary proportion of high-quality grass silage after peak lactation from 50% on a DM basis up to 70% at drying off. This feeding strategy did not result in any negative effects on DMI, milk yield or milk composition compared with feeding 50% silage. However, when the forage proportion was increased further, to 90% in late lactation, the 305-d milk yield was significantly decreased. Feed utilisation was not significantly impaired when the dietary proportion of silage was increased. Increasing the forage proportion increased the concentrations of milk FA beneficial for human health and the concentration of total OBCFA, in addition to increased levels of specific OBCFA. Hence, the OBCFA may be used as a tool to monitor forage intake in the future. The enteric CH_4 emissions showed a tendency to increase with increased dietary proportion of silage. However, conclusions on GHG must include calculations of the total production chain, from cultivation of feed to unit product consumed. The calculations on profitability showed clear benefits of feeding up to 70% silage in the diet, regardless of production system or geographical location. In summary, to be sustainable in future dairy production, the good conditions for cultivation of leys in Sweden should be utilised to a larger extent. Concentrate can be replaced by high-quality silage, at least up to a silage proportion of 70% in late lactation, even in conventional production. This would improve the welfare of the cow in addition to the increase in farm profitability when concentrate prices are as high as they are today.

8 Implications

It is encouraging that the results of increasing the dietary proportion of silage presented in this thesis were positive and can be applied in direct practice in commercial herds. This is especially important at present, when the profitability in general is low on most dairy farms. However, it must be stressed again that the prerequisite for the milk yield obtained with a diet with ~60% silage in this thesis, was silage of high nutritional value, *i.e.* >11 MJ ME and approximately 14-15% CP per kg DM. The use of silage in animal diets requires regular analysis of DM and chemical composition in order to ensure that the total diet is balanced. It is also important to emphasise that the results in this thesis were obtained by gradually increasing the forage proportion after peak lactation up to 70% in late lactation. Using other strategies to increase the forage proportion may or may not result in similar milk yields to those obtained in this thesis.

The results of the profitability calculations in this thesis were influenced by the current high grain prices and the economic support from the EU. Grain prices are dependent on supply and demand on the world market and future scenarios are of course difficult to predict. However, the grain prices may remain high in future due to the increased competition for grain for other purposes. The current economic support from the EU is valid until 2014 and the new proposal by the European Commission for the period 2014-2020 includes continued environmental payment for leys, support for disadvantaged areas and support for organic production (EC, 2012). Decisions will be taken in the beginning of 2013. Nevertheless, according to the results presented in this thesis, a diet with ~60% silage remained the most profitable choice even when economic support was excluded from the calculations.

9 Future Research

Future research to increase existing knowledge in the field should examine:

- The effects on milk production of using fixed high proportions of high-quality silage after peak lactation.
- The effects on growth, milk yield and DMI of using increasing dietary proportions of high-quality silage, fed *ad libitum* to primiparous cows over the lactation.
- The effects on milk production of using different grass/legume mixes and species in high-quality silage diets to dairy cows.
- Combination of a high proportion of silage with concentrate varying in composition, *e.g.* protein content.
- In-depth evaluation of partitioning of energy for milk and body tissues when forage proportion varies.
- The transfer of OBCFA from duodenum to milk, clarification of the correlation between dietary composition and certain milk OBCFA.
- Improvement of FA analysis so that it can be used as a management tool.

10 Sammanfattning

Svensk mjölkproduktion har genomgått stora strukturella förändringar de senaste decennierna. Antalet mjölkkor och besättningar har minskat från 688 000 kor och 77 300 besättningar 1974 till 346 000 kor och 5 300 besättningar 2011. Under samma tidsperiod har mjölkmängden per ko och år från kontrollerade kor ökat från ca 5 500 kg till 9 500 kg energikorrigerad mjölk (ECM). Ökningen i mjölkmängd beror bl.a. på förbättringar i skötselrutiner, fodersammansättning, foderkvalitet och avelsarbete. I takt med att kornas mjölkproduktion har ökat har andelen spannmål/kraftfoder i foderstaten ökat. Detta beror på att en mera energität foderstat krävs för att kon skall kunna konsumera den mängd näring som hon behöver. Tekniken för att skörda och konservera stora mängder gräs som ensilage har utvecklats de senaste decennierna, och numera är det möjligt att få ett grovfoder som håller mycket hög kvalitet, både näringsmässigt och hygieniskt. Energiinnehållet i svenskt gräsensilage 2011 var i medeltal 10,9 megajoule (MJ) omsättbar energi (OE)/kg torrsubstans (TS). Trots utvecklingen i grovfoderkvalitet och goda förutsättningar för att producera ensilage av hög kvalitet i Sverige, har andelen kraftfoder i foderstaten de senaste åren varit över 50% av TS i genomsnitt per år för kor i konventionell produktion.

För närvarande är lönsamheten inom mjölkproduktionen låg i Sverige och i ett flertal andra europeiska länder. Världsmarknadspriset på mjölk är lågt och högt på spannmål. Kostnader för foder utgör ungefär hälften av utgifterna för mjölkproducenterna och förändringar i foderstaten som sänker dessa kostnader kan ha stor påverkan på lönsamheten. Ekonomiska beräkningar av ”mjölkintäkt minus foderkostnad” (Svensk Mjölk, 2012b) visar att mellanskillnaden har varit betydligt högre i ekologisk produktion än i konventionell mjölkproduktion under flera år, men det senaste året har skillnaden mellan produktionsformerna minskat väsentligt p.g.a. sänkta avräkningspriser och höga kraftfoderkostnader i ekologisk produktion.

Den ekologiskt producerade mjölken har ökat i snabb takt i Sverige, av total mjölk som levererats till mejerierna var 5,2% ekologisk 2006 och 11,6% 2011. Trenden visar att vi går mot allt större besättningar och andelen kor i ekologisk produktion ökar. Kraven på hur djuren skall inhysas och skötas har också ökat sedan 1988 då nya djurskyddslagen infördes (SFS 1988:534, 1988). I nybyggda stall krävs det att korna går fritt och många kor mjölkas också i automatiska mjölkningssystem. Reglerna för ekologisk produktion kräver fri tillgång på grovfoder och högst 40% kraftfoder i mjölkkornas dagliga foderintag på TS basis, utom i tidig laktation, då 50% kraftfoder är tillåtet. Studier har visat att fettet i ekologisk mjölk innehåller en större andel fettsyror som är nyttiga för människan, jämfört med mjölk från kor i konventionell produktion. Andra studier har även visat att det finns möjlighet att använda vissa fettsyror i mjölken, de s.k. udda och grenade fettsyrorna, som markörer för hur våmmen fungerar. Detta skulle man möjligen kunna utnyttja i framtiden som ett komplement för att få information om kornas näringsstatus när de går i lösdrift i stora besättningar. I stora besättningar med automatiska skötselsystem finns ofta detaljerad information om hur mycket kraftfoder en individuell ko har ätit, men då grovfodret oftast utfodras på gruppnivå finns inte samma kontroll på intaget. En ko kan därför i ett sådant system äta en stor mängd kraftfoder och en liten mängd grovfoder utan att det märks förrän kon visar sjukdomssymptom. Om det utvecklades verktyg för snabba analyser på gården av vissa markörer i mjölkfettets sammansättning, kunde man kanske redan på ett tidigt stadium se om en viss ko var i riskzonen.

Kon är evolutionärt utvecklad för att konsumera gräs och andra fiberrika fodermedel genom en unik symbios med mikrober i våmmen. Mikroberna bryter ner fibrer och bildar flyktiga fettsyror och protein som kon bl.a. kan använda som energi och byggstenar för mjölkproduktion. Samtidigt bildas också metan och koldioxid. Höga kraftfodergivor kan påverka kornas hälsa och välfärd negativt bl.a. eftersom miljön i våmmen påverkas negativt av stora mängder stärkelse och tiden det tar att äta spannmål är betydligt kortare än tiden det tar att äta grovfoder. Eftersom kon är utvecklad för att spendera större delen av dygnet att beta och idissla, kan hon påverkas negativt om det tar kort tid att äta upp varje foderranson. Kraftfoder innehåller också en liten andel fiber jämfört med grovfoder och stimulerar därför inte till idissling på samma sätt. Detta påverkar miljön i våmmen eftersom idissling genererar stora mängder saliv som har en buffrande effekt på de syror som bildas i våmmen.

Under de senaste åren har animalieproduktionen och inte minst den från idisslare ifrågasatts eftersom foderproduktion, gödselhantering och metanproduktionen i våmmen kan påverka miljön negativt samt bidra till en ökad produktion av växthusgaser. Tidigare studier har visat att produktionen av metan i våmmen är större om djuren utfodras med fiberrikt foder jämfört med stärkelserikt foder. I de studier som gjorts tidigare hade man inte tillgång till ensilage av den höga kvalitet som finns idag och man hade heller inte mjölkkor som åt så stora mängder foder som korna gör idag.

Syftet med den här avhandlingen var att undersöka om man kan öka andelen högkvalitativt gräsensilage i foderstaten till högavkastande mjölkkor utan att få negativa effekter på mjölkproduktionen eller en ökad metanproduktion i våmmen. Vidare har fettsyrasammansättningen i mjölkfettet undersökts, både ur nyttighetssynpunkt för människor och i ett framtidsperspektiv, om det skulle kunna användas som biologisk markör för grovfoderintaget. Till syvende och sist handlar det om lönsamhet när man skall göra förändringar, därför har det även gjorts ekonomiska beräkningar på olika alternativ med ökad andel ensilage i foderstaten.

Studien gjordes vid Sveriges lantbruksuniversitet, Kungsängens försökscentrum i Uppsala. Under drygt två års tid följdes totalt 92 mjölkkor av rasen svensk röd boskap (SRB) under hela laktationen. Korna var indelade i tre grupper som fick samma typ av kraftfoder och gräsensilage, men med olika andel ensilage i foderstaten. De första tre månaderna var andelen grovfoder konstant, men ökades sedan successivt över laktationen. De tre olika strategierna skulle motsvara: 1) utfodring i konventionell produktion, 2) grovfoderandelar enligt de ekologiska reglerna samt 3) en foderstat med ännu mera grovfoder än vad som rekommenderas inom ekologisk produktion, se Tabell 3. På sommaren gick korna på bete och de kor som utfodrades enligt de ekologiska reglerna fodrades då med kraftfoder inomhus och fick sitt grovfoder endast via betet, utom under övergångsperioden från stall till bete och vid betesbrist då ensilage kördes ut i beteshagen. Korna som utfodrades med en konventionell grovfoderandel hade endast rastbete och fick hela sitt näringsbehov tillgodosett med ensilage och kraftfoder inomhus.

Tabell 3. *Andel gräsensilage i foderstaten (på torrsubstans (TS) basis) i de tre försöksgrupperna: låg grovfoderandel (L), medelhög grovfoderandel (M) och hög grovfoderandel (H). Andelarna ökades från fjärde laktationsmånaden och fram till sinperioden efter totalt 44 veckors laktation*

	Grovfoderandel, % av foderintaget på TS basis		
Grupp	Vecka 1-12[1]	Vecka 13-24[1,2]	Vecka 25-44[1,2]
Låg (L)	40	40	50
Medel (M)	50	60	70
Hög (H)	50	70	90

1. Fri tillgång på grovfoder och mängden kraftfoder justerades efter intag till den grovfoderandel som var förutbestämd.
2. Foderintaget begränsades om det överskred 110 % av energibehovet enligt de svenska utfodringsrekommendationerna (Spörndly, 2003).

Resultaten visade att i genomsnitt över laktationen åt korna ca 50% ensilage i grupp L, 60% ensilage i grupp M och 70% ensilage i grupp H. Totala mjölkmängden över hela laktationen (både i kg mjölk och i kg ECM) blev inte lägre när man ökade andelen ensilage till ca 60% som i grupp M (9747 kg ECM) jämfört med när man utfodrade ca 50% ensilage som i grupp L (9796 kg ECM). Däremot sjönk mjölkmängden när man utfodrade ca 70% ensilage i genomsnitt, som i grupp H (9053 kg ECM). Fetthalten i mjölken var i genomsnitt 4,3, 4,4 och 4,5% i grupp L, M och H. Proteinhalten var i genomsnitt 3,5% i alla grupperna. Fettsyrasammansättningen i mjölkfettet visade på ökade halter av de fettsyror som anses som nyttiga för människor, d.v.s. linolensyra och konjugerad linolsyra (CLA), med ökad andel ensilage i foderstaten. Med ökad andel ensilage ökade också halterna av vissa av de udda och grenade fettsyror man kan förknippa med mikrobaktivitet i våmmen. Med ökad andel ensilage i foderstaten sågs en tendens för ökad mängd producerad metan i våmmen. De ekonomiska beräkningarna visade att lönsamheten var bäst om man utfodrade i genomsnitt ca 60% ensilage, d.v.s. som grupp M, oavsett om man hade konventionell eller ekologisk produktion. Full kostnadstäckning uppnåddes bara i ekologisk produktion och högst var lönsamheten i norra Sverige med de stödformer som finns idag när man hade en stor besättning på 160 kor i ekologisk produktion.

Sammanfattningsvis visar den här studien att man kan öka andelen gräs/klöverensilage av hög kvalitet från 50% efter topplaktationen till 70% i sen laktation utan att mjölkproduktionen påverkas negativt jämfört med att utfodra i genomsnitt 50% ensilage över hela laktationen. Det måste dock betonas att det är viktigt att ensilaget är av samma höga kvalitet som det som användes i studien, d.v.s. med ett energiinnehåll på minst 11 MJ OE/kg TS. Förutom att det är positivt för kornas välfärd med en ökad andel ensilage i foderstaten kan det öka lönsamheten när kraftfoderpriserna är höga. Sverige har dessutom goda förutsättningar för att odla vall och producera ensilage av hög kvalitet och detta bör utnyttjas i ännu högre grad i framtiden.

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