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Master's thesis

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Production of hay milk

Farmer's motivation, cow performance and farm economy

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Summary

The sale of dairy products made of haymilk has increased substantially in Austria over the past few years to 4,200 tons of cheese sold in 2011. Haymilk based dairy products are currently being sold in Germany and the interest is increasing in Switzerland. 83 tons of haymilk based cheeses were sold in Denmark in 2011, and there appears to be a market potential haymilk based dairy products in Denmark. The main objective of this thesis was to improve the decision basis for farmers considering switching from silage feeding to hay feeding of their lactating dairy cows.

A semi-structured group interview with four haymilk producing farmers showed that they had been inspired by other farmers abroad, who produce haymilk, and motivated by a belief in hay being healthier for their cows as well as the ability to obtain a premium for their milk. The interview furthermore showed that their workload was increased in summer and decreased in winter, although the overall workload was more enjoyable now.

No clear effect of conservation method on chemical composition of hays and silages were found, although a trend for lower CP and higher NDF content per kg of DM were seen in hay compared with silage. Structural properties measured with peNDF and CT was found to be more related to TCL and season, which was indicated by cutting number, than used conservation method.

The analysis of lactation curves, which was based on data obtained from three of the haymilk producing farmers, showed that DH cows in parity one and parity three or greater had achieved a higher persistency by switching to hay feeding, albeit their peak yields were reduced with 1.1 and 0.4 kg ECM per day respectively. No difference was found for DH cows in parity two and Jersey cows in parity one and parity two, but Jersey cows in parity three or greater had their peak yield reduced by 1.1 kg ECM per day. Fat and protein percentage increased for DH cows in parity one and parity three or greater. Protein percentage furthermore increased for Jersey cows in parity one whereas no difference was found for the other groups of cows.

The feeding software NorFor predicted hay fed cows to have a lower DMI and ECM production per day when compared with silage fed cows. This clear effect could not be confirmed in the literature as both an increasing and decreasing as well as an unchanged effect was seen. The somatic cell count was decreased for all groups of cows by switching to hay feeding except for DH cows in parity three or greater, which increased, and DH cows in parity one where no difference was found.

The cost of producing one FU of hay was estimated to be 0.70 kroner larger compared with silage (2.77 versus 2.07 kroner per FU). This resulted in a difference in feed cost between 0.19 and 0.56 kroner per kg ECM depending on the ration and the assumed effect of switching to hay feeding on DMI and daily ECM production. The simulated difference between hay and silage feeding was between a loss of 0.01 and a gain of 0.04 kroner per kg ECM across six scenarios tested on seven different types of herds or between -161 and 450 kroner per annual cow.

Preface

This thesis was written as part of the MSc programme in Animal Science at The Faculty of Science, University of Copenhagen.

The objective with this project was to improve the decision basis for farmers considering switching from silage to hay feeding of their lactating dairy cows. This project should be seen as background and inspiration for farmers and their advisors when attempting to deduce the consequence of switching to hay feeding in a dairy herd. The project is further aimed at researchers as well as other people interested in a possible alternative to silage feeding.

I am thankful for the profound advices and skilled guidance of my supervisors Associate Professor Hanne Hansen, Department of Large Animal Sciences, Faculty of Health Sciences, University of Copenhagen and Senior Scientist Søren Østergaard, Department of Animal Science, Faculty of Science and Technology, Aarhus University.

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Copenhagen, June 1st 2012

Jesper Overgård Lehmann, QTD526

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Abbreviations

AAT: Amino Acids absorbable in the small intestines

ADF: Acid Detergent Fibre

BCS: Body Condition Score

CF: Crude Fibre

Ci: Chewing index = CT: Chewing Time

CP: Crude Protein

DM: Dry Matter

ECM: Energy Corrected Milk yield

Ei: Eating index

Mcal: Mega calories

NDF: Neutral Detergent Fibre

NEL: Net Energy Lactation

NPN: Non-Protein Nitrogen

OM: Organic Matter

OMD: Organic Matter Digestibility

PBV: Protein Balance in the rumen

pdNDF: potentially degradable Neutral Detergent Fibre

pef: physical effectiveness factor

peNDF: physical effective Neutral Detergent Fibre

Ri: Ruminating index:

SCC: Somatic Cell Count

SFU: Scandinavian Feed Unit (FU)

SV: Structural Value

TCL: Theoretical Cut Length

Definitions

Annual cow: An average cow in terms of parity, size, yield, days in milk etc. fed for 365 days.

Haymilk: Milk from cows fed a silage free diet based on hay

1 Introduction

The sale of dairy products made of milk from cows fed hay (hay milk) instead of silage has increased substantially in Austria over the past few years (ARGE Heumilch, 2012). According to the hay milk producers, a total of 4,200 tons of cheese and 35,000 tons of other dairy products made of hay milk was sold in Austria in 2011 (ARGE Heumilch, 2012). The German dairy company "Gläserne Meierei" (www.glaeserne-meierei.de) produce and sell hay milk products as do the joint German and Austrian company "Käserebellen" (www.kaeserebellen.com). Furthermore,, there appears to be an increasing interest in Switzerland as well (Guggisberg, 2011).

The Danish organic dairy company "Naturmælk" (www.naturmaelk.dk) produces a number of hay milk based cheeses with a total sale of 83 tons in 2011 (Jørgensen, 2011). The total sale of organic cheese was 2,165 tons in Denmark in 2011 (Anonymous, 2011a), and haymilk cheeses can therefore be considered a niche within the organic segment. Nevertheless, there seems to be an interesting trend for haymilk products in the countries south of Denmark, and Jørgensen (2011) claims there to be a market potential for hay milk products in Denmark as well.

In a review on cheese sensory characteristics, Martin *et al.* (2005) compared the effect of conserving grass as either hay or silage and concluded that cheeses made from silage based milk tended to be more bitter and vary more in sensory characteristics within a batch of cheeses. However, they also found that a high quality ensiling process reduced the difference between silage and hay based cheeses as well as that this difference depended on the type of cheese made. Furthermore, Kalac (2011) concluded in a review that the transfer of some components from silage to milk can be of concern, and mentioned spore-forming bacteria to be a potential problem as they can spoil milk during processing. By using a taste panel, Verdier-Metz *et al.* (2005) found, that whenever a difference in sensory characteristics was significant, this difference was always to the benefit of the hay based cheese.

In Denmark haymaking and feeding of hay to lactating dairy cows was the subject of a number of experiments around the time of World War I and World War II (e.g. Hofman-Bang, 1917; Wenzel & Lund, 1928). One direct comparison of hay and silage was conducted in 1937 (Olesen *et al.*, 1937). However, a number of factors may cause one to query the comparability of these experiments to modern day standards. Fodder beets sometimes made up more than half the dry matter fed in these experiments, and hay or silage was fed as an additional feed. Furthermore, the ensiling process was either carried out in a hole in the ground with no lining or in silos with a large amount of hydrochloric acid added. It is also likely that approximately 75 years of genetic progress within breeds of cattle and species of forages used would affect this comparability.

A literature search revealed no recent comparison of the performance of lactating dairy cows fed either hay or silage based rations, which furthermore had been carried out under Danish conditions. Such a comparison is important in order to improve the decision basis for farmers who are considering switching from silage to hay feeding. The four dairy farmers supplying haymilk to "Naturmælk" have practiced hay feeding for three to five years and may serve as case herds.

1.1 Objective

The main objective of this thesis was to improve the decision basis for farmers considering switching from silage feeding to hay feeding of their lactating dairy cows by assessing the effect of switching to hay feeding.

This was done by carrying out a literature review assessing:

1. The effect of conservation method on chemical composition and structural properties
2. The effect of switching to hay feeding on milk production and dry matter intake
3. The effect of switching to hay feeding on the risk of the cow experiencing a metabolic disorder

And by carrying out an experimental assessment of:

4. The farmer’s motivation for switching
5. The farmer’s perception of the effect of switching on cow performance
6. The farmer’s perception of the effect of switching on daily working routines
7. Chemical composition and structural properties of hays made in Denmark compared with feedtable values
8. The effect of switching to hay feeding on the lactation curve and milk yield
9. The effect of switching to hay feeding on protein and fat percentages
10. The effect of feeding either a hay based or a silage based rations on the predicted dry matter intake and milk production using NorFor
11. The effect of switching to hay feeding on somatic cell count
12. The cost of producing hay and silage
13. The effect of switching to hay feeding on total feed cost per kg ECM produced
14. The effect of switching to hay feeding on average profit per kg ECM and per cow simulated through six scenarios on seven types of herds using SimHerd

The study included reviewing the international literature and interviewing four haymilk producing farmers as well as analysing existing data from The Danish Cattle Database, which have been reported by three of the four farmers.

1.2 Delimitation

The existing data supplied by three of the four haymilk producing farmers consists of observations registered over seven years. This means that, potential changes in individual management routines may have affected their reported results and therefore the results of this analysis. A number of factors should be considered when evaluating the outcome of this thesis:

- Each herd acted as its own control
- Only four herds were included in the analysis
- All four herds are certified organic where two furthermore are certified Biodynamic, and one is currently in the process of becoming certified Biodynamic
- Observations are both from Danish Holsteins (two herds) and Jerseys (one herd)

2 Materials & Methods

An array of methods were used during this project with the aim of achieving a broad understanding of the difference between feeding silage and feeding hay to lactating dairy cows in order to fulfil the main objective. The aim was achieved by using both a qualitative method and quantitative methods as well as carrying out a literature review.

2.1 Literature review

Peer reviewed articles were selected based on a number of criteria in order to focus on the effect of either ensiling or drying forage and exclude as many related factors as possible. The forages had to have been harvested on approximately the same date as well as originate from the same crop/field. Furthermore, references published before 1980 were excluded as this was thought to limit a potential effect of genetic progress through plant breeding and change in farm management routines. The year 1980 was randomly selected but 32 years was thought to be sufficient. This resulted in seven references matching these criteria where one of these also aimed at comparing structural properties. Five out of these seven references were used to assess the effect of feeding either a hay based or a silage based ration on dry matter intake as well as milk production of lactating dairy cows.

Two approaches were taken to assess the effect of feeding hay on the health of the dairy cow. First it was attempted to find peer reviewed articles, which had made a direct comparison of the risk of a cow being developing a metabolic disease. This search yielded no articles. Secondly, it was attempted to find peer reviewed articles, which had assessed the effect of structural properties on the risk of a cow developing a metabolic disease. This search yielded no articles. Because these two approaches yielded no result, it was attempted to briefly argue for a relationship between structural properties, pH and metabolic disease risk.

2.2 Interview

A semi-structured group interview was arranged with these four farmers to qualitatively assess their view and perception of the effect of switching from silage feeding to hay feeding. The interview was conducted Monday November 21st 2011. Open ended questions were given to the farmers prior to the interview, which was thought as a guideline for the interview and yet would allow for elaboration by the farmers. The same questions were used as a guideline during the interview and care was taken not to give leading questions. Notes of farmer’s answers were taken throughout the interview and all interviewees have had the chance to review notes written about them. Appendix 1 shows the notes taken during the interview (In Danish)

2.3 Chemical composition and structural properties

Feedstuff analyses of hay samples taken (crop grown in 2010 and 2011) at two of the farms included in the interview was supplied by the organisation Organic Denmark (www.okologi.dk).

Six of those were of barn dried hay where three were first cutting, one was second cutting and two were third cutting. Chemical analyses were done according to NorFor standards (Åkerlind et al., 2011). Averages for each cutting was compared with standard values of clover grass hay in the NorFor feedstuff table (http://feedstuffs.norfor.info) as well as the standard values of first, second and third cutting clover grass silages.

Structural properties were estimated with the peNDF (physical effective Neutral Detergent Fibre) method described by Mertens (1997), and the chewing time index (Ci) method described by Nørgaard *et al.* (2011) where Ci is the product of the Eating index (Ei) and the Ruminating index (Ri). Estimating peNDF requires a pef (physical effectiveness factor) value, which was determined from a list of standard values reported by Mertens (1997).

2.4 Effect on lactation curve and milk yield

2.4.1 Development in average yield per annual cow

The analysis of the effect of switching to hay feeding on milk production of the dairy cow was performed using observations made over seven years. It was believed that factors such as the constant influx of new genetics in the herd through replacement cows could cause a natural change the milk yield over time. Thus, a preliminary analysis of the change in average yield per cow was done in order to obtain an estimate, which could be used to adjust the milk yield observations for this change.

All statistical analysis in this thesis was performed with R version 2.14.0 (R Development Core Team, 2011). Both linear models (lm) and linear mixed effects (lme) models were used to describe data. Significance was tested with the anova procedure of R, and model reduction in lme models was done based on Maximum Likelihood (ML). Parameter estimation in lme models was done based on Restricted Maximum Likelihood (REML). A test was significant if the p-value was 0.05 or less.

Data

Data from The Danish Yield and Registration Organisation (Registrering- og Ydelses-Kontrollen, 2011) was obtained for 2007 to 2011. This data consisted of the average milk yield (volume) and average fat and protein percentage per cow per year for each registered farm along with the breed and average herd size. Data for Jersey or Holstein (DH) cows in the southern region of Jutland in Denmark were selected as these criteria matched the hay milk producing herds. Herds not present in all five years were excluded.

Data was available as PDF reports, which had to be converted to MS Word documents before being imported to MS Excel. The final data set imported to R for analysis included 546 DH herds and 66 Jersey herds. ECM (Energy Corrected Milk) yield had to be calculated based on the reported milk yield as well as fat and protein percentage. This was done using the equation given by Anonymous (2011b: p. 48).

Analysis

Data for individual herds were handled separately for each breed, and Year was used as a continuous explaining variable with ECM yield per cow per year as response. No trend for Year was found for a model including either no or individual herd as a random effect for both breeds (separate models). Linearity was found when the individual herd and an interaction between herd and year were included as random effects. Furthermore, the effect of number of cows in the herd was found to be significant for DH herds. The final models for the two breeds are:

DH: $ECM_{i,k} = \beta_0 + \beta_1 * Year_i + \beta_2 * Cows_{i,k} + \nu_k + \nu_k * u_i + e_i$

Jersey: $ECM_{i,k} = \beta_0 + \beta_1 * Year_i + \nu_k + \nu_k * u_i + e_i$

Where $ECM_{i,k}$ is the average yield per cow-year for year i in herd k, β_0 is the intercept, β_1 is the slope of year, β_2 is the effect of number of cows in herd k for year i, v_k is a random effect of herd k, v_k*u_i is random slope of year of herd k and e_i is the residual error. Model validation was carried out using residual plots and QQ-plots in R.

Due to the result of this analysis, another data set with national average annual ECM yield per cow for all DH and Jersey cows in Denmark was compiled. This data was available for 2005 to 2011 and came from the same source (Registrering- og Ydelses-Kontrollen, 2011). The average annual ECM yield per cow for all DH and Jersey cows in Denmark was analysed with a simple linear regression with year as a continuous explaining variable.

2.4.2 Lactation curves and milk yield

Data

Milk yield observations from the three hay milk producing herds were obtained from Danish Cattle Database. This data contained the milk yield (volume), fat and protein percentage, ECM yield and Somatic Cell Count (SCC). Observations were made and samples taken from their lactating cows 11 times (one day) per year. This day is referred to as test day. Test day limits were set between January 1st 2005 and December 25th 2011 and all cows having produced milk within this period of time were included. Hence, cows purchased, sold or culled and first time calving heifers in a herd were included.

The DIM of each individual cow on each test day was not available from The Danish Cattle Database. Thus, another data set containing all calvings, which have occurred in the herds between January 1st 2001 and December 25th 2011. Four extra years of calvings were included in order to determine DIM at the start of the test period as no cow was thought to have been lactating in the herd without calving within these four years. This assumption was afterwards crosschecked and found to be correct. DIM was determined as the number of days between the individual test day and the most recent calving date of this individual cow. The calving number corresponding to this calving date was used to assign parity.

Each test day was afterwards assigned to one of three lactation categories depending on parity. Test days occurring in parity one were assigned to lactation category one, test days occurring in parity two were assigned to lactation category two and test days occurring in parity three or higher were assigned to lactation category three. Lastly, a "Hay index" value was assigned at each test day. This value was assigned based on the date of conversion to hay feeding (and hence no silage) where one was assigned to test days occurring minimum 90 days before conversion, and three was assigned to test days occurring minimum 90 days after conversion. All test days in between were given the value two. 90 days was selected as the limit as this would allow for any cow to go through a seven week dry period and yet have produced milk of hay before being assigned three in Hay index. All test days occurring at a DIM later than 365 were excluded.

Table 2.1: Number of yield measurements for each of three subsets for each breed. Measurements are spread over the entire lactation

Lac cat[1]	DH[2]	Jersey
1	6,401	1,400
2	4,553	1,002
3+	6,463	1,828

[1]Lactation category: First, second and third or older cows; [2]Danish Holstein

The resulting data set had 17,417 observations for Danish Holstein (DH) cows (two herds) and 4,230 observations for Jersey cows (one herd). Afterwards data was divided into subsets based on breed and lactation category. This created a total of six subsets and the number of observations (n) of these subsets is shown in Table 2.1.

Analysis

Test day milk yield (ECM) was modelled with a lactation curve based on the model developed by Nielsen *et al.* (2012). This particular model was chosen because these authors have used the same type of data (test day milk yields from the Danish Cattle Database) and tested for a potential effect of an occurred event on the shape of the lactation curve. Nielsen *et al.* (2012) defined their time factor similarly to "Hay index" in this thesis. Furthermore, these authors included a different seasonal parameter for first and second parity cows as for older cows, but in this thesis "quarter" (a quarterly value one through four) was chosen for all groups of cows for reasons of simplicity. Nielsen *et al.* (2012) included the natural logarithm of the test day somatic cell count, but this parameter was excluded in this thesis in order to simplify interpretation of model results. Thus, the same model was used for all test day yields regardless of the assigned lactation category. The effect of Year was removed from the model due to the result of the analysis described in the previous section.

Nielsen *et al.* (2012) defined random effects in their model as herd identification (ID) plus cow ID, which creates an individual intercept for each cow in each herd. In this thesis it was tested if including herd ID and/or DIM a random intercept and random slope for each herd improved model fit. Including DIM as a random factor also creates an individual slope for each cow ID. In this thesis including DIM in the random part was significant ($p<0.001$) and reduced the sum of model residuals with approximately 8% whereas including herd ID was not significant ($p=0.31$). Thus, herd ID was excluded.

Lastly, breed was included as a parameter in the model in order to test for a potential difference between DH and Jersey cows. This was found only to complicate the model as a number of interaction effects could be included by forward selection. Hence, this reduced the ability of the model to detect a potential effect of switching to hay feeding, and it was decided to continue with analysing data for the two breeds separately.

The initial model used to test data from each group of cows (based on breed and lactation category) was:

$$ECM_{i,j} = \beta_0 + \beta_1 * DIM(X_{i,j}) + \beta_2 * Wil(X_{i,j}) + \beta_3 * Quart + \beta_4 * Hay + \beta_5 * Hay * DIM(X_{i,j}) + \beta_6 * Hay * Quart + v_j * DIM(X_{i,j}) + u_j + e_i$$

Where $ECM_{i,j}$ is the milk yield on test day *i* for cow *j*, β_0 is the intercept, β_1 is the slope of DIM, β_2 is the effect of Wil($X_{i,j}$), β_3 is the effect of quarter within year, β_4 is the effect of Hay index, β_5 is the slope of DIM within each Hay index, β_6 is the effect of Hay index within quarter within year, $v_{,j}$ is the random slope of DIM for each cow, u_i is random effect of cow *i* and e_i is the residual error of the test day milk yield. Model validation was carried out using QQ-plots and residual-plots. Parameter estimates were significantly different if the confidence interval of the difference did not include zero. "Wil" refers to an exponential function ($e^{-0.05*DIM}$) originally given by Wilmink (1987).

Based on the final models, the total 305 days yield, the peak yield and the day at peak yield as well as the slope before and after the peak yield were estimated.

2.5 Effect on fat & protein percentage

The revised version of the Danish standard lactation function (Skjøth & Trinderup, 2005) was used on the same data the previous section to analyse fat and protein percentage. The model has the same components regardless of the chosen response variable. In addition, to the model by Skjøth & Trinderup (2005), it was decided to add two extra parameters. Hay and Hay*DIM (see previous description). This was done to test for an effect of changing to hay feeding on the intercept as well as on the slope of the curve. The final model was:

$$Log(Y_{i,j}) = \beta_0 + \beta_1 * DIM(X_{i,j}) + \beta_2 * DIM(X_{i,j})^2 + \beta_3 * DIM(X_{i,j})^3 + \beta_4 * \frac{1}{DIM(X_{i,j})} + \beta_5 * Hay + \beta_6 * Hay * DIM(X_{i,j}) + v_{i,j} + u_j + e_i$$

Where $Y_{i,j}$ is the fat or protein percentage on test day *i* for cow *j*, β_0 is the intercept for cow *j*, β_1 is the slope of DIM, β_2 is the effect of DIM to the power of two, β_3 is the effect of DIM to the power of three, β_4 is the effect of the inverted DIM, β_5 is the effect of Hay index, β_6 is the effect of DIM within Hay index, v_j is a random slope DIM for each cow, u_i is random effect of cow and e_i is the residual error of yield on day *i*. Model validation was carried out using qq-plots and residual-plots.

Parameter estimates were significantly different if the confidence interval of the difference did not include zero.

The analysis showed that the interaction effect between Hay and DIM was significant at 10% level (but not at 5%) for all combinations of breed and lactation category with response variable. Despite the interaction being insignificant, they were kept in the model and later analysed with confidence intervals of parameter estimates. The confidence intervals showed that the difference between silage and the transition period was significant in all cases as was the difference between the transition period and hay. However, the difference between silage and hay was only significant at 10% level.

2.6 Predicted dry matter intake and milk production with NorFor

The software feeding program NorFor was used to calculate a feed ration for a lactating Holstein dairy cow as well as estimate corresponding dry matter intake (DMI) and ECM yield. Information about NorFor can be found at www.norfor.info, and the models used in this program have been described by Volden (2011). A feed ration was calculated for a cow at two yield levels (7,500 or 9,500 ECM per year), two parities (First or older) and three lactation stages (Early, Mid or Late in a 305 days lactation) using a forage of either High or Low Organic Matter Digestibility (OMD), which gave a total of 24 combinations. Furthermore, a ration was calculated for each combination using four different fixed roughage percentages (50%, 60%, 70% and 80%). In addition, two different forages (hay or silage) were used separately and thus a total of 192 rations were calculated. Table 2.2 shows all the variables used to describe the type of ration calculated with NorFor.

Table 2.2: Variables used for calculation of feed rations using NorFor

Variable	Potential values
Yield level[1]	7,500 or 9,500 ECM per year
Parity	First or Older
Lactation[2]	Early, Mid or Late
OMD[3]	High or Low
Roughage	50%, 60%, 70% or 80%

ECM: Energy Corrected Milk; OMD: Organic Matter Digestibility
[1]Assumed average milk yield per cow; [2]A 305 days lactation separated into three equal parts; [3]Standards used in the NorFor feedstuff table

Rations were chosen to be optimised to ensure a sufficient AAT (Amino Acids absorbable in the small intestines) balance (%) and PBV (Protein Balance in the rumen) per kg of dry matter as well as fill capacity. These parameters are standards used in NorFor and are compared with a calculated requirement. This was done in order to obtain an estimate for the maximum amount of dry matter intake while ensuring protein supply. However, energy intake and other parameters were not optimised and optimisation is always done based on NorFor' s own estimated requirements. Reference is made to Volden (2011) for description of requirement estimation. However, the optimisation of rations using hay as forage failed in most cases when attempting to optimise PBV and include 80% roughage per kg dry matter (DM). Therefore the optimisation of these rations disregarded PBV.

Results caused an alternative situation to be tested where a 5% increase in total feed intake capacity of cows was assumed when switching to hay feeding.

2.7 Effect on health

2.7.1 Somatic cell count

The SCC was analysed with a simplified version of the model by Skjøth & Trinderup (2005). Two additional parameters were added in a similar way as the model used to analyse milk, fat and protein yield. The final model was:

$$Log\left(SCC_{i,j}\right) = \beta 0_j + DIM\left(X_{i,j}\right) + \frac{1}{DIM\left(X_{i,j}\right)} + Hay + Hay * DIM\left(X_{i,j}\right) + v_{i,j} + u_j + e_i$$

Where $SCC_{i,j}$ is the SCC in x 1000 / ml milk on test day *i* for cow *j*, $\beta 0_{,j}$ is the intercept for cow *j*, $X_{i,j}$ are the fixed effects varying by observation (individual test day yield), $v_{i,j}$ is a random effect of cow on test day *i*, u_i is random effect of cow and e_i is the residual error of SCC on day *i*. The model was validated with plots of residuals against predicted values and predicted against observed values.

2.8 Effect on economy

2.8.1 Price of hay and silage

The Danish Knowledge Centre for Agriculture publishes a number of reports related to agriculture as well as current and expected prices on among other things feed and cattle production. They furthermore estimate budgets for the growing of a number of different crops and the raising of cattle. These budgets can be found on their website (in Danish) here: www.farmtalonline.dk → Budgetkalkuler → Grovfoderafgrøder → Sædskiftegræs med 4 slæt (choose "organic" (økologisk) and "manure" (Med husdyrgødning)). Their principles along with those of the former version of these standard budgets (Andersen, 2010). It was generally assumed that a field would last for three years, and that four cuttings were made per year. Furthermore, it was initially assumed that the yield per hectare followed the standard budgets and did not differ between conservation methods (ensiling versus drying). Detailed calculations are given in Appendix 2. All assumptions are listed in Table 2.3.

General differences from standard budgets

However, a few assumptions made here differ from those in the standard budgets. In this thesis, a price for rent of land was included instead of the cost of an alternative crop. In addition, the cost of manure was assumed to be zero and the cost of storing and feeding was included in the final price.

Field work

The number of pass overs of each individual field treatment was assumed to follow the standard budgets. Except for spreading of hay for field drying and this was assumed to be done twice per cutting. The price per treatment was calculated according to the standard budgets.

Table 2.3: List of assumptions made for estimation of price per FU of hay and silage

Yield, hay	5,800	FU / ha
Yield, silage	6,500	FU / ha
Treatment	**Value**	**Unit**
Ploughing	600	Kr / ha
Harrowing	140	Kr / ha
Seeding	220	Kr / ha
Rolling	140	Kr / ha
Manure	40	Kr / tons
Mowing	270	Kr / ha
Spreading	130	Kr / ha
Raking	130	Kr / ha
Chopping	440	Kr / ha
Chopping wagon	150	Kr / ha
Water (fixed)	1,130	Kr / ha
Water (moving)	100	Kr / move
Water, / mm	5	Kr / mm
Standards		
Topic	**Value**	**Unit**
Energy consumption	0.98	kWh / kg
Hay quality	0.78	FU / kg DM
Silage quality	0.81	FU / kg DM
Silage density	220	Kg DM / m³
Interest	5.00	%
Inflation	2.42	%
Hay, % DM, start	60	%
Hay, % DM, slut	85	%
Plastic	220	m²

Prices		
Topic	**Value**	**Unit**
Grass seeds	67.50	Kr / Kg
Plastic	2.50	Kr / m²
Rent of land	4,000	Kr / ha
Energy, price	0.75	Kr / kWh
Hay handling	0.09	Kr / FE
Feeding out, hay	0.06	Kr / FE
Feeding out, sil.	0.13	Kr / FE
Storage facilities		
Capacity	500,000	FE / year
Building	**Price**	**Unit**
Storage shed	1,900,000	Kr
Drying equipm.	1,250,000	Kr
Bunker silo	360	Kr / m³
Building	**Depreciation**	**Unit**
Storage shed	30	Year
Drying equipm.	15	Years
Bunker silo	20	Years

Storing

The cost of storing silage and hay was estimated using the principle described in one of the Danish agricultural handbooks (Anonymous, 2009b: p. 159-161). The estimation was based on an annuity loan and adjusted for inflation, which was set to 2.42% as this is the average for Denmark over the past 25 years (Anonymous, 2012b). Interest rate was assumed to be 5% per year and depreciation was done according to guidelines (Anonymous, 2009b: p. 164-165), although depreciation of the drying equipment was assumed to be 15 years. The price of storage of hay and drying equipment was based on Høy & Lauridsen (2009), and the storage of silage was based on (Anonymous, 2009b: p. 185). However, a conversation with the farmer owning the hay building analysed by Høy & Lauridsen (2009) caused the capacity of the storage facility to be increased to 500,000 (Scandinavian Feed Units) FU per year, the price of the storage shed to be reduced to 1,900,000 kroner and the price of the drying equipment to be increased to 1,250,000 kroner (Lorenzen, 2012). He also suggested that storing the forage as silage would yield 6,500 FU per hectare whereas storing it as hay would yield 5,800 FU per hectare. The effect of this difference in yield on the price per FU compared with no difference was afterwards tested.

Drying of hay

The cost of drying was based on calculations and registrations published by Høy & Lauridsen (2010).

Feeding out

The cost of delivering a silage ration to the feeding table was assumed to be equal to the average reported by Laursen (2011). The cost of delivering hay was assumed to be half the cost of silage as it was thought to require less equipment.

2.8.2 Effect on feed cost per kg ECM produced

NorFor rations

Two assumptions were made prior to calculations: 1) one kg dry matter of hay can substitute one kg dry matter of silage with respect to fill and 2) the total predicted dry matter intake, calculated ration composition and predicted ECM yield of the silage based ration are unchanged when switching to hay feeding. Thus, the calculated difference in feed cost between hay based and silage based rations are caused by the difference in price of hay and silage. The price of hay and silage was assumed to be equal to those estimated in the previous section. An average price of concentrate was assumed to be 3.50 kroner per kg.

Five scenarios were tested for their effect on the difference in feed cost between hay and silage. The scenarios tested were that switching to hay feeding caused: 1) total dry matter intake to increase with one kg without affecting milk yield and 2) ECM yield to decrease with one kg without affecting dry matter intake. Scenario 3) tested the effect of reducing the estimated hay price with 10% whereas scenario 4) tested the effect of increasing this price with 10%. Scenario 5) combined scenario 2) and 3).

Cost under experimental conditions

The experiment by Bertilsson & Burstedt (1983) was conducted on forages resembling those used to calculate rations in NorFor (See section). Thus, their results can be used to estimate the difference in feed cost per kg ECM, which can be compared with the result of the previous section.

The price of hay and silage was assumed to be equal to those estimated in Section 4.3.2. An average price of concentrate was assumed to be 3.50 kroner per kg and kg ECM was calculated according to the equation given by Anonymous (2011b: p. 48). Afterwards the effect of a change in the price of hay and a change in the price of concentrate on the difference in feed cost was tested.

2.8.3 The simulated effect on average profit per kg ECM and per cow

The SimHerd software (SimHerd A/S) for simulation of scenarios in dairy herd was used to simulate the effect of switching from silage feeding to hay feeding on the average profit per annual cow and per kg ECM produced. Reference is made to the user manual for the SimHerd model by Ettema & Østergaard (2011) and to their website: www.simherd.com.

A total of six different scenarios were set up where the first scenario simulated the effect on the shape of the lactation curve (peak yield and slope) based on the analysis described in Section 2.4.2. All six scenarios included the effect on the lactation curve where scenario two through four included one additional effect and scenario five and six included two additional effects. Scenario two further assumed that switching to hay feeding reduced the somatic cell count of both healthy first parity cows and healthy older cows with approximately one third (minus 0.5 scaling units in SimHerd). Scenario three assumed that the somatic cell count of healthy first parity cows decreased with approximately one third and that the somatic cell count of healthy older cows increased with approximately one fifth (+0.2 scaling units in SimHerd). Scenario four assumed that the number of incidences of ketosis and displaced omasum was reduced by 50%. Scenario five and six were combinations of the first four scenarios. All scenarios are listed and described in Table 2.4.

Table 2.4: Scenarios simulated in SimHerd

Scenario	Simulated change
1: Yield	The slope of the lactation changes according to results from the three farms
2: SCC	Scenario 1 + a general decrease in SCC
3: SCC	Scenario 1 + a decrease in SCC following results from the three farms
4: Health	Scenario 1 + 50% decrease in number of incidences of ketosis and displaced omasum
5: Combi.	Scenario 1 + Scenario 2 + Scenario 4
6: Combi.	Scenario 1 + Scenario 3 + Scenario 4

Each scenario required a number of input parameters in SimHerd to be changed. Table 2.5 shows change in base value of each parameter for all six scenarios.

Table 2.5: Change (units or %) of base value for simulation of each scenario

		Scenario					
SN	Input parameter	1	2	3	4	5	6
8	Displaced omasum	-	-	-	-50%	-50%	-50%
9	Ketosis	-	-	-	-50%	-50%	-50%
26	Max yield, 1^{st} parity	-4.5%	-4.5%	-4.5%	-4.5%	-4.5%	-4.5%
27	% yield loss after 60 DIM, 1^{st} parity	-3.2 units	-3.2 units	-3.2 units	-3.2 units	-3.2 units	-3.2 units
28	Max yield, 2^{nd} parity	-	-	-	-	-	-
29	% yield loss after 60 DIM, 2^{nd} parity	-0.1 units	-0.1 units	-0.1 units	-0.1 units	-0.1 units	-0.1 units
30	Max yield, 3^{rd} parity	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%
31	% yield loss after 60 DIM, 3^{rd} parity	-4.4 units	-4.4 units	-4.4 units	-4.4 units	-4.4 units	-4.4 units
178	Somatic cell count, 1^{st} parity	-	- 0.5 units	-0.5 units	-	- 0.5 units	- 0.5 units
186	Somatic cell count, older	-	- 0.5 units	+0.2 units	-	- 0.5 units	+0.2 units

These simulations were done using seven standard herds supplied by SimHerd A/S where each herd was characterised by a set of base values. However, a number of the initial base values were adjusted in order for each of these herds to reflect the organic situation. Table 2.6 shows selected input parameters characterising the differences between the seven herds. The complete list of parameters can be found in Appendix 3.

Table 2.6: Parameters characterising the starting point of the seven herds used for simulation in SimHerd

SN	Input parameter	Standard	Good repro.	Poor repro.	Good health	Poor health	High yield	Low yield
4	Milk fever	4.8	4.8	4.8	2	7.5	4.8	4.8
5	Calving difficulties	0.5	0.5	0.5	0.2	1.2	0.5	0.5
6	Retained placenta	11	11	11	5	16	11	11
7	Metritis	19	19	19	10	24.6	19	19
8	Displaced omasum	2.4	2.4	2.4	1.4	3	2.4	2.4
9	Ketosis	13.6	13.6	13.6	9.1	15	13.6	13.6
10	Mastitis	55	55	55	29	75	55	55
11	Digital Dermatitis	69	69	69	35	104	69	69
12	Foot rot	5	5	5	2.6	7.5	5	5
13	Hoof and leg problems	49	49	49	20	83	49	49
26[2]	Max yield, 1st parity	25	25	25	25	25	28.7	26.2
27[3]	Yield loss after 60 DIM, 1st parity	17.8	17.8	17.8	17.8	17.8	17.8	17.8
28[2]	Max yield, 2nd parity	35	35	35	35	35	37.9	31.1
29[3]	Yield loss after 60 DIM, 2nd parity	34.1	34.1	34.1	34.1	34.1	34.1	34.1
30[2]	Max yield, older	37	37	37	37	37	40	30.5
31[3]	Yield loss after 60 DIM, older	39.1	39.1	39.1	39.1	39.1	39.1	39.1
-	Desired annual yield	8200	8200	8200	8200	8200	9500	7500

[1]Changed to reflect an organic farm (see text for description); [2]Changed in order to obtain the desired average annual yield per annual cow; [3]Determined based on lactation curves in results section; [4]Changed in order to achieve a total of 225 iterations of each simulation which was assumed to be sufficient

Start insemination (Parameter 1) was increased from 465 to 498 to achieve an average age at first calving 27.1 months (Anonymous, 2009a). The base mortality risk (Parameter 14) was lowered to 1.1 to reflect an average cow mortality of 4.0% in Danish organic dairy herds (Jørgensen & Martin, 2010). The maximum number of cows was set to 154 (Parameter 24) and the minimum to 142 (Parameter 25) in order to achieve an approximate average number of annual cows of 152 (Videncentret for Landbrug, 2011). Organic dairy cows are required to graze (Parameter 40 and 41) minimum six hours per day from April 15th until November 1st (Plantedirektoratet, 2011). The milk yield in organic herds are generally lower, for which reason parameter 63 and 64 were lowered from 15 to 12 in order to avoid cows being dried off too early during simulation. Lastly, the withholding period of milk was increased (Parameter 410, 492, 574, 656, 738, 820 and 984) as it is double the number of days compared with conventional milk (Plantedirektoratet, 2011). 225 iterations of each simulation were thought to be sufficient (Parameter 1917 = 3.5).

3 Literature review

3.1 Chemical composition of hays and silages

Hay is defined as an air-dried crop whereas silage (ensilage) have undergone an anaerobic composting where sugars are fermented under acidic conditions (Van Soest, 1994). Oxygen is removed by respiratory enzymes of the plant, which promotes the production of predominantly lactic acid, and hence reduces the pH value (McDonald *et al*., 1991). McDonald *et al.* (1991) further described that the reduction in pH is essential for the stability of silage and the reduction of the activity by undesirable microorganisms. Factors such as a high moisture content of the crop, and the inflow of oxygen through an incomplete covering of the silage may have a negative impact on the stability of silage and increase the risk of decay as well as the production of toxic compounds (McDonald *et al.*, 1991).

Sugars are furthermore used through plant respiration, which continues after cutting, and is inhibited by either the anaerobic conditions during ensiling or the increasing dry matter content during drying of hay (McGechan, 1989). McGechan (1989) further reviewed that the effect of respiration seen during field curing of hay is likely to be similar to that seen during drying of hay in a barn. Proteolysis of proteins also takes place during wilting and hence drying of grass, but this process is inhibited by oxygen and low moisture content (McDonald *et al.*, 1991). McDonald *et al.* (1991) further described, that the enzymatic breakdown of proteins to primarily ammonia and amino acids during ensiling is increased by a slow decrease in pH. In addition, they mentioned that bruising of grass during field wilting increases dry matter loss. It is beyond the scope here to fully review the process of ensiling, and reference is made to McDonald *et al.* (1991).

The definitions of hay and silage are particularly reflected in the DM content of the preserved crop, where hays varied from 79.7% to 92.1% and silages from 25.6% to 50.2% in the data compiled in Table 3.1 on page 24. When comparing hay and silage in the individual experiments, no apparent difference is found, albeit it is hard to conclude as only one reference (McCormick *et al.*, 2011) reported significance levels for differences in nutrient composition of silage compared with hay. There seems to be a tendency of higher CP (Crude Protein) and lower NDF (Neutral Detergent Fibre) content in silages compared with hay.

Conserving forage as silage will most likely cause a loss of nutrients through fermentation, oxidation and effluent, whereas conservation as hay can cause a loss through leaf shatter (Van Soest, 1994). McGechan (1989) reviewed field losses during conservation of grass forage and found that total respiratory loss of dry matter increases over time (during field wilting) and total mechanical loss of dry matter increases with increasing dry matter content. However, there was a large variation in losses, and the susceptibility of grass forage to mechanical loss increases with increasing dry matter content, which could substantiate the idea of leaf loss due to increased brittleness of drying leaves. Dry matter loss during storage was reviewed by McGechan (1990) who found a loss of 2% to 5% in hay and as much as 20% in silage. Both reviews were done with grass forage and it is unclear if and how much the difference in loss would be compared with for example clovers.

Nevertheless, this could explain a lower CP content, as protein concentration generally is higher in leafs compared with stems in both grasses and legumes (Whitehead, 2000: p. 111-112), for which reason a proportionate larger loss of leaves (compared with stems) will reduce the average protein concentration of the forage. Both Broderick (1995) and Nelson & Satter (1990) attributed the lower content of crude protein in hay to leaf losses in the field, and it seems that first cutting might have a relative larger loss compared with later cuttings (Broderick, 1995). It can be speculated that this is due to a greater fragility of leaves in first cutting as the plant is less mature compared with later cuttings. Nelson & Satter (1990) further attributed the higher content of NDF in hay (52.3 vs. 51.5 % of DM) to a greater loss of leaves, although breakdown of hemicellulose during ensiling also is a possible explanation (Thiago *et al.*, 1992). Hemicellulose is along with lignin and cellulose the main constituents of NDF (Van Soest, 1994: p. 145), for which reason an absolute loss of hemicellulose would reduce the total NDF proportion of a feedstuff given that all other components are unchanged. Broderick (1995) found the same trend as Nelson & Satter (1990) in trial two (first cutting), but the opposite in trial one (second cutting). Perhaps this is explained by a greater leaf fragility of first cutting.

Another factor that potentially affects nutrient content is rain where Bertilsson & Burstedt (1983) (second cutting) and Beauchemin *et al.* (1997) found a greater difference between hay and silage compared with the other references. Hays in both experiments received precipitation during field wilting. The opposite is seen for hay in the experiment by Nelson & Satter (1990), which also received rain, but this might be a result of a relatively small amount of rain (2.5 mm) compared with hay in the experiment by Beauchemin *et al.* (1997) (11 mm).

The effect of the used ensiling method is not considered in any of the experiments. Methods used are direct cut (e.g. Bertilsson & Burstedt, 1983) and wilted (e.g. Beauchemin *et al.*, 1997) as well as treated (e.g. Thiago *et al.*, 1992) and untreated (e.g. Broderick, 1995), which might affect the chemical composition and hence affect the comparison with hay.

Based on these references it is difficult to conclude a specific effect of conservation method, but nevertheless a few trends and indications are seen in Table 3.1 on page 24:

- NDF concentration in DM tends to be of equal value or slightly higher in hay
- ADF concentration in DM tends to be of equal value or slightly lower in hay
- CP content tends to be lower in hay
- Energy concentration in DM tends to be of equal value or slightly lower in hay
- Rain potentially has a negative effect on quality when hay is field dried

Table 3.1: Effect of drying versus ensiling on chemical composition of roughage

Crop	Country	Stored as	DM, %	NDF, % of DM	ADF, % of DM	CP, % of DM	OMD, % of OM[1]	Energy, / Kg DM[2]		Source
Alfalfa (lucerne)	Wisconsin, USA	Hay[4]	85	35.2	25.7	19.7	-	1.56	Mcal, NEL	Broderick (1995: Trial 1)
		Silage[4]	41.3	35.4	26.5	21.2	-	1.56	Mcal, NEL	
Alfalfa (lucerne)	Wisconsin, USA	Hay[3]	85.9	41.4	31.6	16.5	-	1.43	Mcal, NEL	Broderick (1995: Trial 2)
		Silage[3]	40.6	40	31.6	19.9	-	1.46	Mcal, NEL	
Grasses + red clover	Sweden	Hay[3]	87.3	57.1	-	12.3	75.7	10.9	MJ, ME	Bertilsson & Burstedt (1983)
		Silage[3]	25.6	59.4	-	13.8	73.3	11.1	MJ, ME	
Grasses + red clover	Sweden	Hay[4,6]	88.7	58	-	14.7	67.2	9.4	MJ, ME	Bertilsson & Burstedt (1983)
		Silage[4]	31.8	51.1	-	15.9	73.2	11.5	MJ, ME	
Bahiagrass	Louisianna, USA	Hay	79.7[a]	74.9[a]	44.4[a]	13.2	-	1.17[a]	Mcal, NEL	McCormick *et al.* (2011)
		Hay	88.7[a]	69.5[b]	38.8[b]	12.8	-	1.32[b]	Mcal, NEL	
		Baleage	50.2[b]	70.1[b]	39.5[b]	12.9	-	1.32[b]	Mcal, NEL	
Perennial ryegrass	UK	Hay	83.4	52	24.5	-	-	-	-	Thiago *et al.* (1992)
		Silage	21.3	46	29.8	-	-	-	-	
Alfalfa (lucerne)	Alberta, Canada	Hay[6]	92.1	44	32.6	20.6	-	1.37	Mcal, NEL	Beauchemin *et al*. (1997)
		Silage	36.9	36.9	32.3	23.3	-	1.53	Mcal, NEL	
Alfalfa (lucerne)	Wisconsin, USA	Hay[5,6]	-	52.3	40.1	16.5	-	-	-	Nelson & Satter (1990)
		Silage[5]	-	51.5	39.5	18	-	-	-	
Alfalfa (lucerne)	Wisconsin, USA	Hay[3]	-	42.4	32.5	21.0	-	-	-	Nelson & Satter (1990)
		Silage[3]	-	41.7	33.7	21.5	-	-	-	

DM: Dry Matter; NDF: Neutral Detergent Fibre; ADF: Acid Detergent Fibre; CP: Crude Protein; TCL: Theoretical Chop Length; NEL: Net Energy Lactation; Mcal: Mega calories; OM: Organic Matter; OMD: Organic Matter Digestibility; ME: Metabolisable Energy

[1] See reference for details about digestibility determination; [2] See reference for details about energy determination; [3] 1st cutting; [4] 2nd cutting; [5] 3rd cutting; [6] Received precipitation during field drying.

Lucerne: *Medicago sativa*, L.; Red clover: *Trifolium pratense*, L.; Bahiagrass: *Paspalum notatum*, L.; Perennial ryegrass: *Lolium perenne*, L.

The most evident differences are seen between references instead of within. Based on the references in Table 3.1 three factors seem to be important for the overall level of each feed component. Those are species used, cutting number (or time of harvest) and location where the crop was grown. This illustrates that hay is not a specific feed, but a result of the chosen method of conservation method of specific forage at a specific time of the year in a specific location. All these factors have to be taken into consideration as well when comparing hays and silages. A comparison of hays and silages (hence drying/wilting and ensiling) is therefore multifactorial, which complicates quantification. Nevertheless, trends and tendencies, as outlined above, can be seen in the chemical composition when comparing hays and silages made from the same crop, at the same time of the year and at the same location.

In Denmark the main organic crops conserved as roughage (or grazed) are a mixed sward of grasses and clovers (57.7% of total organic roughage) and permanent pastures (21.3% of total organic roughage) whereas lucerne (*Medicago sativa*, L.) is not as widely used (1.9% of total organic area) (The Danish AgriFish Agency, 2011: p. 14). However, three out of six references in Table 3.1 performed their experiments on lucerne. As discussed the actual value is more dependent on the species conserved than the conservation method, for which reason results determined on lucerne can only be used to indicate a trend in difference and not the actual value itself in Denmark.

3.2 Physical properties and ruminal degradation

Dohme *et al.* (2007) investigated among other things the effect of growth stage and method of conservation on physical properties and degradation as well as fermentation characteristics of a mixed species sward grown in Switzerland. Selected results from their experiment will be referred in this section.

The mixed sward contained white clover (*Trifolium repens,* L.) and red clover (*Trifolium pratense,* L.) as well as timothy (*Phleum pratense,* L.), perennial (English) ryegrass (*Lolium perenne,* L.), common meadow grass (*Poa pratensis,* L.) and red fescue (*Festuca rubra,* L.). The chemical composition of the conserved forage is shown in Table 3.2. These data show the same trends as listed in the previous section where crude protein was lower and NDF was higher for both young and mature hay compared with the equivalent silage. ADF (Acid Detergent Fibre) was equal for young silage and hay whereas mature silage had a higher content than mature hay. Furthermore, OM (Organic Matter) content is higher in hay compared with the corresponding silage. This can be caused by either a reduced mineral content or lesser amount of contamination with sand/dirt. Minerals, sand and dirt all show up in the ash component, for which reason it is hard to elucidate whether a difference in ash in due to change in mineral content or due to handling of the crop. Mineral content (dry matter basis) is generally higher in leaves than in stems and generally higher in younger than older leaves (Suttle, 2010: p. 19), for which reason a loss of leaves reduces mineral content (as happens to protein content as mentioned earlier). Furthermore, harvesting hay instead of silage might result in less sand brought with the forage and hence a reduced ash content. However, this is speculation.

Table 3.2: Chemical composition of a mixed sward of grasses and clovers

Conservation	Silage		Hay		Effect of hay vs. Silage[1,2]
Growth stage	Young	Mature	Young	Mature	
DM, g / kg	342	472	938	945	↑↑
OM, g / kg DM	884	920	925	938	↑↑
CP, g / kg DM	166	109	134	77	↓↓
aNDFom, g / kg DM	390	568	441	598	↑↑
ADFom, g / kg DM	263	415	262	389	→↓
Lignin, g / kg DM	18	59	22	47	↑↓
SV, / Kg DM	2.5	3.6	2.8	3.7	↑↑
pef_{PS}	97	98	95	94	↓↓
$peNDF_{PS}$, / Kg DM	380	558	420	563	↑↑

DM: Dry Matter, OM: Organic Matter; CP: Crude Protein; aNDFom: Neutral Detergent Fibre assayed with amylase and expressed exclusive of ash; SV: Structural value; pef_{PS}: physical effectiveness factor determined with a particle separator; $peNDF_{PS}$: physical effective NDF
[1]shows the trend of the individual parameter when forage from a mixed sward is dried instead of ensiled
[2]no significance value were reported
Modified from Dohme et al. (2007)

Dohme *et al.* (2007) chose to describe physical properties of the feedstuffs with the Structure Value (SV) method described by De Brabander *et al.* (1999), and the peNDF method described by Mertens (1997). However, it is beyond the scope here to discuss the applicability, strengths and weaknesses of these methods. A recent review (Mirzaei-Aghsaghali & Mahri-Sis, 2011) concluded that physical characteristics are "critical for obtaining a proper ruminal fermentation as well as animal production". This is in line with the arguments used by Mertens (1997) and De Brabander *et al.* (1999) when they developed their methods of describing physical characteristics of feeds. Both methods rely on the measure of "chewing time", which is also the case for the structure evaluation method used in the NorFor system (Nørgaard et al., 2011).

Table 3.2 shows the determined SV and peNDF of the silages and hays in Dohme *et al.* (2007)'s experiment, and there appears to be a relatively small difference between silage and hay of the same cutting. However, no statistics were performed on the analyses, although hays have a higher value in all cases. The difference seems to be less for mature compared with young crops. The physical effectiveness factor (pef) is lower for hay compared with silage, and the higher peNDF of hay is therefore a result of a higher NDF content. The pef of each sample was determined by dry sieving with a particle separator (Dohme *et al.*, 2007) and perhaps dry hay has a higher brittleness compared with dried silage, which would cause hay particles to break up into smaller fractions. However, this is speculation.

Brittleness can be indicated by measuring grinding resistance, which is shown in Table 3.3. It requires on average approximately 31% less energy to grind a unit of hay through a 5 mm sieve, although this difference was far from significant (p=0.65). Perhaps this is an indication of the variation. Table 3.3 further shows the particle distribution determined with a particle separator where a significant (p<0.001) greater proportion of long particles (963 vs. 898.5 g / kg) are found in silage compared with hay. In addition, Dohme *et al.* (2007) used a theoretical chop length (TCL) of nine cm when preparing both hay and silage. The degree of chopping will inevitably affect the physical properties of the feed and hence SV and peNDF as TCL is part of the definition of both concepts. In Denmark the recommend TCL of a mixed clover grass sward for silage is between 20 and 50 mm (Thøgersen & Aaes, 2005) whereas hay generally is harvested in the long form or with a relatively long TCL. The SV and peNDF values reported for silages in Table 3.2 would have been lower if the silages had been chopped with a shorter TCL.

Table 3.3: Particle distribution, grinding resistance, potential degradability, total VFA and acetate to propionate ratio

	Conservation (F)		Growth stage (G)[1]		P-value		
	Silage	Hay	Young	Mature	F	G	F x G
[2]Particles >19 mm, g/kg	963	898.5	931	918	<0.001	0.05	<0.05
[2]Particles 8-19mm, g/kg	14.8	48.7	27.1	39.3	<0.001	<0.001	<0.001
[2]Particles <8 mm, g/kg	21.8	52.9	42	42.6	<0.001	0.90	0.20
[3]Grinding resistance, kW/kg	1.98	1.37	1.19	1.98	0.65	0.20	0.40
[4]Potential DM degradability, g/kg	849	836	932	757	<0.05	<0.001	<0.05
[4]Potential NDFom degradability, g/kg	867	853	947	777	0.13	<0.001	0.17
[5]Total VFA, mmol/L	84.2	97.9	116	89	<0.05	<0.05	0.64
[5] Acetate:Propionate, mmol/mol	2.74	2.47	2.11	2.53	<0.001	<0.01	<0.01

DM: Dry Matter; NDFom: Neutral Detergent Fibre in organic matter; VFA: Volatile Fatty Acids.
[1]Values for haylage are not listed here under conservation, but they are included in Growth stage values.
[2]Determined with a particle separator
[3]Grinded through a 5 mm sieve
[4]Determined *in sacco* in non-lactating cows fed 50% hay and 50% silage
[5]*In vitro* incubation un rumen fluid from non-lactating cows fed 50% hay and 50% silage
Modified from Dohme *et al.* (2007)

Table 3.3 further shows the estimated potential degradable proportion of DM and NDF (See Dohme *et al.* (2007) for a thorough description of the method used). Dohme *et al.* (2007) determined degradability by *in sacco* incubating forage samples in four rumen-cannulated non lactating Brown Swiss cows that were fed a base ration containing 50% hay and 50% silage. They found the degradability of DM to be significantly lower for hay (p<0.05) whereas there was a trend for the degradability of NDF to be lower for hay (p=0.13). This indicates that cows are less able to utilise a mixed sward feed when this is conserved as hay compared with silage. However, degradability was measured *in sacco* in non-lactating cows fed both hay and silage, and it is unclear whether or not the results would have been different if the cows had been lactating and fed either a pure hay or a pure silage diet.

In addition, Dohme *et al.* (2007) incubated rumen fluid from *in sacco* determination of degradability to *in vitro* assess production of Volatile Fatty Acids (VFA). They found a significantly (p<0.05) larger production of VFAs when the rumen fluid was incubated with hay compared with silage. Nonetheless, was the degradability of hay lower compared with silage, and one can argue that there therefore is less available substrate for synthesis of VFAs. Perhaps VFA producing organisms are able to produce a larger amount of VFA per unit of feed when cows are fed hay. However, this is speculation and the rumen fluid was sampled in the same manner as the *in sacco* incubation of forage samples.

3.3 Effect on milk production and dry matter intake

Five of the references listed in Table 3.1 furthermore reported feed intake and milk production of cows (the sixth experiment was performed on steers) fed either hay or silage. Three of these references performed their experiment(s) on lucerne while one reference used bahiagrass and one used a mixed sward of grasses and red clover. Selected results from these references are compiled and shown in Table 3.4. Nelson & Satter (1990) showed contradicting results compared with those of Broderick (1995) and Beauchemin *et al.* (1997). Broderick (1995) and Beauchemin *et al.* (1997) showed cows to have a higher Dry Matter Intake (DMI), higher weight gain and equal milk production with a lower fat and higher protein concentration when they were fed hay instead of silage. However, Broderick (1995) did find a higher milk and fat corrected milk yield in one out of two experiments. Nelson & Satter (1990) found a lower DMI, weight loss instead of weight gain of the cows and equal milk production with a lower fat and lower protein content when fed hay instead of silage. It is unclear why milk production is less affected by switching to hay feeding in the experiment by Broderick (1995) and why Nelson & Satter (1990) found the opposite effect on weight gain (loss instead of gain). Broderick (1995) fed a higher proportion of the ration as roughage (66 - 70% vs. 55%) and under the assumption of a higher energy concentration of concentrate, then cows in Nelson & Satter (1990)'s experiment should receive more energy. However, cows in Broderick (1995)'s experiment tended to have a higher total DMI, but they also produced more milk. Both experiments were conducted in Wisconsin, USA, and used Holstein cows and a possible explanation can perhaps be found in either the chemical composition of the feeds used, although Nelson & Satter (1990) only reported few values (see Table 3.1 on page 24). Furthermore, Broderick (1995) found a lower milk production per kg DMI when cows were fed hay whereas Nelson & Satter (1990) found the opposite effect.

Bertilsson & Burstedt (1983) conducted their experiment in Sweden and fed silage and hay made from a mixed sward of grasses and red clover. They found a higher DMI, higher weight gain and lower milk production of cows in early lactation when there fed hay compared with silage. Hay fed cows tended to have a lower fat and a lower protein concentration and produced less milk per kg DMI regardless of this being adjusted for fat content (FCM) or not. Bertilsson & Burstedt (1983) regrouped their cows at week 11 after calving and created six groups where each were fed either a low, medium or high amount of concentrate along with either silage or hay. At high concentrate allowance (61% - 64% roughage) they found results equivalent to those from early lactation. At decreasing concentrate allowance the total DMI decreased for hay fed cows, and low and medium concentrate resulted in a higher total DMI of cows fed silage. Milk production was continuously lower while fat and protein concentration tended to be higher for hay fed cows.

Table 3.4: Performance of cows fed either hay or silage as roughage

Feed	# cows	Roughage %	DMI, kg / d	BW gain, kg / d	Milk, kg / d	FCM, kg / d	Fat, %	Prot, %	Kg milk / DMI	Kg FCM / DMI	Ref.
Silage[1]	4[4]	69.1	22.5[b]	-0.40[b]	35.9[b]	34.9[b]	3.34[a]	3.02[b]	1.60[a]	1.55	1)
Hay[1]	4[4]	69.6	23.3[a]	0.39[a]	35.7[b]	33.5[b]	3.14[b]	3.08[a]	1.53[b]	1.44	
Silage[1]	4[4]	65.9	22.0[c]	-0.39[b]	34.6[b]	34.6[c]	3.53[a]	2.90[b]	1.59[a]	1.57	
Hay[1]	4[4]	65.7	24.6[b]	0.51[a]	36.5[a]	36.0[b]	3.42[a]	3.01[a]	1.49[b]	1.46	
Early hay[2]	8[5,6]	55.7	18.3	0.00	27.6	27.6	4.04	3.29	1.51	1.51	2)
Early silage[2]	8[5,6]	54.7	17.0	-0.21	28.1	28.9	4.27	3.42	1.65	1.70	
Early hay[2]	8[5,7]	61.0	20.5	-	21.8	22.7	4.29	3.54	1.06	1.11	
Early silage[2]	8[5,7]	64.1	19.8	-	23.3	24.0	4.21	3.46	1.18	1.21	
Early hay[2]	8[5,7]	71.7	18.7	-	20.1	21.3	4.44	3.48	1.07	1.14	
Early silage[2]	8[5,7]	73.0	18.9	-	22.9	23.4	4.17	3.35	1.21	1.24	
Early hay[2]	8[5,7]	84.7	17.0	-	19.9	21.2	4.46	3.41	1.17	1.25	
Early silage[2]	8[5,7]	85.4	17.8	-	21.5	22.0	4.19	3.28	1.21	1.24	
Early hay[2]	13[5,6]	61.5	20.0	0.24	30.3	31.2	4.20	3.27	1.52	1.56	2)
Late hay[2]	13[5,6]	60.3	18.4	-0.02	26.6	28.6	4.50	3.33	1.45	1.55	
Early hay[2]	13[5,7]	61.7	19.6	-	24.4	25.9	4.36	3.48	1.24	1.32	
Late hay[2]	13[5,7]	59.6	18.8	-	22.1	23.5	4.44	3.56	1.18	1.25	
Early hay[2]	13[5,7]	74.2	19.8	-	23.7	25.2	4.49	3.45	1.20	1.27	
Late hay[2]	13[5,7]	70.4	17.9	-	21.1	23.0	4.65	3.50	1.18	1.28	
Early hay[2]	13[5,7]	85.6	18.1	-	22.2	23.6	4.47	3.41	1.23	1.30	
Late hay[2]	13[5,7]	85.0	17.3	-	19.9	22.1	4.72	3.44	1.15	1.28	
Outdoor hay[3]	10[4]	45.4[ab]	20.5[ab]	0.15	28.2[b]	27.7	3.46	3.02	1.38	1.35	3)
Barn hay[3]	10[4]	49.3[a]	22.1[a]	-0.45	30.2[a]	29.6	3.42	3.00	1.37	1.34	
Baleage[3]	10[4]	42.9[b]	19.6[b]	-0.11	29.0[ab]	28.7	3.39	3.03	1.48	1.46	
Silage[1]	8[4]	40.8[a]	21.1[a]	0.20[a]	30.3[a]	26.9[a]	3.34[a]	3.14[a]	1.42[a]	1.25[a]	4)
Hay[1]	8[4]	43.4[b]	23.9[b]	0.94[a]	31.2[a]	25.7[a]	2.90[a]	3.19[b]	1.28[b]	1.06[b]	
Early silage[1]	6/7[4]	55.0	22.0[a]	0.06[a]	27.2[a]	26.6[a]	3.94[ab]	3.31[a]	1.24	1.21	5)
Early hay[1]	6/7[4]	55.0	20.1[b]	-0.12[b]	26.6[ab]	25.0[bc]	3.59[b]	3.20[bd]	1.32	1.24	
Mid silage[1]	6/7[4]	55.0	22.3[a]	0.14[a]	27.0[a]	26.0[ab]	3.82[ac]	3.21[bc]	1.21	1.17	
Mid hay[1]	6/7[4]	55.0	18.7[b]	-0.21[b]	25.5[a]	24.5[c]	3.78[bcd]	3.12[cd]	1.36	1.31	
Late silage[1]	6/7[4]	55.0	22.5[a]	0.14[a]	27.7[a]	27.4[a]	3.96[a]	3.25[ab]	1.23	1.22	
Late hay[1]	6/7[4]	55.0	19.1[b]	-0.15[b]	25.5[b]	24.4[c]	3.73[bcd]	3.14[cd]	1.34	1.28	

DMI: Dry Matter Intake; BW: Body Weight; FCM: Fat Corrected Milk
[1]Lucerne; [2]Mixed clover and grass; [3]Bahiagrass; [4]Holstein; [5]Swedish Red and White; [6]Early lactation; [7]Mid lactation
All cows were multiparous and Days in Milk varied between and within experiments. Different superscripts are significantly different ($p<0.05$) within reference. Colouring shows within reference comparison of results depended on trial / experiment number.
1) Broderick (1995); 2) Bertilsson & Burstedt (1983); 3) McCormick (2011); 4) Beauchemin *et al.* (1997); 5) Nelson (1995)

Interestingly, silage fed cows produced approximately equivalent amounts of milk per kg DMI irrespective of concentrate allowance while this increased for hay with decreasing concentrate allowance. Hence, the more concentrate hay fed cows were given, the less milk they produced per kg total DMI. However, these values were calculated by the author of this thesis, and there is therefore no test of significance. Bertilsson & Burstedt (1983) only discussed feed utilisation for milk production in relation to oestrogen content in silage and not in relation to concentrate allowance in their companion paper (Bertilsson & Burstedt, 1984). Bertilsson & Burstedt (1983) furthermore looked at the effect of late versus early harvested hay at three levels of concentrate on DMI and milk production. They found DMI and milk production to higher for cows fed early harvested hay while fat and protein concentration was lower. Kg FCM per kg DMI was either equal or higher for cows fed early harvested hay. However, Bertilsson & Burstedt (1983) stressed, that their late hay was of "relative" good quality. This part of the experiment was performed in year three while the comparison with silage was performed in year two. Feed conversion efficiency (kg FCM per kg DMI) of early harvested hay in year three seems equal at the three levels of concentrate allowance, which was not the case in the year two. It is unclear why there is this difference as the same forage and concentrate was used in both years. McCormick *et al.* (2011) found a similar trend for a lower milk production per kg DMI when they compared outdoor and indoor stored hay with baleage made of bahia grass.

3.4 Effect on health

Feeding and hence nutrition may be of major importance for the health of the dairy cow and act as an indirect effect through health on the production of the cow (Østergaard & Sørensen, 1998). Feeding related disorders, such as ketosis, milk fever and acidosis, can impair production of the dairy cow and thus negatively affect the profitability of the dairy cow. As reviewed by Goff (2006) there is a complex interrelationship between nutrition and disorders as well as between the different disorders. Goff (2006) termed these disorders as being metabolic and emphasized that the risk of a cow developing a second metabolic disorder is greater than developing the first disorder.

A literature search failed to retrieve any peer reviewed articles, which compared a direct effect of feeding silage versus hay as the sole forage source to lactating dairy cows on the risk of the cow developing a feeding related disorder. However, it can be speculated that there is an indirect effect of feeding hay instead of silage on metabolic disorder risk through the structural properties of hay. Goff (2006) suggested that insufficient intake of dietary effective fibre is a key factor for developing metabolic disorder. This is substantiated in another review by Mulligan *et al.* (2006) who suggested using dietary fibre and particle distribution to monitor rumen health and in particular sustain a sufficiently high rumen pH. However, they did not define high and low pH, but only reviewed that a low rumen pH could cause a subacute ruminal acidosis, which further could lead to other disorders such as abomasal displacement or immune-suppression. A direct relationship between pH and subacute ruminal acidosis has though recently been questioned (Calsamiglia *et al.*, 2012).

It is unclear what Goff (2006) meant by effective fibre. Mertens (1997) referred effective Neutral Detergent Fibre (eNDF) as being related to the ability of a forage to replace another forage and maintain the same milk fat percentage. He further introduced the concept of physically effective

Neutral Detergent Fibre (peNDF), which he defined as the measure of the ability of forage to promote a sufficiently high ruminal pH. Mertens (1997) based the development of this concept on the fact that the physical characteristics of fibre can influence animal health, and he measured these physical characteristics with peNDF. A literature search was therefore undertaken to see if any articles had been published on the relationship between peNDF and the risk of a cow developing a feed related disorder. This search yielded no articles but two recent reviews (Mirzaei-Aghsaghali & Mahri-Sis, 2011; Zebeli *et al.*, 2012) outlining the importance of peNDF in maintaining a healthy rumen environment. These two reviews focus on chopped silage based rations, and it is unclear whether their discussions are completely applicable for hay based rations or not. Both reviews discuss the importance of particle size, but Zebeli *et al.* (2012) further notes that there some uncertainty regarding the measurement of particle size. Zebeli *et al.* (2012) also mentioned that there is an interaction effect between fermentability of the feedstuffs and the concentrate source as well as the used mixing procedure on the effect of peNDF in the ration. Long grass hay is the most "effective" feedstuff in promoting a sufficiently high rumen pH as all other feedstuffs defined use this as their reference (Mertens, 1997).

The discussion here shows that there is agreement on the importance of physically effective fibre in the ration, but this is based on the structural value of ensiled forages relative to long grass hay. Feeding rations based on long grass hay results in peNDF being higher relative to the equivalent ration with ensiled grass, although this presumes that the type and level of concentrate fed is unchanged. Chopping hay will reduce peNDF.

Zebeli *et al.* (2012) discussed the effect of concentrate source, and it can be speculated if the concentrate proportion of the ration has a dilution effect of the total structural value of the ration. Dohme *et al.* (2007) compared ensiled and dried forage (mixed sward) using two fibre describing concepts (SV and peNDF) and concluded that the effect of conservation method is not significant. However, they chopped both their silage and hay with a TCL of nine centimetres. When forage is stored as hay in Denmark, the TCL is generally longer compared with the forage stored as silage. Storing forage with the same TCL probably dilutes a difference in peNDF between conservation methods. One can then argue whether this is an effect of conservation or chopping.

Dohme *et al.* (2007) did not measure ruminal pH, but Broderick (1995) did when he fed lucerne hay (not chopped) or lucerne silage (TCL of one centimetre) to lactating dairy cows. Interestingly, he found no difference is his first trial, but a significantly ($p<0.05$) lower pH in the rumen of the hay fed cows (6.41 versus 6.18) in his second trial. Thiago *et al.* (1992) performed a similar study where they fed perennial ryegrass stored as either hay or silage to steers. However, they only provided a figure showing a slower decrease and a faster increase in pH with the same minimum value for hay compared with silage.

There is, therefore, no clear difference in pH between hay and silage fed cattle. However, if one assumes a direct inverse relationship between peNDF and the risk of a cow developing a metabolic disorder, then the larger volume of peNDF in long clover grass hay should result in reduced risk compared chopped clover grass silage. This raises the question if this effect is caused by feed conservation (hay or silage) or the degree of chopping. Furthermore, this assumes that peNDF is the only difference between hay and silage. If feeding hay instead of silage, for example, reduces total energy intake due to factors such as altered dry matter intake, reduced energy concentration, or digestibility, then this might have other detrimental health effects on the dairy cow (Goff, 2006; Mulligan *et al.*, 2006). In addition, Zebeli *et al.* (2012) mentioned that a high concentration of peNDF could reduce dry matter intake, which can have other negative effects.

Another aspect is the risk of growth of yeasts, moulds and bacilli as a result of unstable fermentation during ensiling, which may be harmful to ruminants (McDonald *et al.*, 1991). McDonald *et al.* (1991) particularly mention the bacterial genus *Listeria* where there is a high mortality risk of animals experiencing listeriosis. However, it is beyond the scope here to go into a detailed discussion, but mere mention this risk in relation to feeding hay versus feeding silage. Although, it can be speculated that this risk also applies to hay if this is poorly dried and stored.

Based on this brief literature review it is not possible neither exclude nor substantiate a positive effect of feeding hay compared with silage on the health of the lactating dairy cow. With this section it was attempted to investigate a potential health effect, but it is acknowledged that the field of nutritional effects on health is too broad to be covered in depth here.

4 Results

4.1 Interview

4.1.1 Brief description of the four farms

Herd size ranged from 70 to 200 annual cows where all had an average yield of 7,400 to 7,600 kg of ECM yield per cow per year. All four farms are certified organic by the Danish State and have been so for minimum of 12 years. Two farms have also been certified biodynamic by The Association for Biodynamic Agriculture in Denmark (Demeter) for a minimum of two years. One herd is of the Jersey breed, two Danish Holstein-Friesians and one herd has a mixed breed with part Danish Holstein-Friesian, part Red Danish Milking breed and part Red Holstein-Friesian. Two herds have completed two full years of hay feeding, one three years and one four years. All milk produced on the four farms is delivered to the same pure organic cooperative dairy company in southern Jutland, Denmark. Table 4.1 shows an overview of the four participating farms.

Table 4.1: Characteristics of participating farms in group interview

Farm number	1	2	3	4
Certified	Biodynamic	Biodynamic	Organic	Organic
Certified since[1]	1987 (1997)	1989 (2009)	1995	1999
Annual cows	200	115	90	70
Yield, kg ECM[2] / cow	7,500	7,400	7,500	7,600
Breed	DHF[3]	DHF	DHF x RDM[4] x Red DHF	Jersey
Hay feeding since	Spring 2009	June 2007	Summer 2008	October 2009

[1]Biodynamic certification date in parenthesis
[2]Energy Corrected Milk yield, kg
[3]Danish Holstein Friesian
[4]Red Danish Milking Breed

4.1.2 The farmer's reasoning behind switching to hay feeding

The first one of the farmers to start feeding cows with hay instead of silage was originally inspired on a trip to a biodynamic dairy farm north of Hamburg in Germany. Feeding a silage free diet based on hay had here been practiced for some time. Two main reasons caused this farmer to switch and those were a belief about a positive health effect on the cow and the fact that the dairy company was and is willing to pay a premium for the milk. Feeding hay had reminded the farmer about "the old days" where a rule of thumb was to put a sick cow on a pure hay diet.

Three of the farmers participated on a trip to Austria where feeding of hay is extensively practised. This trip inspired the farmers; particularly after visiting a herd yielding 10,000 kg ECM per cow per year. Two farmers emphasised that production of haymilk[1] aligns well with the vision of their dairy company to produce the healthiest milk of the market, and one of them mentioned that hay is the preferred feed in a biodynamic production system. According to this farmer hay has a better

[1] Milk from cows fed a silage free diet based on hay.

nutritional value for the cow and gives the cow a healthy metabolism. Lastly, one farmer said the trip to Austria had inspired him to try something new, and he had already been considering investing in feed storage as his bunker silos were too small and worn out. He further expected hay to improve his working environment and relieve his back problems because of an easier work load. This expectation has been fulfilled.

Figure 4.1: Barn for storage and drying of hay. Drying boxes are at the end
Photo: Jesper Lehmann

4.1.3 Effect on daily routines and working conditions

The four farmers were all happy with having switched to hay instead of silage. One said hay was more fun to work with and another it was more enjoyable. A third farmer noted that there was less physical work and gave him an easier workday, and the last said that feeding hay was good for the soul of the farmer. The four farmers all mentioned hay to have a delightful smell, and one farmer experienced his cows to appear more comfortable.

Two of the other farmers mentioned that the cost of reduced work load during winter was an increased work load during summer, which had made it hard for their families to go on a summer holiday. Harvesting of hay is more time consuming in terms of field work compared with harvesting of silage. Whenever the weather forecast gives a chance of three days without rain, the farmers have to start moving, spreading, raking, drying and bringing hay home. They agreed though that their summer work is more enjoyable now.

4.1.4 Effect of switching on performance of their dairy cows

4.1.4.1 Milk yield

The milk yield (kilogram) was unchanged on one farm, but had an increasing trend. The milk yield decreased slightly on the three other farms, but two of the farmers stressed that this possibly was due to other factors than the change to feeding of hay. One farmer had reduced the amount of protein supplements and had had problems with a staff member. Two farmers experienced increasing protein and fat concentrations in delivered milk where one farmer estimated this to be as much as 15% to 20%. The same farmer saw a smaller seasonal variation in yield whereas the other farmers experienced no difference.

4.1.4.2 Growth and mobilisation post parturition

One farmer noted that it had become easier for him to maintain an adequate Body Condition Score (BCS) with a smaller variation and a smaller drop in weight of the cow after parturition. Two other farmers had experienced the variation in weight after parturition to be unaffected or at least not reduced. This has caused one of the farmers to consider feeding an alternative high energy feed such as fodder beets to reduce the loss of weight after parturition. Fewer cows were estimated to be skinny on one farm, but the farmer was unsure whether this was because of rumen fill or fatness.

4.1.4.3 Health status of the herd

The general opinion among the four farmers is that exchanging silage with hay has improved the overall health status of their herds. Two farmers experience fewer diseases in general where one particularly had seen fewer hoof and digestion related diseases as well as fewer milk fevers. The other farmer had though not seen fewer cases of milk fever, but noted this disease only to be a problem during the summer months. A third farmer mentioned that his veterinary bill had been reduced.

Three farmers saw their average SCC being reduced after switching to hay and one noted it to be unchanged. One farmer had experienced SCC to be unstable during the summer months, and another stressed that SCC could still be improved, though it had decreased.

4.1.4.4 Feed intake

The four farmers agreed that their cows appeared to be more willing to eat roughage and that the palatability of good hay was higher than silage. One farmer did though mention that cows will reject bad quality hay, but they nonetheless agreed that their cows in general are able to eat a larger amount of feed when fed hay. They further agreed that it was more complicated to estimate the amount of feed eaten as hay is administered ad libitum without the amount of feed being weighed.

One farmer noted that his cows could eat more than the feed plan prescribes. Two other farmers estimated that their cows eat 11 and 12 FU in hay per cow per day respectively. The fourth farmer added that his cows would even wait for hay to be fed during early summer before going out on the paddock. He further noted that he had found it necessary to mix straw with his hay ration in order to keep faeces in a proper consistency and not too fluid.

4.1.4.5 Primiparous versus multiparous cows

The two biodynamic farmers do not dehorn their cows and mentioned that to potentially affect primiparous more than multiparous cows. He suggested this to be caused by an increased competition for feed (possibly caused by an increased feed intake of hay compared with silage) where multiparous cows generally are placed higher in the herd hierarchy. One of the two farmers noted that it was harder to maintain a sufficient weight of primiparous cows and harder for them to gain access to feed, but both farmers agreed that these issues could be resolved by ensuring plenty of space by the feeding alley. Frequent feeding was furthermore important. The two other farmers had not noticed any differences, but evaluated that space requirement are important.

Figure 4.2: Dairy cow eating hay
Photo: Jesper Lehmann

4.1.4.6 Early versus late lactation

No farmer had neither experienced nor noticed any particular differences of the performance of the cow after switching to hay in early and late lactation.

4.1.5 Other comments given by farmers

The questions asked caused the interviewees to start an extensive discussion about the challenges that they are facing after having switched to hay feeding. Many comments relate to aspects concerning production of hay where energy use and wastage in the field were among the most important. One of the farmers noted that garbage production on the farm had decreased substantially now that more or less no plastic is used.

This discussion led one of the biodynamic farmers to elaborate and suggest a few areas of further research: Hay should not only be evaluated quantitatively as a feed but also qualitatively. Here focus should be placed upon effect on health of the cow, protein and protein digestibility as well as utilisation of protein for milk production. Separate norms for nutrients should be estimated for cows whose ration is based on hay instead of silage as the current norms are based on silage feeding. He further mentioned that there is another aspect with raising young stock and genetic breeding for a cow that is capable utilising nutrients in hay more efficiently for milk production and growth.

4.2 Feedstuff analyses

4.2.1 Chemical composition

Table 4.2 shows the average nutrient composition of first, second and third cutting barn dried hay. These results are shown along with the standard composition of hay with either high or low OMD and the standard composition of first, second and third cutting clover grass silage from the NorFor Feedstuff table.

Hay seems to have a lower content of CP in Table 4.2; particularly when comparing hay and silage of the same cutting. NDF was higher in hay than silage and the indigestible proportion of NDF seems to be higher in hay when looking at the feedstuff table values. Hence, the potentially digestible proportion of NDF seems to be lower in hay. No clear trend is seen for organic matter digestibility and energy content. However, there is a trend for the protein balance in the rumen (PBV) to be lower in hay and negative in all cases except one.

The energy concentration determined as the Net Energy for Lactation (NEL) was lower in hay compared with silages from the NorFor feedstuff table. However, the analyses of barn dried hay indicate that it is possible to achieve approximately equivalent energy concentrations in hay compared with silage. The estimated fill value (FVL) per kg of dry matter was in all cases higher for hay as was the chewing time (CT) measured as minutes per kg of dry matter.

Table 4.2: Nutrient composition based on analyses[3] (Barndried hay) and the NorFor feedstuff table (Hay and Clover grass silages grown in Denmark)

	Unit	Barndried hay	Barndried hay	Barndried hay	Hay, high OMD	Hay, low OMD	Cl grass silage	Cl grass silage	Cl grass silage
Note[1,2]	-	1st cut (n=3)[1]	2nd (n=1)[1]	3rd (n=2)[1]	403[2]	404[2]	1st cut (520)[2]	2nd cut (521)[2]	3rd cut (522)[2]
DM	g / Kg	913	810	816	836	867	405	441	426
Ash	g / Kg DM	70	73	101	87	74	83	89	104
CP	g / Kg DM	108	137	150	145	106	140	150	171
NDF	g / Kg DM	525	467	483	451	542	386	409	412
pdNDF	g / Kg NDF	-	-	-	818	770	876	830	812
iNDF	g / Kg NDF	-	-	-	182	230	125	170	188
OMD	% of OM	74.4	76.7	70.9	73.6	65.9	78.7	74.2	72.9
DM_FU	Kg DM / FU	1.28	1.20	1.39	1.37	1.54	1.18	1.27	1.30
AAT	g / Kg DM	81	85	78	88	81	80	77	75
PBV	g / Kg DM	-18	-15	9	-12	-30	11	25	47
NEL	MJ / Kg DM	5.83	6.19	5.35	5.42	4.86	6.30	5.87	5.70
FVL	FVL / Kg DM	0.51	0.48	0.54	0.48	0.55	0.42	0.45	0.46
CT	Min / Kg DM	86	86	86	65	80	51	55	57

Cl grass: Clover grass; DM: Dry Matter; CP: Crude Protein; NDF: Neutral Detergent Fibre; pdNDF: potentially degradable Neutral Detergent Fibre; iNDF: indigestible Neutral Detergent Fibre; OMD: Organic Matter Digestibility; DM_FU: Dry Matter per Feed Unit; AAT: Amino acids Absorbed in the small intestines; PBV: Protein Balance in the rumen; NEL: Net Energy Lactation; FVL: Fill Value Lactation; CT: Chewing Time
[1]Number of available analyses; [2]Feedstuff number in the NorFor Feedstuff Table; [3]Samples for analyses were taken on two of the haymilk producing farms in 2010 and 2011.

4.2.2 Structural properties

Table 4.3 shows the calculated peNDF, Eating index (Ei), Ruminating index (Ri) and Chewing index (Ci) values of the feedstuffs listed in Table 4.2. These results show that the calculated structural value is considerably higher for hays compared with silages regardless of the method used (peNDF or Ci). The calculated Ci is equivalent to the reported CT in Table 4.2 and is the sum of Ei and Ri. It is furthermore seen that approximately one third of Ci is Ei and two thirds Ri for all the listed feedstuffs.

Table 4.3: Calculated peNDF, Ei, Ri and Ci of hays and silages from the NorFor feedstuff table and analyses from farms

	Unit	Barndried hay	Barndried hay	Barndried hay	Hay, high OMD	Hay, low OMD	Cl grass silage	Cl grass silage	Cl grass silage
Note[1,2]	-	1st cut (n=3)	2nd (n=1)	3rd (n=2)	403	404	1st cut (520)	2nd cut (521)	3rd cut (522)
DM	g / Kg	913	810	816	836	867	405	441	426
NDF	g / Kg DM	525	467	483	451	542	386	409	412
iNDF	g / Kg NDF	206[3]	206[3]	206[3]	182	230	125	170	188
TCL	mm	50[4]	50[4]	50[4]	50	50	20	20	20
Pef[5]	-	0.925	0.925	0.925	0.925	0.925	0.85	0.85	0.85
peNDF	g / Kg DM	485	432	446	417	501	328	348	350
Ei[6]	Min / Kg DM	26	23	24	22	27	17	18	18
Ri[6]	Min / Kg DM	50	45	46	42	53	33	37	38
Ci[6]	Min / Kg DM	76	68	70	64	80	51	56	57

Cl grass: Clover grass; DM: Dry Matter; NDF: Neutral Detergent Fibre; iNDF: indigestible Neutral Detergent Fibre; TCL: Theoretical Cut Length; pef: physical effectiveness factor; peNDF: pef*NDF; Ei: Eating index; Ri: Ruminating index; Ci: Chewing index;
[1]Number of available analyses; [2]Feedstuff number in the NorFor Feedstuff Table; [3]assumed value based on feedstuff table; [4]assumed; [5]assumed based on Mertens (1997) and 50% grass + 50% lucerne (no clover data available); [6]Nørgaard *et al.* (2011)

4.3 Effect on milk production and dry matter intake

4.3.1 Change in average annual yield per cow in southern Denmark

The change in average annual yield per cow in southern Denmark was analysed as this was thought to increase over time and be confounded with a potential change in yield caused by the switch to hay feeding.

The interaction effect between number of cows (in herd) and year could be removed for both DH and Jersey herds while the number of cows only could be removed for Jersey herds. The effect of year was only significant for DH cows, which is seen in the confidence interval for the year estimate in Table 4.4. The average yield of a cow in a DH herd was reduced by -12.47 kg ECM per year while the corresponding value for Jerseys was -24.11 kg ECM per year. However, year was only significant at 10% level. The estimate for number of cows was not included here as it only affects the intercept and not the slope of the regression.

Table 4.4: Change in average ECM yield per cow in southern Jutland in Denmark. P-values of individual parameter reduction and confidence interval for change per year

Breed		P-value of parameter reduction			Confidence interval[2]		
	n	Year * Cow	Cow[1]	Year	2.5%	Estimate	97.5%
DH	546	0.12	-	0.04	-24.37	-12.47	-0.56
Jersey	66	0.94	0.27	0.10	-52.83	-24.11	4.60

[1]No of cows in herd. A model containing "Year" as the only parameter could for convergence reasons not be modelled for DH cows; [2]For the estimate of the effect of Year; n shows number of herds included.

Model validation indicated that the assumptions of equal variance and normality are reasonably fulfilled. The mean of numeric residuals was 66.7 and 64.0 kg ECM for DH and Jersey cows respectively, which should be seen in relation to an average predicted value of 9,489 kg ECM per cow per year for DH cows and 8,475 kg ECM per cow per year for Jersey cows.

Because these results were unexpected, they were with the national average annual kg ECM yield per cow for DH and Jersey cows. The results of this linear regression are shown in Table 4.5. The average yield per cow during the seven years increased with 60.11 and 63.87 kg ECM per year for DH and Jersey cows respectively. These results show the complete opposite trend as the results based on individual herds. Based on this analysis it was decided to proceed with the analysis of the test day milk yields from the Danish Cattle Database without any adjustment.

Table 4.5: Estimate and confidence interval of change in average annual kg ECM yield per cow for DH and Jersey cows respectively

	2.5%	Estimate	97.5%
DH	24.42	60.11	95.79
Jersey	30.60	63.87	97.14

DH: Danish Holsteins

4.3.2 Lactation curves

The interaction effects between Hay and Quarter and Hay and Year had to be excluded from all six models for singularity reasons as not all combinations were represented in the data set. The previous section further showed that the effect of Year could be removed from the model as the average yield per cows was unchanged over the past seven years. The systematic seasonal effect could in no case be removed and was highly significant ($p<0.001$) for all models. Table 4.6 shows p-values of reducing selected fixed effects. The interaction effect between Hay and DIM was significant for DH cows in parity one and three or higher while the effect of Hay could be reduced for Jerseys in parity one and parity two. This essentially means that there is no detectable difference between feeding lactating Jersey cows silage compared with hay on ECM yield in this data set. No further calculations were therefore performed for Jerseys in parity one and parity two.

Table 4.6: P-values for reduction of fixed effects for the six tested models

Cow group	DH.1	DH.2	DH.3	Jer.1	Jer.2	Jer.3
Hay * DIM	0.051[2]	0.397	0.015	0.654	0.981	0.378
Hay	-	<0.001	-	0.255	0.541	<0.001
Quart	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

[1]Results within lactation category (1, 2 or 3) within breed (DH = Danish Holsteins or Jer = Jerseys); [2]This effect was kept in the model despite having set a significance limit of p = 0.05 or less

Table 4.7 shows estimates and confidence intervals for significant effects related to Hay for DH cows in parity one, parity two and parity three or higher as well as Jersey cows in parity three or higher. Estimates are of the difference between feeding hay and feeding silage. There was a significant effect on the intercept for DH cows in parity two when comparing the period of time in between feeds (Hay2) and silage, but not between Hay3 (hay) and Hay1 (silage). The interaction effect was significantly positive for DH cows in both parity one and parity three or higher. This gives a lactation curve that is more flat for hay fed than silage fed cows. For DH cows in parity one there was a significant negative effect on the intercept of feeding hay while there was a negative tendency for DH cows in parity three or higher. Jerseys in parity three or higher had a significant lower intercept when fed hay compared with silage.

Table 4.7: Estimates and confidence intervals of selected fixed effects from four of six tested models. Estimates are the difference between Hay3 and Hay1 i.e. Hay and Silage

Cow group[1]	DH.1			DH.2		
Effect	2.5%	Est.[2]	97.5%	2.5%	Est.[2]	97.5%
Hay3 * DIM	0.0007	0.0037	0.0067	-	-	-
Hay3	-1.9361	-1.2603	-0.5845	-0.5441	0.0869	0.6979
Cow group[1]	**DH.3**			**Jer.3**		
Parameter	2.5%	Est.[2]	97.5%	2.5%	Est.[2]	97.5%
Hay3 * DIM	0.0016	0.0053	0.0090	-	-	-
Hay3	-1.1846	-0.4599	0.2649	-1.6847	-1.1116	-0.5385

[1]Results within lactation category (1, 2 or 3) within breed (DH = Danish Holsteins or Jer = Jerseys); [2]Estimate

Based on the estimates listed in Table 4.7 a predicted lactation curve was generated for each of the four combinations of breed and parity (seen as cow group). From this predicted curve a maximum daily ECM yield was estimated along with the corresponding DIM as well as the slope prior and after this point and an accumulated 305 day ECM yield. Results are listed in Table 4.8 along with the difference between feeding hay and feeding silage. When an interval is given, this illustrates the seasonal effect between quarters of the year.

The largest effect of switching from feeding silage to feeding hay is seen for DH cows in parity one and parity three or higher. In both cases the curve peaks later in the lactation (five and two days later respectively) while the first parity cows have a lower maximum and the third parity cows have a higher maximum yield. When the same curve is used to predict an accumulated 305 days lactation ECM yield, it is seen that the cost of switching from silage to hay is 212 kg ECM over the entire lactation for DH cows in parity one. However, DH cows in parity three or higher produces on average 104 kg ECM more over the lactation when fed hay compared with silage. DH cows in parity two produced 26 kg ECM more although this was not significant. Jerseys in parity three or higher had its accumulated lactation yield reduced by 339 kg ECM. The predicted effect of switching from feeding silage to feeding hay indicates a dependency of parity.

Table 4.8: Estimated maximum yield, DIM at max yield, slope prior and after max yield and accumulated 305 days ECM yield. Interval depicts difference between high and low depended on quarter

Cow group[1]	**DH.1**		**DH.2**	
Parameter	Hay	Diff.[2]	Hay	Diff.[2]
Max yield	22.9 - 24.3	-1.1	29.1 – 30.5	0.1
DIM at max	41	5	23	0
Slope, prior	0.0281	-0.0008	0.0311	0
Slope, after	-0.0139	0.0037	-0.0391	0
305 day ECM	6546 - 6967	-212	7502 - 7927	26 – 27
Cow group[1]	**DH.3**[3]		**Jer.3**	
Parameter	Hay	Diff.[2]	Hay	Diff.[2]
Max yield	29.3 – 31.4	-0.4	29.2 – 30.9	-1.1
DIM at max	24	3	55	0
Slope, prior	0.0338	0	0.1491	0
Slope, after	-0.0412	0.0052	-0.0391	0
305 day ECM	7679 - 8128	104	7698 - 8215	-339

[1]Results within lactation category (1, 2 or 3) within breed (DH = Danish Holsteins or Jer = Jerseys); [2]Difference between feeding hay and feeding silage; [3]Year was significant for DH.3 and was set to 2011 for prediction ; DIM: Days In Milk

Figure 4.3 shows a graphical illustration of the four predicted lactation curves from which the values in Table 4.8 are estimated. The difference in slopes are clearly seen for DH cows in parity one and parity three or higher. For DH cows in parity two the difference is either non-existent or non-detectable as the two curves lie on top of each other.

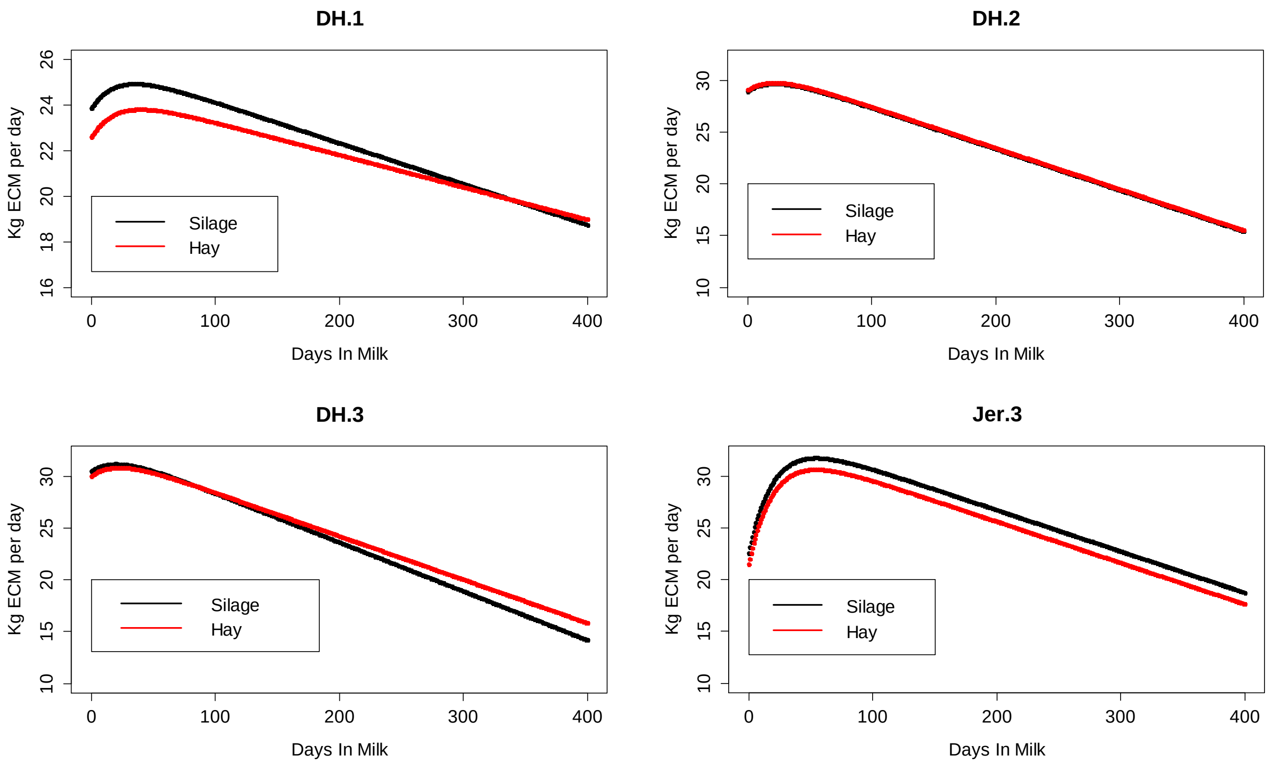


Figure 4.3: Predicted lactation curve for DH.1 (Danish Holsteins in parity 1), DH.2 (Danish Holsteins in parity 2), DH.3 (Danish Holsteins in parity 3 or higher) and Jer.3 (Jerseys in parity 3 or higher) in first quarter

Model validation indicated that the assumptions of equal variance and normality are fulfilled. All QQ-plots (not shown) indicated the same trend where low milk yields are overestimated and high milk yields and underestimated. This furthermore means that the uncertainty is greatest around the top of the curve and at the end. Despite this uncertainty it was possible to find a significant difference in slope of the curve for DH cows in parity one and parity three or higher. This might also explain why no significant difference was found for Jersey cows as the data set simply contained too few data points to show a statistical trend.

4.3.3 Fat and protein percentage

No difference could be detected for cows in parity two regardless of breed. Table 4.9 shows parameter estimates of significant fixed effects for DH and Jersey cows in parity one and parity three or higher. As an example feeding hay has a significant positive effect on the intercept and a significant negative effect on the slope of fat percentage in milk from DH cows in parity three or greater.

Table 4.9: Estimates of difference between Hay3 (hay) and Hay1 (silage) for fat and protein percentage. Estimates have a confidence interval significantly different from zero. Effect is on log of response

Parameter	Effect	DH.1	DH.3	Jer.1	Jer.3
Fat %	Hay * DIM	-	$-1.027*10^{-4}$	-	-
	Hay	$2.071*10^{-2}$	$0.0283*10^{-5}$	-	-
Protein %	Hay * DIM	$9.972*10^{-5}$	-	-	-
	Hay	-	$2.60*10^{-2}$	$2.263*10^{-2}$	-

DH: Danish Holstein; Jer: Jersey; DH.1: DH in parity one; DH.3: DH in parity three or higher; Jer.1: Jer in parity one; Jer.3: Jer in parity three or higher

The values in Table 4.9 are difference in effect on log of the response and these differences were used to predict development of the log of daily fat and protein percentage. Graphs in Figure 4.4 were produced after converting these results to depict the actual fat and protein percentage for DH cows in parity one and parity three or higher depended on DIM.

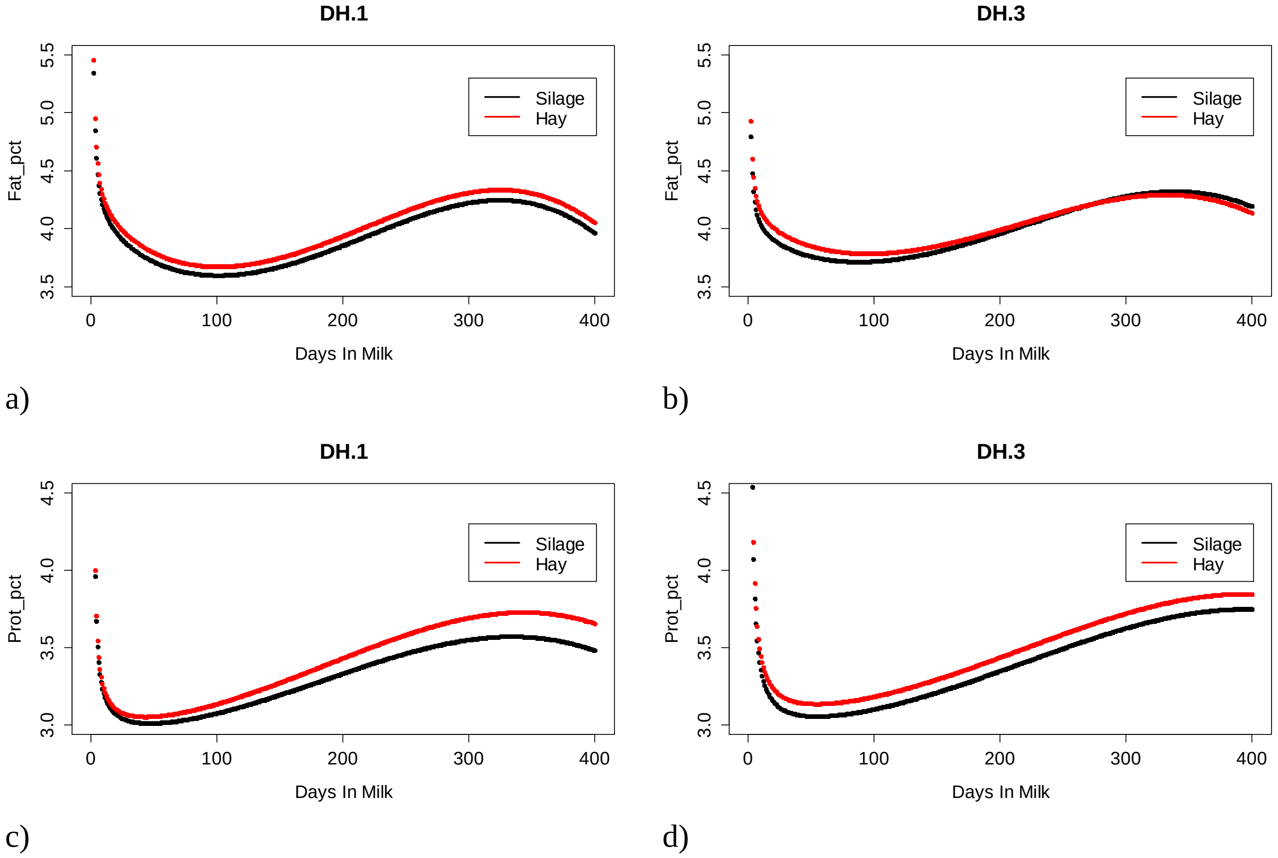


Figure 4.4: Development of fat (a and b) and protein (c and d) percentage in milk for Danish Holstein cows in parity one (DH.1) and DH cows in parity three or higher (DH.3)

Figure 4.4 shows that the overall fat and protein concentration have increased for both groups of cows after switching to hay feeding. Based on these results the average daily fat and protein percentages over 305 days (one standard lactation) were predicted for cows fed hay as well as the difference between hay and silage fed. These results are listed in Table 4.10 and show that the average concentration of fat and protein have increased for DH cows in parity one and parity three or higher. In addition, the protein concentration had increased for Jersey cows in parity one as well. Predictions were only carried out if a significant difference in parameter estimates were found (Table 4.9).

Table 4.10: Estimated mean per day or sum for a lactation of 305 days. Difference is between hay and silage

Parameter	Unit	DH.1	DH.3	Jer.1	Jer.3
Fat %	Mean / day	4.02	4.04	-	-
	Difference	+0.09	+0.03	-	-
Protein %	Mean / day	3.42	3.48	4.29	-
	Difference	+0.10	+0.09	+0.10	-

DH: Danish Holstein; Jer: Jersey; DH.1: DH in parity one; DH.3: DH in parity three or higher; Jer.1: Jer in parity one; Jer.3: Jer in parity three or higher

4.3.4 Predicted dry matter intake and milk production

Holstein dairy cows were predicted to have a higher DMI and a higher ECM yield when fed silage compared with hay irrespective of the cow's theoretical yield capacity (7,500 versus 9,500 kg ECM per year), OMD of the used forage (High versus low) and the roughage percentage in the ration (50%, 60%, 70% or 80%). DMI and ECM was furthermore predicted for cows at three lactation stages (Early, Mid and Late) as well as two parities (first and older), but neither lactation stage nor parity were found to change the result. Figure 4.5 shows results for older cows in mid lactation, and it is seen that both total DMI and ECM yield decreases as the roughage percentage increases. The used software (NorFor) was only able to optimise a ration containing 80% roughage when forage with high OMD was fed to cows with a theoretical yield capacity of 7,500 EMC per year.

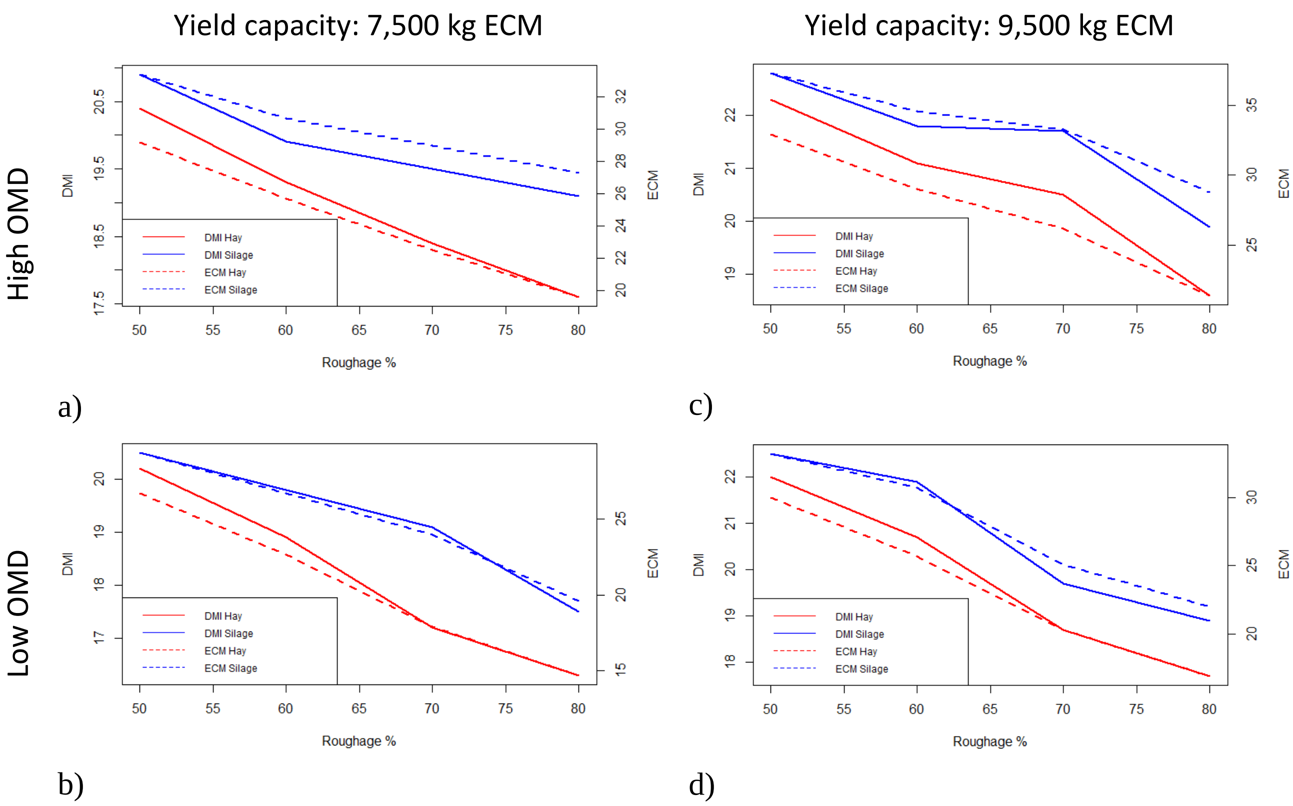


Figure 4.5: DMI and ECM yield of multi parous cows fed either a silage or a hay based ration at four levels of roughage percentage. Rations were optimised for cows at two yield levels (7,500 ECM per year and 9,500 ECM per year) and at two standard OMD levels.

OMD: Organic Matter Digestibility; ECM: Energy Corrected Milk; DMI: Dry Matter Intake.
Kg DMI and corresponding kg ECM production was predicted with NorFor for an average cow older than first lactation at four fixed roughage percentages (50, 60, 70 and 80). NorFor could not optimise a ration with 80% roughage in b), c) and d) with respect to AAT and PBV.

Figure 4.6 shows the same figures as Figure 4.5 with the addition of a predicted DMI and ECM of hay fed cows where the theoretical intake capacity had been increased with 5%. The total DMI was increased in all cases, although it never exceeded DMI of silage rations, which were unchanged. Interestingly, the predicted ECM yield exceeded that of silage fed cows in most cases, which indicates a predicted higher utilisation of feed for milk production.

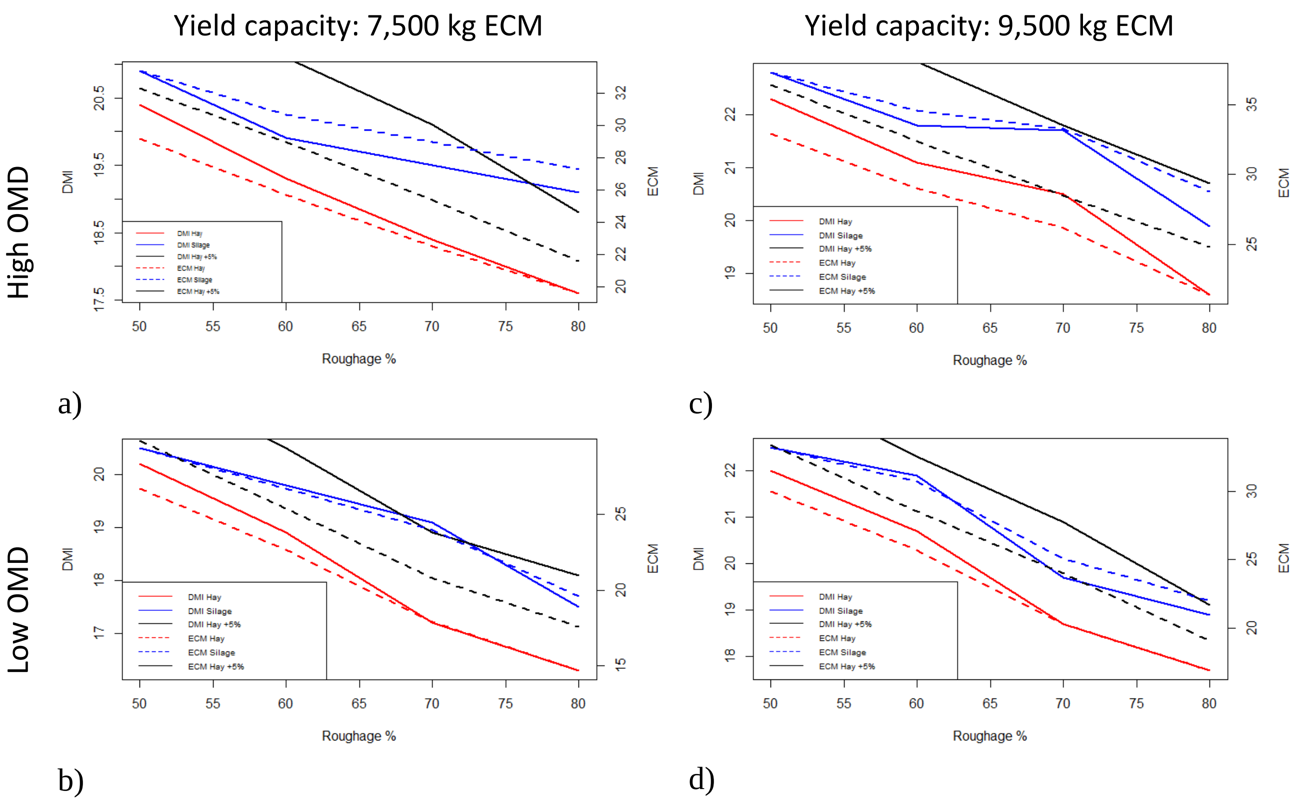


Figure 4.6: Effect of increasing DMI capacity with 5% on DMI and ECM yield of multi parous cows fed either a silage or a hay based ration at four levels of roughage percentage. Rations were optimised as in Figure 4.5.

OMD: Organic Matter Digestibility; ECM: Energy Corrected Milk; DMI: Dry Matter Intake.
Kg DMI and corresponding kg ECM production was predicted with NorFor (www.norfor.info) for an average cow older than first lactation at four fixed roughage percentages (50, 60, 70 and 80). NorFor could not optimise a ration with 80% roughage in b), c) and d) with respect to AAT and PBV.

4.4 Effect on health

4.4.1 Somatic cell count

A significant difference was found in the test day SCC for all groups of cows except DH cows in parity one. Hence, results for these cows were omitted. Except for DH cows in parity three or higher, the interaction effect between DIM and Hay could be reduced for all other groups of cows.

Figure 4.7 shows the development of SCC in milk starting at parturition. Jersey cows in parity one, two and three or higher showed a similar trend as DH cows in parity two (not shown). It is furthermore seen that the difference between silage and hay for DH cows in parity three or higher diminishes over time as an effect of the significant interaction between Hay and DIM.

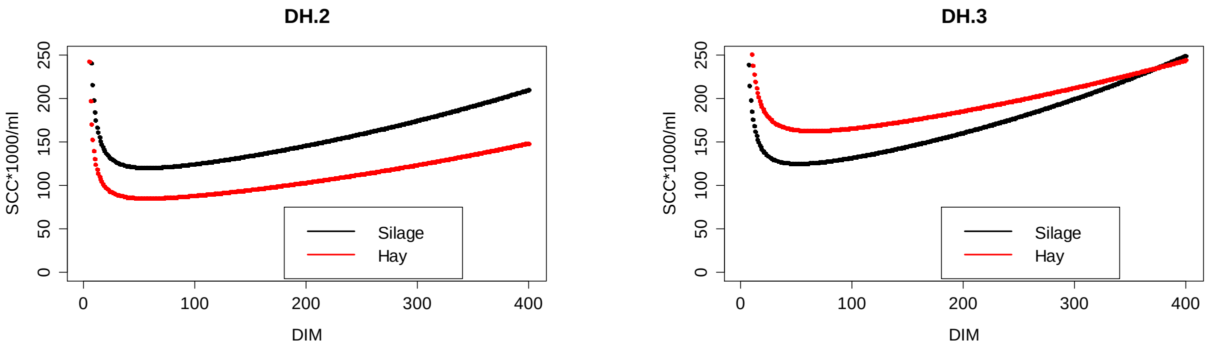


Figure 4.7: Predicted daily Somatic Cell Count (SCC) in milk for cows fed either silage or hay. DH.2: Holsteins in parity two. DH.3: Holsteins in parity three or higher

Table 4.11 shows the predicted mean SCC of each of the five groups of cows, which had a significant effect of the Hay factor. The first 20 days after parturition were omitted as these showed to be considerable different from the rest of the lactation (also seen in Figure 4.7).

Table 4.11: Mean of daily predicted SCC (x 1,000 cells / ml) between 20 and 305 DIM for cows fed either silage or hay

	Silage	Hay	Diff[1]	Diff in pct[2]
DH.2	141	100	-41	-29
DH.3	153	181	+28	+20
Jer.1	126	79	-47	-37
Jer.2	151	104	-46	-31
Jer.3	176	141	-35	-20

SCC: Somatic Cell Count; DIM: Days In Milk; DH: Danish Holsteins; Jer: Jerseys; 1: Parity one; 2: Parity two; 3: Parity three or higher; [1]Difference between hay and silage; [2]Difference between hay and silage in percentage

4.5 Effect on production economy

4.5.1 Price estimation of hay and silage

The cost of producing one FU of hay was estimated to be 2.77 kroner whereas silage was estimated to cost 2.07 kroner per FU, which is a difference of 0.71 kroner per FU. The total field related cost was estimated to be 0.06 kroner higher per FU for hay. Likewise was the total cost storing estimated to be 0.72 kroner per FU higher for hay of which approximately two thirds was accounted for through the cost of drying. Detailed calculations are shown in Appendix 2, and a complete list of assumptions is shown in Section 2.8.1.

Table 4.12: Estimated price of hay and silage per FU

	Hay	Silage	Diff.	
Yield	5,800	6,500	-700	FU / ha
Field	0.94	0.88	0.06	Kr. / FU
Other	0.84	0.84	-	Kr. / FU
Field, total	**1.78**	**1.72**	**0.06**	**Kr. / FU**
Storage	0.38	0.13	0.25	Kr. / FU
Drying	0.46	-	0.46	Kr. / FU
Handling	0.09	-	0.09	Kr. / FU
Plastic	-	0.08	-0.08	Kr. / FU
Storage, total	**0.94**	**0.21**	**0.72**	**Kr. / FU**
Feeding out	0.06	0.13	-0.07	Kr. / FU
Total price	**2.77**	**2.07**	**0.71**	**Kr. / FU**

See appendix X for detailed calculations

If the yield of hay was changed to be equal that of silage (6,500 FU per hectare), then the difference was reduced to 0.63 kroner per FU. Likewise a reduction in the capacity of the hay drier from 500,000 to 200,000 FU per year would cause the difference to increase to 1.29 kroner per FU. Halving the energy consumption to 0.49 kWh per kg of water removed from the hay caused the price difference to be reduced to 0.48 kroner per FU. Furthermore, drying of the forage in the field to dry matter percentage of 70 instead of 60 would reduce the difference in price to 0.48 kroner per FU.

4.5.2 Feed cost per kg ECM produced

The cost of feeding hay was in all cases found to be higher when compared with silage. Table 4.13 shows the estimated difference between hay and silage for an average cow at two theoretical yield capacities (7500 versus 9500 kg ECM Per year) fed one of eight types of rations, which varied by OMD (high versus low) and proportion of roughage (50%, 60%, 70% or 80%). The difference between hay and silage varied from 0.15 to 0.35 kroner per ECM in the standard scenario where hay and silage were assumed to substitute each other at a one to one ratio. The difference was increased to between 0.25 to 0.44 kroner per ECM if switching to hay feeding caused to the cow to consume one kg DM more per of the ration. Approximately, the same result was found when hay feeding was assumed to reduce milk yield with one kg ECM per day with an unchanged DMI. Reducing the estimated price of hay (see Section 4.5.1) with 10% reduced the difference to vary between 0.09 and 0.18 kroner per ECM whereas increasing the price of hay caused the difference to vary between 0.23 and 0.47 kroner per ECM. If switching to hay caused both total DMI to increase with one kg per day and daily milk yield to decrease with one kg, then the difference varied between 0.36 and 0.56 kroner per ECM.

The average across all scenarios in Table 4.13 showed that the effect of the theoretical yield capacity of the cow was small. The difference was always less than 0.01 kroner per ECM. The difference between hay and silage were 0.01 to 0.04 kroner per ECM less in scenarios where the forage had a high OMD compared with low. The difference between hay and silage increased in all scenarios as the proportion of roughage increased.

Table 4.13: The difference between a hay based and a silage based ration in total feed cost (in kroner) per kg ECM produced. Effect of theoretical yield capacity, OMD and proportion of roughage in ration on six scenarios.

Yield[1]	OMD[2]	R %[3]	Standard[4]	Plus DM[5]	Less milk[6]	Min 10%[7]	Pl 10%[8]	DM Milk[9]
7500	High	50	0.15	0.26	0.26	0.09	0.23	0.37
7500	High	60	0.19	0.30	0.30	0.11	0.29	0.41
7500	High	70	0.23	0.35	0.34	0.13	0.35	0.45
7500	High	80	0.28	0.41	0.40	0.17	0.43	0.52
7500	Low	50	0.17	0.27	0.27	0.09	0.24	0.38
7500	Low	60	0.22	0.31	0.31	0.11	0.30	0.42
7500	Low	70	0.27	0.37	0.37	0.14	0.37	0.48
7500	Low	80	0.35	0.44	0.43	0.18	0.47	0.56
9500	High	50	0.15	0.25	0.26	0.09	0.23	0.36
9500	High	60	0.19	0.29	0.30	0.11	0.28	0.40
9500	High	70	0.22	0.34	0.34	0.13	0.35	0.45
9500	High	80	0.27	0.40	0.40	0.16	0.43	0.51
9500	Low	50	0.17	0.26	0.27	0.09	0.24	0.37
9500	Low	60	0.21	0.31	0.31	0.11	0.30	0.42
9500	Low	70	0.27	0.36	0.36	0.14	0.37	0.48
9500	Low	80	0.34	0.44	0.43	0.18	0.47	0.56

[1]Theoretical yield capacity in kg ECM per year; [2]Organic Matter Digestibility of forage;
[3]Proportion of roughage in ration;
[4]Standard scenario where DMI and ECM production is equal regardless of the forage fed;
[5]Switching to hay caused DMI of ration to increase 1 kg;
[6] Switching to hay caused ECM production per day to decrease with 1 kg;
[7]Standard hay price was increased with 10%;
[8]Standard hay price was decreased with 10%;
[9]Swithcing to hay caused both total DMI to increase with 1 kg and daily ECM production to decrease with 1 kg

The cost per day of feeding a cow, per kg DMI and per kg ECM was estimated under experimental conditions and results are shown in Table 4.14. It was always more expensive to feed hay compared with silage, and the price of the complete ration increased with increasing concentrate level. The estimated price per kg DMI and per kg ECM was lowest at the low level of concentrate.

Table 4.14: Cost of feeding hay compared with silage rations under experimental conditions. Effect of level of concentrate in ration

	Week[1]	4 to 10		11 to 26					
	Forage	Hay	Silage	Hay	Silage	Hay	Silage	Hay	Silage
	Concentrate[2]	-	-	L	L	M	M	H	H
Forage	Kg DM	10.20	9.30	14.40	15.20	13.40	13.80	12.50	12.70
Concentrate	Kg DM	8.10	7.70	2.60	2.60	5.30	5.10	8.00	7.10
Total DMI	Kg DM	18.30	17.00	17.00	17.80	18.70	18.90	20.50	19.80
Milk	Kg	27.60	28.10	19.90	21.50	20.10	22.90	21.80	23.30
ECM	Kg	27.48	29.05	21.02	21.79	21.29	23.27	22.79	23.99
ECM / DMI	Kg / Kg DM	1.50	1.71	1.24	1.22	1.14	1.23	1.11	1.21
Price	Kr.	55.39	47.30	41.82	36.19	50.78	44.14	59.95	50.53
Price / Kg DM	Kr. / Kg DM	3.03	2.78	2.46	2.03	2.72	2.34	2.92	2.55
Price / ECM	Kr. / ECM	2.02	1.63	1.99	1.66	2.38	1.90	2.63	2.11

[1]Week in lactation of multiparous cows; [2]Level of concentrate in ration
Dry matter intakes and milk yield were obtained from Bertilsson & Burstedt (1983)

Table 4.15: Effect of change in price of hay and concentrate on the difference in cost between feeding hay and silage per kg ECM

		Week[1]	4 to 10	11 to 26		
	Change	Concentrate[2]	-	L	M	H
Hay price	-20%	Kr. / ECM	0.23	0.03	0.22	0.29
	-10%	Kr. / ECM	0.31	0.18	0.35	0.41
	-	Kr. / ECM	0.39	0.33	0.49	0.52
	+10%	Kr. / ECM	0.47	0.48	0.62	0.64
	+20%	Kr. / ECM	0.55	0.62	0.76	0.76
Concentrate price	-20%	Kr. / ECM	0.36	0.32	0.46	0.48
	-10%	Kr. / ECM	0.38	0.33	0.48	0.50
	-	Kr. / ECM	0.39	0.33	0.49	0.52
	+10%	Kr. / ECM	0.40	0.33	0.50	0.55
	+20%	Kr. / ECM	0.41	0.33	0.51	0.57

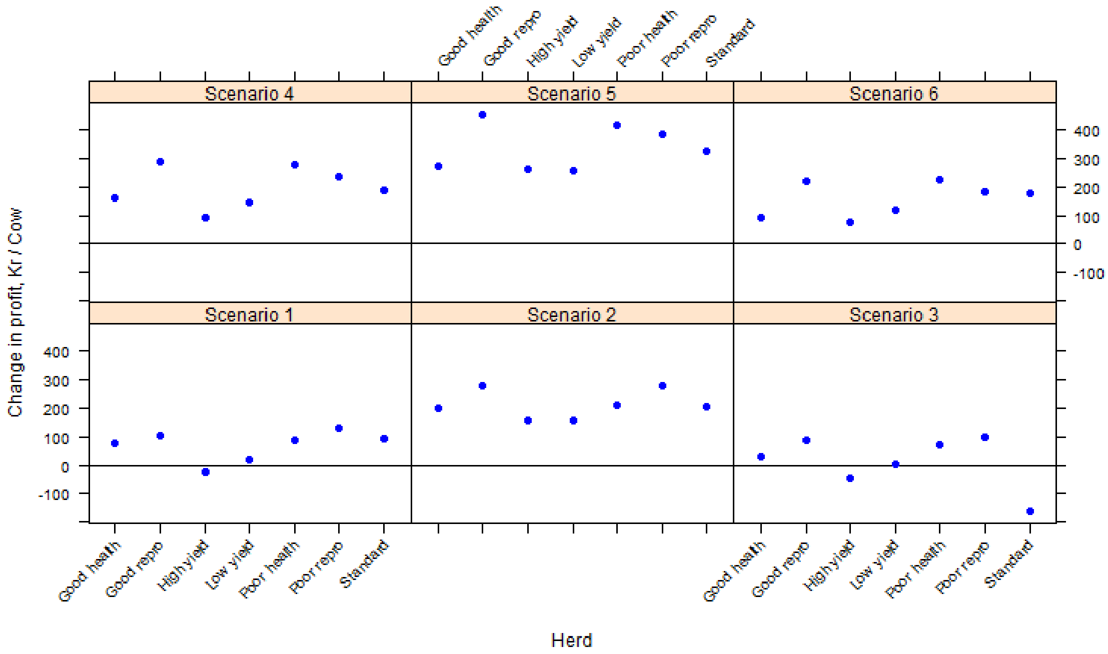
[1]Week in lactation of multiparous cows; [2]Level of concentrate in ration

The calculated differences between hay and silage in Table 4.14 are shown in Table 4.15 along with the estimated effect of changing the price of hay and changing the price of concentrate. It seen that the difference between hay and silage increases as the concentrate level increases. Furthermore, the price of hay has a relatively large effect on the difference where this effect was largest at the low level of concentrate. Reducing the price of hay with 20% caused the difference between hay and silage to be mere 0.03 kroner per ECM at the low level of concentrate. The price of concentrate had on the other hand a relatively small impact on the difference between hay and silage when compared with the price of hay.

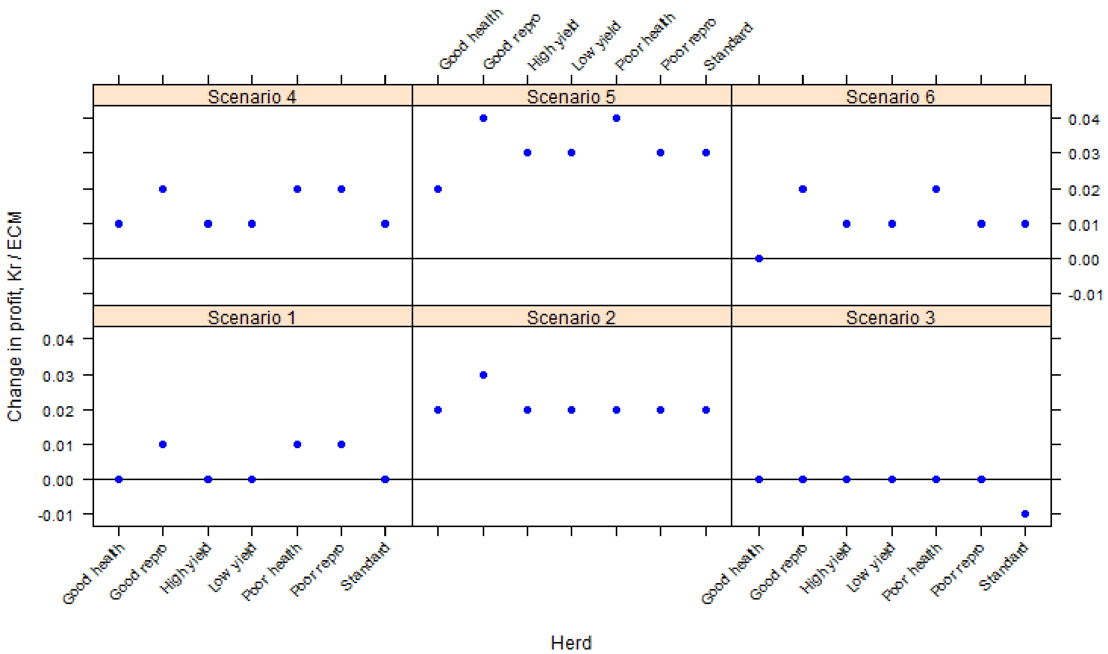
4.5.3 SimHerd simulations

The results of the simulations performed with the SimHerd model showed that switching to hay feeding resulted in an average change in profit of 164 kroner per annual cow per year across all six scenarios and all seven herds. However, this change varied from -161 to 450 kroner per annual cow across all six scenarios and all seven herds. Figure 4.8 shows the result of the simulation of each herd within each scenario where the herd "Good repro" appears to achieve the highest gain in profit per annual cow by switching to hay feeding across all scenarios. The herd "High yield" (Scenario 1 and Scenario 3) and the herd "Standard" (Scenario 3) were the only herds achieving a loss in profit per annual cow.

The average change in profit per kg ECM was positive for all simulated scenarios except one (Scenario 3 simulated for Herd "Standard) where the change was estimated to be -0.01 kroner per kg ECM. In contrast the maximum positive change was estimated to be 0.04 kroner per kg ECM (Scenario 5 for Herds "Good repro" and "Poor health").



a)



b)

Figure 4.8: Change in profit per annual cow (a) and profit per kg ECM (b) of switching to hay feeding. Effect of six scenarios on seven types of herds

Scenario 1: Change in yield
Scenario 2: Scenario 1 + SCC reduced for both younger and older cows
Scenario 3: Scenario 1 + SCC reduced for younger and increased for older cows
Scenario 4: Scenario 1 + risk of ketosis and displaced omasum reduced with 50%
Scenario 5: Scenario 1 + Scenario 2 + Scenario 4
Scenario 6: Scenario 1 + Scenario 3 + Scenario 4

5 Discussion

The main objective of this thesis was to improve the decision basis for farmers considering switching from silage feeding to hay feeding of their lactating dairy cows. This was attempted through a literature review and a qualitative analysis as well as quantitative analyses. This section discusses the combined results of the review and analyses.

5.1 Farmer's motivation and effect on work routines

Three factors appeared to have affected the four farmers' motivation for switching to hay feeding. Those were inspiration from other farmers, a belief in hay being "better" for their cows and the ability to obtain a premium for their milk from the dairy company. The interview was not designed to and did not reveal which of these factors was the predominant, and the farmers likely motivated each other as the conversion took place over two to three years. It is interesting that three of the farmers emphasize their trip to Austria as being important for their inspiration. The conditions under which hay is made in Austria are likely substantially different compared with Denmark due differences in geography and climate. In addition, the average dairy herd size in Austria is 10.6 cows per farm (Eurostat, 2007) where the equivalent figure for Danish organic dairy herds is 152 (Videncentret for Landbrug, 2011). One of the farmers interviewed even runs a dairy herd with 200 annual cows, which furthermore illustrates that they have up scaled the Austrian system a number of times. However, this does not necessarily mean that it will not work.

A potential positive health effect of hay is discussed in a subsequent section, but it is hard to elucidate where their belief in hay being better for their cows stems from. Two of the farmers are certified biodynamic, which requires cattle to be fed hay and not a pure silage based diet (Loehr-Petersen, no year), and this might affect their opinion. It can also be speculated that this is a mere secondary claim meant to substantiate and justify a decision already made. Analyses in this thesis showed that the feed cost per kg of milk produced is greater when cows are fed a hay based diet (discussed in a subsequent section). A positive health aspect might aid in justifying a premium for their milk. The ability to achieve a premium from their dairy company was furthermore mentioned as a motivation for switching, but this is likely influenced by the company's ability to obtain a premium from their customers. However, this is speculation.

Another perspective of the farmer's switch to hay feeding is how it appears to have affected their daily working routines. They all agreed that working with hay was more enjoyable despite that their annual work load was more unevenly distributed. Their increased summer work load was compensated for by a reduced work load during winter, which, according to the farmers, was caused by more field work during summer and for example no frozen silage packs during winter. Perhaps the problem with an increased summer work load could be solved by outsourcing field work; although the farmers agreed that they enjoyed this work.

Irrespective of how these farmers have perceived their changed work load, and why and how they were motivated to switch to hay feeding, then these perceptions and arguments are likely to be individual. Thus, the reasoning behind these farmers' switch to hay feeding might not apply to other farmers, and the results of this interview should be seen as an example. The enthusiasm of these farmers for hay feeding was apparent during the interview, and this enthusiasm has likely affected their answers. It is furthermore likely that a farmer, who is more enthusiastic about switching to hay feeding, will achieve different results and perceive the switch differently when compared with a farmer, who is less enthusiastic.

5.2 Effect on chemical composition and structural properties

The literature review showed that the actual chemical composition of both silages and hays are to a higher degree dependent on botanical composition and maturity of the crop than the used conservation method. There was however a tendency for a higher NDF as well as lower CP and energy content of hay compared with silage. As discussed in the literature review; this is likely affected by a higher brittleness of hays, which was indicated by a lower grinding resistance. If hays are more brittle and thus have a lower ability to withstand mechanical treatment, then there might be a technological solution to this issue. The CP content of first cutting barn dried hay was lower (108 g / kg DM) compared with second (137 g / kg DM) and third cutting (150 g / kg DM). However, the CP level of first cutting barn dried hay was determined as the average of three analyses where one showed 82 g / kg DM and the two others showed 122 and 120 g / kg DM respectively. Nevertheless, the chemical composition of hays and silages based on analyses of barn dried hay and values from the NorFor feedstuff table indicated the same trend for NDF and CP; although the analyses of barn dried hay also showed that it was possible to achieve equivalent contents of CP and energy.

The analyses of barn dried hay (Table 4.2) showed that there was a trend for the protein balance in the rumen (PBV) to be lower in hay and negative in all cases except one. The PBV value is used to evaluate the adequacy of protein for microbial growth (Volden & Larsen, 2011). In contrast, the PBV value for silage was positive, which implies that silage and hay based rations have to be balanced differently in order to meet the recommended average PBV value between 10 and 40 g / Kg DM (Anonymous, 2011b).

The analyses of barn dried hay provided a measure of the relative FVL, which was used to predict the total amount of feed that can be consumed by a specified cow (Figure 4.5). The fill value of individual forages are not fixed in the NorFor system, but affected by the other feedstuffs included in the individual ration. However, assuming the difference between hays and silages to be fixed, then the higher fill value of hays relative to silages determined in this thesis, would cause a reduced consumption. This furthermore assumes that the intake capacity of the cow is unchanged. The effect of switching to hay feeding on the intake capacity of the cow is discussed in a subsequent section. Nonetheless, a reduced feed intake combined with a lower CP content in hays would increase the difference between hay and silage in total consumed CP.

The discussion here is, however, based on relatively few samples taken of hay, and they are compared with standard values for silage and hay from the national feedstuff table. Sampling variation from the national table and from the samples taken in this thesis should be considered. The volume of hay can be expected to be larger for hay compared with an equivalent amount of silage dry matter. It can be speculated that there is a large variation in the chemical composition of hay across samples as there is a risk of dried leaves falling off and avoiding sampling. However, no data could be found to back up any of these claims.

Structural properties were evaluated using CT (= Ci) and peNDF (Table 4.3). As expected, CT was larger for hays, which probably relates to a coarser structure and longer average particle length, although these attributes were not listed in the analyses. As no particle length for hays were given with the analyses, they were assumed to have the standard particle length from the feedstuff table, which were 50 mm for hays and 20 mm for clover grass silages.

Both peNDF and CT (Table 4.3) are dependent on NDF and TCL, and a larger difference in NDF content combined with a larger TCL enhances the difference in physical structural value between hays and silages in Table 4.3 compared with Table 3.2. The difference in peNDF found here between hay and silage was not seen in the experiment by Dohme *et al.* (2007), who concluded that peNDF (or SV) do not differ between conservation methods. This indicates that drying a feed on its own instead of ensiling it does not alter the structural value significantly, but it is also affected by the particle length. The general practice in Denmark is to chop a crop of mixed clover and grass for silage with a shorter TCL compared with hay, for which reason Table 4.3 should provide a "better" picture of the feed fed to lactating dairy cows in Denmark. However, the hays and silages in Table 3.2 were grown under the same conditions, which is not necessarily the case for hays and silages in Table 4.3. This implies that the forages analysed may have been harvested on different dates, at different stages of maturity, in different regions in Denmark and have different botanical compositions as well as other factors such as TCL and the use of silage additives. These factors may affect the comparability between the two conservation methods as they likely affect the chemical composition as well as CT and peNDF.

5.3 Effect on milk production and dry matter intake

None of the interviewed farmers had noticed a significant change in milk production, although one of the DH farmers and the one Jersey farmer mentioned there to be a slightly negative trend. It is unclear based on the interview whether the reduced milk production is in bulk volume or ECM. If the bulk volume has been reduced, then this reduction might be compensated for by an increased fat and protein concentration. If the production effect is depended on parity, then the distribution of cows between parities in the particular herd will affect how the effect on milk yield is experienced by the farmer. A reduced milk yield of DH first parity cows could be compensated for by cows in third or greater parity resulting in an unchanged total daily milk yield for the herd. However, this implies that the farmer uses the total daily milk yield to assess the effect of switching to hay feeding on milk yield. One DH farmer experienced an increasing trend whereas the other DH farmer experienced a decreasing trend in milk yield, and these diverging views of the effect can possibly be explained by differences in distribution of cows between parities among these two herds. However, this was not investigated. The total yield during a lactation of 305 days was estimated (Table 4.8) to be -212 kg ECM lower for DH cows in parity one whereas DH cows in parity three or greater were estimated to produce 104 kg ECM more when they were fed hay. There seems to be a partial compensation effect, although this implies that the proportion of first parity cows is equal to the proportion of cows in parity three or greater.

A decreased yield can be due to other factors such as changed concentrate feeding and/or changed management routines as well as changed herd composition (older/younger cows or fewer/more days in milk). Furthermore, production could be affected by decreased accessibility of hay for primiparous cows because of dominance by multiparous cows wanting to fulfil a potential increased feed intake capacity. However, this is speculation, although multiparous cows do generally have a greater feed intake capacity within each breed at equivalent milk production levels. The literature review showed contradicting results where increased and decreased as well as unchanged milk yields were seen.

The analysis of yield (Table 4.8) showed that the effect of hay feeding on Jersey cows appeared to be different from DH cows. The Jersey data set contained relatively few observations compared with the DH data set, and this likely reduced the ability of a potential effect being detected assuming that the variation within the two data sets are equivalent. The Jersey data set had 1,203 observations from the silage period and 505 from the hay period for cows in parity three or higher. In comparison the same data set for DH cows contained 3,362 and 2,555 observations respectively. The other data sets had fewer observations compared with Jerseys in parity three or higher. If the model is true, despite the limited data, and cows in parity three or higher are the only ones affected by the change of feed, then the total reduced daily milk yield (a herd with 70 annual cows) is approximately 17.9 kg ECM per day. However, this implies an assumed 1.1 completed lactations per annual cow per year and 25% of the herd being in parity three or higher. The farmer mentioned a slight negative trend for the daily herd milk yield and perhaps this is what he meant. Regardless, one has to take into account that this data set only included one Jersey herd with limited data.

Table 5.1 shows the uncertainty regarding the four plotted lactation curves in Figure 4.3. The values are means and medians of all numeric residuals and are therefore calculated across the entire lactation (305 days). The average uncertainty is larger for DH cows in parity three or higher than cows in parity two or parity one. The predicted daily milk yields of a DH cow in parity three or greater is therefore on average ± 3.48 kg ECM of the true value. This uncertainty has to be taken into account when comparing the lactation curve of hay fed with silage fed dairy cows in Figure 4.3. However, the significant interaction effect between Hay and DIM (Table 4.6) shows that DH cows in parity one and parity three or greater generally have a more persistent milk production over the course of a lactation.

Table 5.1: Mean and median of numeric residuals of model for Danish Holsteins in parity three or higher

Cow group[1]	Mean res[2]	Med res[3]
DH.1	2.44	1.79
DH.2	2.68	1.97
DH.3	3.48	2.65
Jer.3	2.67	2.15

[1]Results within lactation category (1, 2 or 3) within breed (DH = Danish Holsteins or Jer = Jerseys); [2]Mean of residuals; [3]Median of residuals

The overall fat and protein concentration have increased for both groups of cows after switching to hay feeding. This is in line with two of the farmers in the interview (Section 4.1), who experienced increasing protein and fat concentrations. One farmer claimed the increase to be as much as 15% to 20%, but this was not supported by the data. However, his herd was not part of the data set, and his claim can therefore neither be verified nor disproven.

The literature review showed the same trend for dry matter intake as for milk yield where increased, decreased and unchanged DMI were seen. One farmer noted that his cows seemed to be able to consume more feed than calculated in the feed plan. His feed plan was calculated with NorFor, and thus the same software as used to estimate the theoretical feed plans in order to predict DMI and ECM production of cows fed either hay or silage based rations. NorFor predicted in all cases that a cow fed a hay based ration would consume less feed and produce less milk. This is not in line with the view of the farmer, although the reduction in predicted DMI was within what was seen in parts of the literature.

If one assumes that the feed plan is well balanced according to the desired cow and its current milk production, then the deviation between estimated and observed feed intake can be explained by either a wrong feed analysis or an insufficient nutrient model. A wrong analysis and hence a wrong knowledge on nutrient composition of the feed, can be caused by a large variation and therefore greater uncertainty or possibly insufficient methods when it comes to analysing dried instead of ensiled forages. In addition, the model used to balance the ration might not be sufficient to handle dried forages properly if the model is based on total mixed silage rations. However, these considerations are speculations.

5.4 Effect on health and somatic cell count

Feeding hay instead of silage resulted in a reduced SCC level, albeit this is based on relatively few cows. This result is in agreement with a recent Danish study (Helleshøj, 2012). This study showed that the average bulk tank SCC for all herds in Denmark had been reduced with approximately 30,000 cells / ml from 270,000 cells / ml over 16 years (~11%). This may explain part of the decrease in SCC seen on the three haymilk producing herds, although data analysed here was individual test day measurements and only seven years were included. Helleshøj (2012) further showed there to be a considerable seasonal variation, which was not taken into account here, and a relatively constant difference of approximately +35,000 SCC cells/ml between bulk tank and produced milk as well as no apparent difference between organic and conventional milk. The three haymilk producing herds are all certified organic. In addition, numerous management practices affect herd level SCC as was reviewed by Dufour *et al.* (2011), who also concluded that these effects are inconsistent in how and how much they affect SCC.

Comparing these results with Helleshøj (2012) shows, that the SCC has been reduced with two to three times as much (percentagewise) for all groups of cows except DH cows in parity three or greater. The general opinion among the farmers were that SCC had been reduced, which is confirmed here. However, it is unclear why DH cows in parity three or higher behaves completely different, but this can be attributed to a management issue or uncertainty due to the relative small data set, although this was not investigated. In addition, all groups of cows in Table 4.11 have an average SCC below the limit, which the Danish dairy company Arla Foods (Anonymous, 2011c: p. 41) uses to pay their suppliers the highest premium (2%). This indicates that the three farms, whose data were analysed here, are relative well managed regarding SCC. Furthermore, Helleshøj (2012) reported an average SCC varying between 265 and 310 depending on time of the year, which is well above the levels listed in Table 4.11.

The literature review showed that it was not possible to substantiate the perception of the farmers that feeding hay instead of silage has positive effect on the health of their cows. A reduced veterinary bill is in one way a good indicator of this, but perhaps the reduced workload in relation to time spent feeding has increased farmer’s level of attention towards his animals due to more time available. It is nevertheless their experience that the prevalence of diseases related to digestion and hoofs as well as milk fever in some cases is reduced. The literature furthermore showed that there might be chance of a reduced disease risk through in increased level of structural fibre in the diet. However, no evidence could be found to substantiate this claim and it is likely to be affected by the level of concentrate as well as the time at which concentrate is fed relative to hay and the number of meals, which the concentrate is separated into.

5.5 Effect on economy

5.5.1 Price estimation of hay and silage

Høy & Lauridsen (2009) estimated a price of 2.45 kroner per FU for the growing, drying and storing of one FU of hay assuming a total yield of 8,100 FU per hectare per year. This is approximately 83% (1.11 kroner) higher than the price of silage estimated here. However, Høy & Lauridsen (2009) included irrigation in estimation, which could cost around 2,280 kroner per hectare (Anonymous, 2012a) or 0.28 kroner per FU in their test, although their calculations are not described in detail. Høy & Lauridsen (2009) furthermore estimated the cost of storing hay (depreciation plus interest) to be 1.02 kroner per FU (not including cost of drying).

Using the same principles along with the construction prices and capacities reported by Høy & Lauridsen (2009), the price of storing hay was estimated to be 0.59 kroner per FU, which is 42% less than the price reported by Høy & Lauridsen (2009). However, it is unclear how they performed their estimation and it was only performed on one farm. The owner of this farm claims the capacity to be set too low, and the price of the drying equipment to be set too low by Høy & Lauridsen (2009) where he recommended the capacity to be set at 500,000 FU per year and the price at 1,250,000 kroner (Lorenzen, 2012). Using these values instead reduced the estimated price of storing hay to 0.38 kroner per FU. It is possible that the difference between the price estimated here and the one reported by Høy & Lauridsen (2009) is caused by a difference in the depreciation assumption.

Høy & Lauridsen (2009) furthermore reported the cost of drying to be 0.22 kroner per FU or 0.58 kroner per kg of removed water from the hay. The amount of DM in their experiment was estimated to be 30.375 tons and 9,875 kWh was used to dry the hay from 67.5% to 86.9% DM. This is equivalent to 219 kWh per ton of fresh hay (45 ton before start of drying). A Swedish experiment estimated the energy consumption for drying to be as low as 50 kWh per ton of fresh hay (Jeppsson, 1980). However, this was estimated at a higher density of hay (200 kg / m^2 vs. 133 kg / m^2) and with lower water content (30% vs. 32.5%). Increasing initial water content to 40% increases energy consumption to approximately 160 kWh per ton of fresh hay (Jeppsson, 1980), which indicates that energy consumption is greatly affected by initial water content. It is unclear why drying of hay consumed more than three times as much energy in the test by Høy & Lauridsen (2009), but it might be caused by their usage of dehumidifiers as these accounted for 76% of total energy consumption.

Finally, the total estimated price of growing a mixed sward of clover grass and stored as either silage or hay is divided by the total yield of the field (FU per hectare) in order to obtain an estimate for the average price per FU. Some of the costs included here are fixed and do not vary with the yield. Hence, the yield can affect the final estimated price. Høy & Lauridsen (2009) reported a yield of 8,100 FU per hectare in their test when the crop was stored as hay, but the standard assumed for organic clover grass stored as silage is 7,300 FU per hectare (Anonymous, 2012a). Without going into detailed discussion here, it is claimed that yield per hectare is affected by numerous factors and hence these factors also affect the price of producing one unit of feed. It is unclear which of the two yields mentioned here is more correct than the other. The estimation here assumed the yields suggested by Lorenzen (2012), but increasing the yield to 6,500 FU per hectare (equal to silage) decreased the difference to 0.63 kroner per FU. However, it can be argued that storing clover grass as hay results in a lower total yield; perhaps due to a loss of leaves during handling as discussed earlier. The size of this of this loss will however at present rely on speculation.

This section clearly illustrates that there is great uncertainty regarding estimation of the price of producing hay (and silage), storing it and feeding it to cattle. The capacity of the storage shed and drying equipment as well as energy and the yield per hectare rely on assumed values where each of them can have a significant effect on the final price. Thus, the estimated price is highly dependable on the assumptions made and the prerequisites chosen to be included as well as those chosen to be excluded. It was attempted to use the same principles when estimating a price of hay and silage in order to make the comparison as fair as possible. It is likely that one could argue to have made the assumptions differently as well as chosen to include other or exclude any of the prerequisites used in the estimation here. There final price estimated here will therefore never be more than a "best guess" under these particular circumstances. Detailed calculations are shown in Appendix 2.

5.5.2 Farm economy

There is as discussed in the previous section great uncertainty around estimation of the price of hay and the price of silage. This uncertainty inevitably will affect the difference in total feed cost between feeding hay and silage based rations. It was not possible to establish a clear effect of switching to hay feeding on DMI and ECM production, for which reason it was initially assumed that one kg DM of hay could substitute one kg DM of silage. This resulted in a difference between 0.15 and 0.35 kroner per ECM when comparing with the equivalent silage ration. However, the organic legislation requires a dairy cow to be fed minimum 60% roughage (Plantedirektoratet, 2011), which increases the minimum difference to 0.19 kroner per ECM.

The maximum difference was estimated to be between 0.41 and 0.56 kroner per ECM where an increased daily DMI (plus one kg) and decreased daily ECM (minus one kg) production were assumed. One farmer did mention that his cows seemed to consume more feed than predicted in the feed plan. This feed plan was calculated with NorFor, and the calculations carried out in this thesis with NorFor showed that feed intake was reduced after switching to hay feeding. Combining the farmer's comment and the result of the predicted rations indicates that DMI is likely to be unaffected by switching to hay feeding. However, there is no definite data to back up this claim.

The results in this thesis showed that effect of switching to hay feeding depended on the parity of the cow, but the farmers agreed that there was a slight negative trend in milk yield. Assuming a one kg ECM decrease in milk yield resulted in a difference in total feed cost between 0.30 and 0.44 kroner per kg ECM. This is in line with the estimated difference in total feed cost based on the experiment by Bertilsson & Burstedt (1983) where a difference varying between 0.33 and 0.52 kroner per kg ECM was estimated. This experiment was however conducted almost 30 years ago and is the only experiment where similar feeds have been used.

This difference in total feed cost per ECM produced may be interpreted as the premium, which the farmers have to be paid in order for their profit to be equivalent to that of their colleagues, who feed a silage based ration. However, there might furthermore be an indirect premium through a changed lactation curve and / or a changed SCC as well as through a potential health effect. Thus, SimHerd was used in order to estimate this indirect positive or negative premium. Regardless which the six scenarios tested on any of the seven different types of herds, a positive effect was found when switching to hay feeding. This positive effect may be interpreted as an indirect premium as it is an estimation of money saved, which may be used to pay for other increased expenses such as feed. Thus, a premium of 0.40 to 0.45 kroner per ECM seems sufficient in order to cover additional feed related costs for milk produced during winter where no grazing is included. The difference in feed costs between hay and silage feeding is supposedly less during the grazing period as the cost of grazing may be assumed equal for the two systems.

Lastly, the uncertainty around the estimation of the price and hay and the price of silage as well as the uncertainty around the effect of switching to hay feeding on milk production have to be emphasized. The premium required for cost of switching to hay feeding to be neutral will inevitably vary from farm to farm.

5.6 Weaknesses and strengths of this project

The basis of this thesis relies on perceptions and experiences by four farmers where three of them have registered milk yields over the past seven years. It may be a limitation for the statistical analysis in this project that observations were registered on-farm over time with no option of a control group within each herd. It may also be a strength to the analysis as inherent side effects within the herd will be included that were not meant to be analysed. Whether this is a weakness or strength depends on the research objective. It may be a weakness when aiming at estimating the physiological effect of feeding hay on factors such as individual milk yield, but it may be strength when estimating the effect on the overall herd yield. The statistical analysis may well detect a difference in milk yield, but the detectability likely is reduced when adding fixed explanatory variables.

An example of inherent effects in relation to this project could be the effect on daily working routines that possibly allow the farmer to spend more time observing animals with a potential induced positive health effect. In this case a reduced number of disease incidences can be a direct result of changed observation routines, and an indirect result of the farmer having switched to hay feeding.

This project furthermore has a case study resemblance, which may aid farmers in relating the results to their farm. Hence, this gives an option of having farmers provide input to future projects where aspects of the switch to hay feeding can be studied in order to further improve the decision basis. In addition, the use of existing farms gives the possibility of having the farmers provide potential answers to the results of the data analysis, which may widen the understanding of the analysed effect and thereby aid in defining new aspects for future analysis.

6 Conclusions

The main objective of this thesis was to improve the decision basis for farmers considering switching from silage feeding to hay feeding of their lactating dairy cows. The assessment of the effect of switching to hay feeding started with a group interview with four haymilk producing farmers, who were motivated to switch by primarily three factors. They were inspired to try this feeding concept after visiting farms abroad and motivated by a belief in hay being “better” for the health of their dairy cows as well as the ability to obtain a premium for their milk from the dairy company. They found, that the switch had given them less winter work and more summer work, although their work overall was more enjoyable now. In addition, the farmers found that their cows seemed to produce slightly less milk while being able to consume more feed than estimated with the feed plan, and that their veterinary bill had been reduced.

Drying instead of ensiling forage was shown to cause a trend for a higher concentration of NDF as well as a lower concentration of CP and energy per kg of dry matter forage. However, it was found possible to achieve equivalent energy concentrations per kg DM harvested in hay as in silage under Danish conditions. Chemical composition was found to be more closely related to the forage species conserved and stage of maturity at harvest than the used conservation method. In addition, structural properties measured with peNDF and CT was found to be more closely related to TCL than conservation method. Hay is generally chopped with a longer TCL than silage in Denmark

The analysis of lactation curves showed that first parity DH cows produced less milk whereas DH cows in parity three or greater produced more milk after switching. An improved persistency was found for both groups of cows. However, the peak yield was found to be lower for both groups. No difference as found for DH cows in second parity. Peak yield was found to be lower for third parity Jersey cows as well. The protein percentages were found to have increased after switching for Jersey and DH cows in parity one as well as for DH cows in parity three or greater. The fat percentage was increased for DH cows in parity one and parity three or greater.

The NorFor program predicted, in all cases, a lower dry matter intake and a lower milk production when cows were fed hay compared with silage. A trend for a lower milk production from hay fed cows were seen in the literature, although both increased and decreased as well as unchanged levels were seen. Dry matter intake tended to be either unchanged or increasing, although decreasing levels were seen as well.

No published articles were found comparing the effect of feeding hay instead of silage to lactating dairy cows on their disease risk. However, it is argued that there might be a positive indirect effect on health through structural properties. The data analysis showed that SCC was reduced for first parity DH cows and increased for DH cows in parity three or greater. No difference was found for second parity DH cows. SCC was reduced for all Jersey cows.

The production of one Scandinavian feed unit (FU) of hay was estimated to cost 0.70 kroner more when compared with silage (2.77 versus 2.07 kroner per FU). A difference between 0.19 and 0.35

kroner per ECM when comparing with the equivalent silage ration assuming one kg DM of hay can substitute one kg DM of silage. An increased daily DMI (one kg) and decreased daily ECM (one kg) production resulted in a difference between 0.41 and 0.56 kroner per ECM. Simulations with SimHerd showed that switching to hay feeding resulted in a difference between -0.01 and 0.04 kroner per kg ECM extra across six scenarios tested on seven different types of herds.

7 Perspectives

This thesis used a multidisciplinary approach with both qualitative and quantitative assessments. This approach has been applied for a number of years within animal welfare research where it is believed that “collaboration between natural and social sciences enhances explanatory power” as was discussed by Lund *et al.* (2006). Lund *et al.* (2006) further stated that this “multidisciplinary research provides a more coherent and comprehensive approach”. Thus, this type of approach to understanding the complex interrelationships seen in the animal production sector, may prove useful to improve farmers’ general decision basis, as well as the farmer’s ability to apply and implement research results. The Danish handbook for farmer field schools (Lisborg *et al.*, 2005) states that “one learns best when one’s starting point is one’s own reality”. This means, that the farmer has to be able to visualise the effect of implementing a research result on the farmer’s own farm in order for the farmer to comprehend the usefulness and get the full benefit of this implementation. This thesis included an interview with four farmers with regards to their motivation to switch to hay feeding. These farmers’ perception of the effect of switching may aid other farmers in relating the other results of this thesis to their farm, and thereby improve their decision basis.

This interview showed that the ability to obtain a premium for their milk was a motivation factor for these farmers. However, this thesis illustrated that the cost of producing hay milk is higher compared with the cost of producing milk based on silage feeding. There are two principle ways of determining the premium paid to the farmers from the dairy company. One way is based on the additional profit the dairy company is able to obtain by selling haymilk based products. Another way is to base the premium on the additional cost the farmers incurred by producing haymilk. The farmers are likely to demand, as a minimum, that their additional costs are covered whereas the dairy company is likely not to pay more than their obtainable extra profit. The farmers’ premium is therefore affected by how the dairy company and the farmers are able to motivate the consumers to pay a higher price for this product.

The effect of switching to hay feeding on the economy of the farm is a central point that is affected by a number of factors such as changes in milk yield and changes in dry matter intake as well as the difference in the cost of producing hay and silage. The assessment of the effect on the milk yield assumed that there had been no increase in average yield per cow in Denmark over the past five years. This assumption was based on reported data, but the assessment could also have been done with the “double-difference” method that has been used for developmental work in Africa (Simler *et al.*, 2005). Applying this method in this thesis would have meant comparing the milk yield data from the haymilk producing farms with similar data from the same time period observed on a group of similar farms, which have not switched to hay feeding. This means, that each herd would still have been its own control, but uncontrolled factors, which were not measured, such as changes in management, changes in milk yield and changes in the level of forage quality might have been accounted for. This assumes that these factors are unaffected by the feeding regime (hay or silage) or vary equally from farm to farm.

The comment by one farmer that his cows appear to ingest more feed than predicted in the feed plan could be explored further by comparing predicted intake with observed intake on the farms. This would indicate if the feed intake prediction software is made for rations based on hay. If the predicted intake and observed intake are not in alignment, adjustment to the existing model or new equations should be made. However, this is complicated by the ability or inability to provide the software with the chemical composition of hay and whether or not the chemical composition has been measured sufficiently accurately. Perhaps a new method of fractioning hay is needed, and perhaps the haymilk producing farmers should use a different software system. It is possible that an initial investigation is required, which assesses the sample variation within a stack of hay, although the variation within a stack of silage is likely to be of the same size. In addition, the within herd variation in the distribution between parities as well as the DIM of each individual cow are likely to affect the predictability of DMI and thereby the comparison.

The estimation of the price of hay and the price of silage showed that a number of factors were affected by large uncertainties. The prices estimated in this thesis were based on assumed yields of hay and silage by one of the farmers (Lorenzen, 2012) as well as his assumption of the capacity of his drying equipment. It can be argued that he is the most knowledgeable to a correct estimation on his own farm, but the accuracy of the estimation may have been improved if the yields and the capacity had been measured. It was furthermore discovered that the energy use per unit of dried hay was approximately four times larger in a Danish study (Høy & Lauridsen, 2009) compared with a Swedish study (Jeppsson, 1980). The use of dehumidifiers in the Danish study accounted for 76% of the total energy use, and these were not used in the Swedish study. Perhaps the Danish farmers can reduce the cost of drying by adapting the method used in the Swedish study, although factors such as the species dried and the local climatic conditions might affect the adaptability, albeit these factors are likely to be somewhat similar in the two countries.

Another perspective which has not been mentioned in this thesis is the use of concentrate to balance a hay based ration. Danish produced hay was found to have a positive PBV value whereas PBV in silage generally is negative (See Section 4.2.1). This implies, that the concentrate part of the ration has to have a neutral or a slightly negative PBV as the Danish recommendation for a ration is between 0 and 40 g PBV per kg DM (Anonymous, 2011b). Furthermore, the feeding system should be investigated as concentrate is not as mixable with hay as it is with silage, and thus concentrate is more likely to be fed separately from hay.

This thesis furthermore showed there to be an effect of switching to hay feeding on the somatic cell count of the cows as well as discussed a potential effect on the health of the dairy cows. Both the somatic cell count and overall health are affected by numerous factors, and it will likely be difficult to relate the switch to hay feeding to a reduced somatic cell count and an improved health.

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Appendix 1

	Gård 1	Gård 2	Gård 3	Gård 4
Antal køer	200	115	90	70
Race	SDM	SDM	SDM x RDM x Rød SDM	Jersey
Gns. Ydelse per ko, EKM	7500	7400	7500	7500 – 7600
Certificeret økolog	1987 (Bio i 1997)	1989 (Bio i 2009)	1995	1999
Skiftede til kun hø i år	Forår 2009	Juni 2007	2008	Oktober 2009
Sidste år med ensilage	Forår 2009	2006	2008 (store kvier får stadig ensilage når der ikke er nok hø)	2009
Græsmarksblandinger	24 + 21 + rød kl.	722-726 + lucerne	Ø821 fra frøsalget	22 + 45 + rent græs
Antal slæt per år	3 -5	3 – 5	4	3 -4
Crimpning	Lidt	Lidt	Nej	Lidt
1) Motivation for at skifte til høfodring	-Driver ejendommen biodynamisk, hvor hø er langt at foretrække. -Giver køerne et sundt stofskifte.	-Besøgte Hof Dannwisch for at få praktisk information -Hø er oplagt kofoder og giver tanker om gamle	-Hø flugter godt med mejeriets vision om at producere markedets sundeste mælk. -Deltog på samme tur	-Deltog på samme tur som Henning. -Skulle i gang med ombygning pga. opslidt ensilageplads.

	-Vil producere den sundeste mælk. -Mælk fra køer fodret med hø har bedre ernæringsmæssige egenskaber	dage -Besøgte høbesætninger i Østrig med 10.000 kg mælk -Syge køer skal have hø -Mulighed for tillæg fra mejeriet -Overbevist om sundhedsfordele ved høfodring	som Henning -Duften af hø er en fornøjelse	-Træt af markstakke -Hø giver bedre arbejdsmiljø -Motiveret til at prøve noget nyt
2) Udvikling i mælkeydelse	-Uændret i starten men derefter faldende (skyldes måske en medarbejder) -proteintildeling reduceret -tynd gødning – giver halm med god hø	-Gået lidt ned men skyldes måske andre faktorer -Oplever samme sæsonudsving -Fedt og protein % er steget	-Uændret med stigende tendens -Fedt og protein er steget 15-20% -mindre sæsonudsving	-Lidt faldende -Køerne kan æde mere end de får tildelt -Kender ikke eventuel ændring i fedt og protein
3) Udvikling i køernes vægt	-1. kalvs køer har problemer med huld -alle køer i besætningen fodres ens	-Vurderes uændret – i hvert fald ikke bedre -overvejer roer pga mangel på højenergi foder	-nemmere at holde gennemsnitlig huld -mindre udsving i vægt -Har en strategi om selvforsyning, hvor der fodres med havre og rug => påvirkning af huld?	-Vurderes uændret men har færre "magre" køer (fyldte maver eller fedt?)
4) Sundhedstilstanden i besætningen	-celletal er reduceret men kan blive bedre -ingen sporer	-Forbedret -Celletal er reduceret -Dyrlægeregning er reduceret	-Forbedret -Uændret celletal -Bedre klove -Bedre fordøjelse	-Reduceret celletal men ustabilt i sommerperiode -Færre sygdomme -Uændret mælkefeber

			-Færre mælkefeber	-problemer i sommer
5) Leverbylder eller anden sygdom i slagtekøer	-uændret -Har dyr i marsken og det kan give leverikter -leverbylder forekommer	-ikke et stort problem	-ikke bemærket	-uændret
6) Køernes foderoptagelse	-køerne fodres efter ædelyst -svært at vurdere -køerne vurderes til at have en større lyst til foder -hø er mere appetitligt -køerne venter på hø om sommeren	-stor appetitlighed ved god hø -dårligt hø afvises -æder ~11 FE dagligt	-køernes vurderes til at have en større appetit -æder ~12 FE dagligt	-køerne æder mere end foderplanen beregner -der er mindre styr på foderoptagelse og kvalitet af foder
7) Forskel imellem 1. kalvs køer og øvrige	-køerne har horn og gør det vanskeligere for 1. kalvs køerne at komme men kan løses ved øget plads	-uændret i forhold til før -har reduceret foderbord og skubber foder ind mange gange dagligt	-ikke observeret men vurderer at rigeligt med ædepladser er vigtigt	-ikke bemærket
8) Forskel imellem tidlig og sen laktation	-uændret	-uændret	-uændret	-uændret
9) Daglige rutiner og arbejdsforhold	-sjovere at arbejde med hø -god duft	-fornøjelse at arbejde med hø -forbedret arbejdsmiljø	-hø gør godt for landmandens sjæl -mindre tungt arbejde	-har ingen problemer med hø på spalterne -mindre hårdt fysisk

	-køerne virker mere tilpasse -udfodring med kraftfoder uden automat er en udfordring -blander hø med kraftfoder og gulerødder	-besværligt hvis der kommer hø ind på spalterne		arbejde -en nemmere dagligdag -fodrer med kraftfoder i robot og automat
10) Andet	-har en mindre jævn tildeling af kraftfoder -det er et mål at udfase kraftfoder -vil forsøge udfodring med blandede hø kvaliteter -problem med energiforbrug -mere arbejde om sommeren -andre frøblandinger bør undersøges i forhold til dyrkning, tørring og lagring -der bør udarbejdes fodernormer til køer fodret med hø som indeholder en kvalitativ del, fokus på protein og fordøjelighed -protein i hø er bedre -> hvordan påvirkes udnyttelsen?	-mindre affaldsproduktion på ejendommen -burde være nemmere med godkendelse fra kommunen -samlet energiforbrug er mellem uændret og 3 x større = stor udfordring!	-køerne virker mere rolig og mindre stressede -svært at planlægge sommerferie pga øget arbejdsmængde -fokus bør være spild i marken	-har ikke længere et problem med stære i stalden -mere arbejde om sommeren og mindre om vinteren -mere fornøjeligt arbejde -stort spild på marken

	-fokus på sundhed -ingen surhed i foderet -hvordan skal ungdyr opdrættes? (ens eller hø) -kan man avle efter køer der bedre kan håndtere hø? -kvalitativ vurdering af hø som fodermiddel			

Appendix 2

Estimation of price per Feed Unit (FU) of silage and hay

The following are images of calculations made in MS Excel.

Assumptions

Yield, hay	5,800	FU / ha
Yield, silage	6,500	FU / ha

Watering (select)	No

Treatment	Value	Unit	Yield	Unit
Ploughing	600	Kr / ha	-	-
Harrowing	140	Kr / ha	-	-
Seeding	220	Kr / ha	-	-
Rolling	140	Kr / ha	-	-
Manure	40	Kr / tons	-	-
Mowing	270	Kr / ha	8,000	FU /ha
Spreading	130	Kr / ha	8,000	FU /ha
Raking	130	Kr / ha	8,000	FU /ha
Chopping	440	Kr / ha	8,000	FU /ha
Chopping wagon	150	Kr / ha	8,000	FU /ha
Water (fixed)	1,130	Kr / ha	-	-
Water (moving)	100	Kr / move	-	-
Water, / mm	5	Kr / mm	-	-

Prices

Topic	Value	Unit	Note
Grass seeds	67.50	Kr / Kg	FarmTal Online
Plastic	2.50	Kr / m²	FarmTal Online
Rent of land	4,000	Kr / ha	Assumed
Energy, price	0.75	Kr / kWh	Assumed
Hay handling	0.09	Kr / FE	FarmTest
Feeding out, hay	0.06	Kr / FE	Assumed (guess!)
Feeding out, sil.	0.13	Kr / FE	KvægInfo, (0.10 - 0.20 kr / FU)

Standards

Topic	Value	Unit	Note
Energy consumpti	0.98	kWh / kg	FarmTest, use per kg water removed
Hay quality	0.78	FU / kg DM	NorFor
Silage quality	0.81	FU / kg DM	NorFor
Silage density	220	Kg DM / m³	Håndbog i Kvæghold
Interest	5.00	%	Assumed
Inflation	2.42	%	Danish Statistics
Hay, % DM, start	60	%	Assumed
Hay, % DM, slut	85	%	Assumed
Plastic	220	m²	FarmTal Online

Storage facilities

Capacity	500,000	FE / år

Building	Price	Unit	Depreciation	End value	Note
Storage shed	1,900,000	Kr	30	-	FarmTest
Drying equipm.	1,250,000	Kr	15	-	FarmTest
Bunker silo	360	Kr / m³	20	-	220 - 550 kr / m³

Cost of hay

Storage

	Value	Unit	Note
Capacity	500,000	FE	Assumed
Building	1,900,000	Kr	FarmTest
Drying equip.	1,250,000	Kr	FarmTest
Interest	5.0	%	Assumed
Inflation	2.42	%	Danish Statistics

	Building	Note
Depreciation	30	Years
End value	-	Kr
Depreciation	63,333	Kr / year
Annual cost	6.51	% of price
Inflat. Corr.	0.025	-
Annual cost	4.79	% of price

Total cost	**91,008**	**Kr**

Total cost	**0.18**	**Kr / FU**

	Drying eq.	Note
Depreciation	15	Years
End value	-	Kr
Depreciation	83,333	Kr / year
Annual cost	9.63	% of price
Inflat. Corr.	0.025	-
Annual cost	8.09	% of price

Total cost	**101,100**	**Kr**

Total cost	**0.20**	**Kr / FU**

Drying

	Value	Unit	Note
DM %, start	60	%	Assumed
DM %, final	85	%	Assumed
Quality	0.78	FU / kg DM	NorFor

Kg water	3,645

Energy	0.98	kWh / kg water
Energy	3,572	kWh
Energy	288	kWh / t fresh hay
Energy	408	kWh / t fresh hay
Price	0.75	Kr / kWh

Total price	2,679	Kr / ha

Total price	**0.46**	**Kr / FU**

Total

Yield	**5,800**	**FU / ha**

Field	0.94	Kr / FU
Watering	-	Kr / FU
Other	0.84	Kr / FU

Field, total	**1.78**	**Kr / FU**

Storage	0.38	Kr / FU
Drying	0.46	Kr / FU
Handling	0.09	Kr / FU

Storage, total	**0.94**	**Kr / FU**

Feeding out	0.06	Kr / FU

Total price	**2.77**	**Kr / FU**

Cost of silage

Storage

	Value	Unit	Note
Capacity	500,000	FE	Assumed
Ave. Quality	0.81	Fe / kg ts	NorFor
Ave. Density	220	Kg ts / m^3	Håndbog
M^3 requirem.	2,806	m^3	-
Price per m^3	360	Kr. / m^3	Håndbog
Silo, price	1,010,101	Kr	FarmTest
Interest	5.00	%	Assumed
Inflation	2.42	%	Danish Statistics

	Building	Note
Depreciation	20	Years
End value	-	Kr
Depreciation	50,505	Kr / year
Annual cost	8.02	% af price
Inflat. Corr.	0.025	-
Annual cost	6.43	% af price

Total cost	**64,912**	**Kr**

Total cost	**0.13**	**Kr / FE**

Total

Yield	**6,500**	**FU / ha**

Field	0.88	Kr / FU
Watering	-	Kr / FU
Other	0.84	Kr / FU

Field, total	**1.72**	**Kr / FU**

Storage	0.13	Kr / FU
Plastic	0.08	Kr / FU

Storage, total	**0.21**	**Kr / FU**

Feeding, out	0.13	Kr / FU

Total price	**2.07**	**Kr / FU**

Appendix 3

Definition of base herds in SimHerd

SN	Input parameter	Standard	Good repro.	Bad repro.	Good health	Bad health	High yield	Low yield
1[1]	Start insemination	498	498	498	498	498	498	498
2	Insemination pct.	60	60	60	60	60	60	60
3	Pregnancy pct.	55	55	55	55	55	55	55
4	Milk fever	4.8	4.8	4.8	2	7.5	4.8	4.8
5	Calving difficulties	0.5	0.5	0.5	0.2	1.2	0.5	0.5
6	Retained placenta	11	11	11	5	16	11	11
7	Metritis	19	19	19	10	24.6	19	19
8	Displace omasum	2.4	2.4	2.4	1.4	3	2.4	2.4
9	Ketosis	13.6	13.6	13.6	9.1	15	13.6	13.6
10	Mastitis	55	55	55	29	75	55	55
11	Digital Dermatitis	69	69	69	35	104	69	69
12	Foot rot	5	5	5	2.6	7.5	5	5
13	Hoof and leg problems	49	49	49	20	83	49	49
14[1]	Base mortality risk	1.1	1.1	1.1	1.1	1.1	1.1	1.1
15	Risk of stillborn	5.9	5.9	5.9	5.9	5.9	5.9	5.9
16	Risk of mortality after birth	6.8	6.8	6.8	6.8	6.8	6.8	6.8
17	Start insemination, young	43	43	43	43	43	43	43
18	Start insemination, older	50	50	50	50	50	50	50
19	Insemination pct.	35	51	25	35	35	35	35
20	Pregnancy pct.	45	52	49	45	45	45	45
21	Stop insemination, young high yield	322	301	322	322	322	322	322
22	Stop insemination, older high yield	301	280	301	301	301	301	301
23	Unexpected replacement	7	7	7	7	7	7	7
24[1]	Maximum no of cows	154	154	154	154	154	154	154
25[1]	Minimum no of cows	142	142	142	142	142	142	142
26[2]	Max yield, 1st parity	25	25	25	25	25	28.7	26.2
27[3]	Yield loss after day 60, 1st parity	17.8	17.8	17.8	17.8	17.8	17.8	17.8
28[2]	Max yield, 2nd parity	35	35	35	35	35	37.9	31.1
29[3]	Yield loss after day 60, 2nd parity	34.1	34.1	34.1	34.1	34.1	34.1	34.1
30[2]	Max yield, older	37	37	37	37	37	40	30.5

31[3]	Yield loss after day 60, older	41.8	41.8	41.8	41.8	41.8	41.8	41.8
32	Stop insemination, low yield young	105	105	35	105	63	105	105
33	Stop insemination, low yield older	105	105	35	105	63	105	105
-	Desired annual yield	8200	8200	8200	8200	8200	9500	7500
40[1]	Grazing start	105	105	105	105	105	105	105
41[1]	Grazing end	305	305	305	305	305	305	305
63[1]	Yield at drying off	12	12	12	12	12	12	12
64[1]	Yield at drying off	12	12	12	12	12	12	12
178	SCC level, young	13.3	13.3	13.3	13.3	13.3	13.3	13.3
186	SCC level, older	13.3	13.3	13.3	13.3	13.3	13.3	13.3
410[1]	Withh. period of milk	10	10	10	10	10	10	10
492[1]	Withh. period of milk	6	6	6	6	6	6	6
574[1]	Withh. period of milk	10	10	10	10	10	10	10
656[1]	Withh. period of milk	10	10	10	10	10	10	10
738[1]	Withh. period of milk	12	12	12	12	12	12	12
820[1]	Withh. period of milk	10	10	10	10	10	10	10
984[1]	Withh. period of milk	10	10	10	10	10	10	10
1917[4]	Iterations factor	3.5	3.5	3.5	3.5	3.5	3.5	3.5

[1]Changed to reflect an organic farm; [2]Changed in order to obtain the desired average annual yield per annual cow; [3]Determined based on lactation curves in results section; [4]Changed in order to achieve a total of 225 iterations of each simulation which was assumed to be sufficient