MILK AND GROWTH RESPONSES TO ENERGY INTAKE IN DAIRY CATTLE – IN THE PERSPECTIVE OF THE NON-ADDITIVE FEED EVALUATION SYSTEM – NORFOR

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Preface

Formulation of the feed rations and the feeding level (energy fed per cow per day) are of great importance for the milk production and economy in dairy herds as feed is generally the greatest expense in milk production. Feeding to obtain as high milk yield as possible in the herd will seldom be the economically optimal, this is where marginal cost of feed equals marginal income from production. However, the knowledge for developing a functionality of maximizing the economic profit by finding optimum energy level within the new Scandinavian feed evaluation system, NorFor, has not been available.

The overall aim for this thesis is to provide new production response functions in terms of milk and growth to feed energy intake based on the NorFor feed evaluation system. The perspective is to provide response functions for future use and incorporation with a model of economical optimization of the feed energy level in dairy cow feed rations within a specific herd.

Moreover, this thesis intends to fulfill the requirements of obtaining an industrial PhD degree from Department of Animal Science, Faculty of Science and Technology, Aarhus University in cooperation with Knowledge Centre for Agriculture. The PhD project was carried out at Department of Animal Science, Faculty of Science and Technology, Aarhus University and Knowledge Centre for Agriculture, Cattle, Aarhus. The funding was provided by the Danish Cattle Federation, the Department of Animal Science, Faculty of Science and Technology, Aarhus University and The Danish Council for Technology and Innovation.

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The PhD project is a meta-analysis based on a large number of data from 13 feeding and production trials previously performed in Norway, Sweden and Denmark, and on data from private Danish farms. I greatly appreciate the access to those original data without which this work would not have been possible. Especially I would like to thank Ingunn Schei, Arnt Johan Rygh and Harald Volden at TINE Norwegian Dairies, and Jan Bertilsson at the Swedish University of Agricultural Sciences for aiding with compiling data sets, and dairy farmers and advisors for access to data through Danish Cattle Federation, and Anne Mette Kjeldsen, Agro Tech for assistance in database handling.

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Summary

Feed is generally the greatest expense in milk production and feeding to obtain the highest possible milk yield will seldom be the economically optimal due to a decreasing marginal milk production response with an increasing feeding level. However, the knowledge for developing a functionality of maximizing the economic profit by finding optimum feeding level according to prices of feed and milk within the new Scandinavian feed evaluation system, NorFor, has not been available. The overall aim for this thesis was to improve knowledge on production responses in terms of milk and growth to feed energy intake based on the NorFor feed evaluation system. To approach the aim meta-analyses of milk and growth responses to increased net energy for lactation (NEL) intake (Paper 2 and 3) were performed. The new prediction models in this thesis were intended for use in an optimization of the feed energy level for a group of lactating cows and it was chosen to use group data (treatment means) contrary to using individual cow observations. To further evaluate the performance of the milk production response function the prediction model from Paper 2 was applied with commercial herd data (Paper 4). The consequences of using group level (treatment means) versus individual level (cow observations) data for the modeling of response functions was analyzed in a separate study (Paper 1).

Paper 1 used data from two block experiments lasting from week 3 to 15 after parturition and including 90 multiparous Danish Holstein cows and 18 group level observations (treatment means). A mixed linear effects model with random effect of experiments was used for analyses of energy corrected milk (ECM) response. A declining marginal milk yield response was found for all scenarios. At both low and high levels of energy intake, there was a significant difference between using individual versus group data.

Paper 2 used compiled data from 13 previous Scandinavian production trials with 195 treatment means to develop prediction models of ECM response to increased energy intake levels based on the NorFor feed evaluation system and specific to parity, stage of lactation and breed. Data were analyzed using linear mixed effects model with trials as random effect. Best fit model was by use of linear and natural log transformation of NEL intake and including NorFor specific nutrient concentrations. The curvilinear ECM response was found for multiparous cows in early (0 to 100 days in milk (DIM)) and mid lactation (DIM 101 to 200) and for primiparous cows in mid lactation, whereas early primiparous cows showed significant linear responses. For multiparous cows the ECM response to NEL was higher than for primiparous cows. Breed specific ECM responses were parallel and only differed by their intercept. The marginal ECM responses decreased to increased net energy intake especially for the multiparous cows, whereas the primiparous cows only decreased slightly.

Paper 3 used compiled data from 6 previous Scandinavian production trials with 78 treatment means to develop prediction models of growth response to increased energy intake levels based on the NorFor feed evaluation system and specific to parity, stage of lactation and breed. Data were analyzed using linear mixed effects model with trials as random effect. Curvilinear response functions for daily live weight gain (DG) were found for primiparous and multiparous cows at the specific stages of lactation of DIM 30, 60 and 90. The DG responses to NEL intake level was increasing curvilinear at a decreasing rate for both parities. Though, multiparous cows had larger live weight losses at low NEL intake but also a larger response to increased NEL intake than primiparous cows. The live weight change...
to increased NEL intake of multiparous cows at DIM 30 was higher than at DIM 60 and 90 with DG at
DIM 90 being lowest. There were no effects of ration nutrients or breed.

Paper 4 used 2,580 recordings of group level of feed intake and milk production from 728
commercial dairy herds to evaluate the use of the ECM prediction model from Paper 2 and to study
possible factors causing a deviance in predicted ECM production in the herds. The predicted ECM
production based on the paper 2 model deviated from actual ECM in commercial herd data by plus 4 kg,
1 kg and 2 kg for Danish Holstein, Danish Red and Danish Jersey, respectively. The main factors
explaining this deviance were stage of lactation and feed ration characteristics, but 47% of the deviance
was due to other factors like management or environment. There was a larger effect of NEL intake on
ECM response with the between herd data than with the within herd data and for the between herd
data there was a larger response for Danish Holstein than for Danish Jersey. The response curves of herd
data resulted in increasing marginal responses to increased energy intake possibly due to factors
originating from the commercial herd data compared to controllable experimental data. The difference
in the response curves of between and within herd data indicates good reason for further work on
combining ECM prediction models with herd data to obtain a herd specific milk production function.

The new knowledge gained with this thesis on the production responses can be incorporated with a
model of economical optimization of the feed energy level in dairy cow feed rations and thereby be one
among other tools for optimizing the production economy for the dairy farmer.
Sammendrag (summary in Danish)

Foder udgør den største omkostning i mælkeproduktionen, og det er sjældent økonomisk optimalt at fodre efter højest mulig mælkeydelse på grund af et faldende marginalt mælkeydelsesudbytte ved stigende foderniveau. Der mangler imidlertid viden som grundlag for at udvikle et værktoy til maksimering af det økonomiske udbytte ved at finde det optimale foderniveau i forhold til priserne på foder og mælk i det nye skandinaviske fodervurderingssystem NorFor. Det overordnede formål med denne afhandling var, at bidrage med viden om produktionsrespons set i form af mælk og kød i forhold til optagelsen af energi med foderet baseret på NorFor fodervurderingssystemet. I artikel 2 og 3 blev der gennemført meta-analyser af produktionsrespons set i form af mælk og kød ved stigende optagelse af nettoenergi til laktation (NEL) (artikel 2 og 3). Præediktionsmodellerne forventes brugt til optimering af foderniveauet for grupper af lakterende køer, og derfor blev det valgt at bruge gruppdata (behandlingsgennemsnit) som datagrundlag for meta-analyserne frem for at bruge individuelle data. Med henblik på yderligere at evaluere de udviklede præediktionsmodeller for mælkeproduktion (artikel 2) blev modellerne anvendt på data fra kommercielle besætninger (artikel 4). Konsekvenserne for modellering af responsfunktioner ved at bruge gruppe data (behandlingsgennemsnit) frem for individuelle data (enkelt ko observationer) blev analyseret i et separat studie (artikel 1).

I artikel 1 blev der anvendt data fra to blokforsøg, som varede fra 3 til 15 uger efter kælvning og inkluderede 90 ældre (2. eller senere laktation) Danske Holstein køer og 18 observationer per gruppeniveau (behandlingsgennemsnit). En lineær mixed model med tilfældig effekt af forsøg blev anvendt til analyse af ydelsesrespons set i energikorrigeret mælk (EKM) på stigende optagelse af NEL. Der blev fundet et faldende marginalt mælkeydelsesrespons for alle analyserede scenarier. Ved såvel lavt som højt niveau af energioptagelse var der signifikant forskel mellem på at anvende individuelle versus gruppe data.

I artikel 2 blev der samlet data fra 13 tidligere skandinaviske produktionsforsøg med i alt 195 behandlingsgennemsnit som grundlag for udviklingen af præediktionsmodeller for EKM respons ved øget optagelse af NEL baseret på energivurdering i NorFor fodervurderingssystemet og specifikt for forskellige pariteter, laktationsstadier og racer. Data blev analyseret ved brug af lineære mixed modeller med forsøg som tilfældig effekt. Modellen med det bedste fit blev opnået ved at inkludere lineær effekt og naturlig logaritme transformation af NEL optagelse og ved at inkludere NorFor specifikke næringsstofkonzentrationer. Det kurvelleære EKM respons på NEL blev fundet for ældre køer (2. laktation og ældre) i tidlig (0 til 100 dage efter kælvning (DIM)) og midt laktation (DIM 101 til 200) og for førstekalvsskær i midt laktation, mens førstekalvskær i tidlig laktation viste et signifikant lineært respons. For ældre køer var EKM responsen på NEL større end for førstekalvskær. De racespecifikke EKM,responsen var parallell og afveg kun fra hinanden med hensyn til intersectet. De marginale EKM responsen faldt med stigende NEL optagelse, især for ældre køer, mens responsen for førstekalvskær kun faldt lidt.

I artikel 3 blev der samlet data fra 6 tidligere skandinaviske produktionsforsøg med i alt 78 behandlingsgennemsnit som grundlag for at udvikle præediktionsmodeller for tilvækst respons på øget optagelse af NEL baseret på energivurdering i NorFor fodervurderingssystemet og specifikt for forskellige pariteter, laktationsstadier og racer. Data blev analyseret ved brug af lineære mixed modeller
med forsøg som tilfældig effekt. Der blev fundet kurvelineært responsfunktioner for daglig tilvækst (DG) hos førstekalvs- og ældre kører på laktationstadierne 30, 60 and 90 DIM. Responsen i DG på NEL optagelse steg kurvelineært med en faldende stigningstakt for begge pariteter. Dog havde ældre kører større vægttab ved lavt NEL optag men også større respons på stigende NEL optag end førstekalvskærer. Vægtændringen ved stigende NEL optagelse hos ældre kører ved DIM 30 var større end ved DIM 60 og 90, hvor DG ved DIM 90 var lavest. Der var ikke effekt af specifikke næringsstoffer eller af race.

I artikel 4 blev der anvendt 2.580 registreringer af foderoptagelse og mælkeydelse på gruppeniveau fra 728 kommercielle danske mælkevægsbesætninger til at evaluere the anvendelse af EKM prædiktionsmodellen udviklet i artikel 2 og til at analysere mulige faktorer som forårsager afvigelser i prædiktionen på besætningsniveau. Den prædikterede EKM produktion baseret på modellen fra artikel 2 afvek fra den observerede EKM produktion med plus 4 kg, 1 kg og 2 kg for Dansk Holstein, Dansk Rød og Dansk Jersey, respektivt. De mest betydende faktorer til forklaring af afvigelser var laktationsstadium og rationskarakteristika, men 47 % af afvigelserne skyldtes andre faktorer, som kunne være fx management og miljø. Der var en større effekt af NEL optagelse på EKM responsen ved anvendelse af ”mellem besætninger” data (between herd data) end ved anvendelse af ”indenfor besætning” data (within herd data), og ved anvendelse af mellem besætninger data var der et større respons hos Dansk Holstein end hos Dansk Jersey. Responskurverne for besætningsdata viste et stigende marginal respons på stigende energioptagelse, hvilket formentlig skyldes specielle faktorer hos de kommercielle besætningsdata sammenlignet med data fra de kontrollerede forsøg. Forskellene i responskurverne mellem anvendelse af “mellem besætninger” data og ”indenfor besætning” data markerer, at der er behov for at arbejde yderligere med at kombinere EKM prædiktionsmodeller med besætningsdata med henblik på at opnå en besætningsspækkifik responsfunktion for mælkeproduktion.

Denne afhandling bidrager med ny viden om mælkeproduktionsresponsen på basis af NorFor energivurderingssystemet. Responsfunktionerne kan indbygges i et værktøj til økonomisk optimering af foderniveauet i rationer til malkekøer og dermed bidrage til at optimere produktionsøkonomien hos den enkelte mælkeproducent.
# Table of contents

Preface .......................................................................................................................... I
Acknowledgements ......................................................................................................... III
Summary .......................................................................................................................... V
Sammendrag (Summary in Danish)..................................................................................... VII
Table of contents .............................................................................................................. IX
List of scientific papers and manuscripts included in thesis ........................................... XI
List of other published work during PhD period not included in thesis ......................... XIII
List of abbreviations ....................................................................................................... XV

1. Introduction .................................................................................................................. 1
   1.1. General introduction .......................................................................................... 1
   1.2. State-of-the-art ............................................................................................... 2
   1.3. Hypotheses and aims ...................................................................................... 6
2. Brief presentation of applied methodology ................................................................. 7
   2.1. Data material ................................................................................................... 7
   2.2. Statistical methods ......................................................................................... 8
3. Results ......................................................................................................................... 11
   3.1. Paper 1: Evaluation of individual versus group level observations and different feed ration evaluation systems for estimating milk yield responses ................................................................. 11
   3.2. Paper 2: A meta-analysis of milk production responses to increased net energy intake in Scandinavian dairy cows ......................................................................................................................... 15
   3.3. Paper 3: Responses in live weight gain to net energy intake in dairy cows ........ 41
   3.4. Paper 4: Milk responses to energy intake estimated within and between commercial dairy herds ................................................................................................................................. 61
4. General discussion ....................................................................................................... 85
   4.1. Milk and growth responses to increased net energy intake ................................. 85
   4.2. Effects of parity and stage of lactation on production responses ....................... 86
   4.3. Prediction variables; DMI, NEL and nutrients ..................................................... 87
   4.4. Genetic and management factors ...................................................................... 89
   4.5. Production response in terms of milk and growth ............................................. 91
   4.6. Methodological considerations ....................................................................... 93
5. Conclusion .................................................................................................................... 97
6. Perspectives ................................................................................................................. 99
7. References ..................................................................................................................... 101
List of scientific papers and manuscripts included in thesis

Paper 1

Paper 2

Paper 3

Paper 4
Jensen, C., Østergaard, S., Weisbjerg, M.R., Nielsen, N.I., Aaes, O., Kristensen, T. Milk responses to energy intake estimated within and between commercial dairy herds. Draft manuscript.
List of other published work during PhD period not included in thesis


List of abbreviations

AA: Amino acids
AAT: Amino acids absorbed in the small intestine
AAT_NEL: AAT in g per MJ NEL
AIC: Akaike Information Criterion
AMS: Automatic milking systems
BIC: Bayes information criterion
BW: Body weight
CFat: Crude fat
CFat_NEL: CFat in g per MJ NEL
CHO: Carbohydrates
Ci_DM: Chewing index of ration
CNCP: Cornell Net Carbohydrate and Protein System
Conc_share: Concentrate share of ration
Conc_DM: Concentrate intake
CP: Crude protein
DE: Digestible energy
DG: Daily gain
DH: Danish Holstein
DIM: Days in milk
DJ: Danish Jersey
DM: Dry matter
DMI: Dry matter intake
DMS: Dairy Management System
DR: Danish Red
ECM: Energy corrected milk
EB: Energy balance
FER: Feeding evaluation record
FVL: Fill value of ration
GE: Gross energy
iNDF: Indigestible NDF
LW: Live weight
ME: Metabolizable energy
Multi: Multiparous
NDF: Neutral detergent fiber
NDF_NEL: NDF in g per MJ NEL
NEL: Net energy for lactation
NIR: Near infrared spectroscopy
NorFor: Nordic Feed Evaluation System
NR: Norwegian Red
OM: Organic matter
PBV: Protein balance in the rumen
Primi: Primiparous
RMSE: Root mean square error
SR: Swedish Red
WIM: Weeks in milk
1. Introduction

1.1. General introduction

Formulation of feed rations and feeding level (energy fed per cow per day) are of great importance for the milk production in dairy herds as feed is generally the greatest expense for the milk production. Feed costs typically constitute 80% of the variable costs in Denmark (Thøgersen and Laursen, 2009). Thereby feed is the single factor of greatest importance to the economy in the dairy herd. The increasing focus over time on dairy herds being more economical efficient as well as the more frequent fluctuations in feed and milk prices make an economical approach to the feed planning, including the feeding level quite necessary. To improve formulation of feed rations nutritionally and to improve milk production new mechanistic physiological models have been developed in recent years. However, corresponding modeling of the economic optimal feeding level has not been developed.

The Nordic feed evaluation system (NorFor) is such a model and is recently developed and implemented in Denmark, Iceland, Norway and Sweden (Volden, 2011). The approach of the NorFor system and the other newly developed system ‘Cornell Net Carbohydrate and Protein System’ (CNCPS) (Fox et al., 1992; Russell et al., 1992; Sniffen et al., 1992) is a non-additive model of the physiological mechanism involved in converting feed into milk and growth. The systems account for important interactions in the digestion of the feed stuffs, which is essentially different from the classical additive systems where the nutrients of each feedstuff were additive in a given ration (van der Høning and Alderman, 1988). In the NorFor system the non-additive approach results in a decrease in NEL per kg DM with increased dry matter intake (DMI) (Volden and Nielsen, 2011) for a given feed ration. In previous feed evaluation systems the diminishing production return with increased feeding level was also accounted for by various correction factors in relation to the maintenance feeding level (van Es, 1978; ARC, 1980; Danfær, 1983; Vermorel, 1989). The new model type and the complexity of NorFor only imply a feed ration optimization as a cost minimization, the lowest cost ration given a fixed energy level.

The knowledge for developing a functionality of maximizing the economic profit by finding optimum energy level within NorFor has not been available. However, several studies have shown the effect of energy level and energy concentration of the ration (Mertens, 1997; Friggens et al., 1998; Bossen et al., 2009). Feeding to obtain as high milk yield as possible in the herd will seldom be the economically optimal. When assuming no carry-over effect, economic optimum is where marginal cost of feed equals marginal income from production. This is due to a decline in excess profit as the utilization of feed energy for production decreases with increasing feeding level (Østergaard, 1979). However, due to lack of knowledge about production functions that are based on dynamic feed evaluation systems and are applicable to contemporary production levels of dairy cows, the NorFor system and other feed planning systems available are not able to determine the economically optimal feeding level.

The overall aim for this thesis is to provide new production responses in terms of milk and growth to feed energy intake in high yielding lactating cows based on the NorFor feed evaluation system and net energy for lactation (NEL). The perspective is to provide response functions for future use and
incorporation in a model of economical optimization of the feed energy level in dairy cow feed rations within a specific herd.

1.2. State-of-the-art

*Feed evaluation and ration planning systems, mechanistic vs. additive models*

New systems for evaluating nutrients of dairy feeds and predicting the absorption and digestion of these within the dairy cow have been developed; i.e. CNCPS (Fox et al., 1992; Russell et al., 1992; Sniffen et al., 1992) and NorFor (Volden, 2011). These new systems are derived from non additive models of the physiological mechanism and account for important interactions in digestion and nutrients of the feed stuffs, which is essentially different from the classical additive systems (van der Honing and Alderman, 1988) where the nutrients of each feedstuff were additive in a given ration. In the classic energy evaluation system, still used worldwide, the energy as digestible energy (DE), metabolizable energy (ME) or net energy (NE) is the primary unit determining the value of the digested nutrients. Around year 1900, the feeding level of milking cows was much closer to that of cows fed at maintenance level as compared with today. Digestibility obtained at maintenance level, therefore, gave reliable values when compared with milking cows. However, as the milk production and thereby the feed intake increased, especially during the last half of the 20th century, it became clear that there was a diminishing production return with increasing feeding level. In the Dutch feed evaluation system, this was controlled by a reduction in the predicted NE with 1.8 %-unit per multiple of maintenance (van Es, 1978) as was also used in the UK (AFRC, 1993). In the French system both feeding level and roughage quality was used where the roughage correction was made according to the concentrate share in the ration (Vermorel, 1989). In Denmark the correction term ‘feed efficiency’ was introduced, where feed efficiency was estimated in production experiments as the NE in feeding units (FU) obtained in maintenance and production in proportion of FU input in feed, and feed efficiency was related to feeding level (Danfær, 1983). This approach has been further developed recently by Kristensen et al. (2003). They predicted feed efficiency from feeding level, feed intake capacity of the cow, and digestibility of the forage in the ration. Similar analyses have also been performed in Finland (Huhtanen et al., 2009; Nousiainen et al., 2009).

In the NorFor system the mechanistic non additive principle results in a decrease in NEL per kg DM with increased DMI (Volden and Nielsen, 2011) like in the CNCPS, whereas in the classic additive energy evaluation systems NE per kg DM is constant when increasing DMI. The mechanism of reduced NEL per kg DM with higher DMI is due to an increased passage rate of feed fractions through rumen and thereby less nutrients are digested and used by the cow. Thereby the energy value of a feed stuff is not constant but can only be determined depending on the other feedstuffs used in the feed ration and the production situation. In this way the NorFor NEL value of a feed ration becomes a more precise estimate of the net energy supplied to the cow in the specific feeding situation as compared to net energy in the ration in the additive feeding systems. The model type and the complexity of NorFor only imply a feed ration optimization as a cost minimization, the lowest cost ration given a fixed energy level. The knowledge for developing a functionality of maximizing the economic profit by finding optimum energy level within NorFor has not been available.
Production response to increased energy intake

Questions like “what is the shape of the function describing the milk response to changed feed input” and “how much additional milk is produced for each unit of additional feed” are not only asked in the recent times. Jensen (1940) performed a study including 200 cows to make up an immense lack of data on this subject. He found that the milk response to increased energy intake is not constant and there was a diminishing curve of return due to partition of energy from milk towards tissue. The diminishing marginal milk response to increased energy intake has been confirmed by others through years (Blaxter, 1966; Dean et al., 1972; Moe and Tyrrell, 1975; Østergaard, 1979; Broster and Broster, 1984; Hulme et al., 1986; Agnew et al., 1998; Woods et al., 2003; Huhtanen and Nousiainen, 2012). This diminishing return of increased energy intake was Denmark integrated in feed planning tools based on the additive models (Østergaard, 1983; Kristensen and Hansen, 1989).

To optimize the output from a given feeding level and at the same time make use of the new mechanistic feed ration evaluation system requires new research. There is a need for models based on data from production trials with cows at contemporary levels of milk yield for estimation of input–output relations considering the variables in use with the mechanistic physiological feed planning systems (Agnew and Yan, 2000). Furthermore a method of calibrating a general milk response function obtained from research feeding trials to the herd specific response to increased energy intake is likely to enhance the optimization of the feeding level in the individual herd. The large amount of feed and milk production data that today is available also within many commercial herds gives rise for studying herd specific responses.

The NorFor system utilizes a linear milk response of 0.318 kg ECM per MJ NEL_{milk}, where NEL_{milk} is the total NEL value of the ration minus basal energy requirement for maintenance, gestation and growth of primiparous cows and corrected for any change in LW by mobilization or deposition (Åkerlind and Volden, 2011). The NorFor system does not predict the changes in partitioning of NEL between milk yield and deposition or mobilization due to changes in energy intake, but utilize a standard mobilization/deposition according to parity and days in milk (DIM). The cow is assumed to mobilize from DIM 1 to 70 and hereafter from DIM 70 to 300 to deposit the same kg LW as was mobilized. Consequently, the NorFor system does not provide a prediction of milk yield as a function of total NEL intake as deposition or mobilization is also expected to respond as a function of total NEL intake.

Previous Danish production response and its application

Prior to the development of NorFor and use of NEL as feed energy units a model for economical optimization of the feeding level within the Scandinavian Feed Unit (SFU) system was developed (Østergaard et al., 2003). The model was built on the assumptions of the ad libitum feeding principle and incorporated the production responses originating from large Danish production trials and the pertaining assumptions (Kristensen and Ingvarsten, 2003; Kristensen et al., 2003). From the milk production function by Kristensen et al. (2003) the marginal milk response was derived as the ECM response to a one unit increase in SFU intake. The marginal response was dependent of the roughage digestibility (FK, %), the yield capacity of the herd (Y, kg/year) and the feeding level (SFU/d). The marginal ECM response function was: Marginal ECM = (3.472 - 0.006*FK)*(1.37 – 0.00005*Y) –2*(0.1243
– 0.0007*FK)*SFU_r*(1.37 – 0.00005*Y)^2. That is the marginal response decreases with an increased feeding level; however it increases with increased yield capacity and increased digestibility of the roughage.

The feeding level was increased by the ratio of concentrate from which the cow will reduce the intake of roughage due to the limited feed intake capacity. In the feed intake system used it was assumed that the feed intake capacity, given by a fill value system, would decrease when the total fill value of the feed ration decreases below 0.35 fill units per SFU (Østergaard et al., 2003). Feed intake would change from a physical regulation to physiological regulation with a significant influence on the rate of substitution between roughage and concentrate. The yield capacity of the herd was an important premise for the response. Yield capacity was expressed in kg ECM per year based on all feeding days in the herd including dry cows; in experimental trials the yield capacity was estimated from mean daily ECM yield of the treatment group of cows with highest yields and then compared to standard lactation curves according to parity and stage of lactation for a conversion to ECM per year (Kristensen et al., 2003). In the commercial herds the yield capacity was estimated from mean ECM yield of healthy third calving cows during week 1 to 24 after parturition and multiplied by 250 with a correction according to feeding level (Østergaard et al., 2003). Importantly was it that it was the capacity of the herd and not the future goal of production level or the latest herd production result that was used, as the expression yield capacity covers both influence of genetics and environment.

The resulting feeding level given from the milk response model was a combined level for all parities in the herd and the model did not give any applications as to calculate the response separately according to parity. The model for optimal energy intake first calculated a common optimal energy intake for all cows and based on that the energy level for each of primiparous and multiparous was calculated. This latter was based on the consideration that the feeding efficiency of high yielding cows is the same as for low yielding cows, though the high yielding cows have a higher feed intake than the low yielding when all fed the same feed ration (Kristensen et al., 2003). Thereby the marginal milk response was expected to be the same for high as well as low yielding cows (herds), which can be seen in Figure 1 by the response curves only differing by an upwards and right shifted level with increased yield capacity. The limit of application for the model was within yield capacity of 7,500 to 9,500 kg ECM.

The milk production response function of Kristensen et al. (2003) was following the law of diminishing return by the diminishing marginal response. This was due to a decrease in feeding efficiency, a decrease in mobilization by a change in nutrient partition towards body tissues and the important effect of roughage quality. A higher roughage quality obtained by an increased digestibility of the roughage implies that at constant energy intake the roughage part of the feed ration will increase. This effect of the increased roughage digestibility results in a smaller decrease in the feeding efficiency with increased feeding level in comparison to maintenance level. With a low concentrate to roughage ratio of the feed ration there is a large effect of higher roughage quality on the milk production response, whereas this effect is minimized at high concentrate to roughage ratios.
Figure 1. ECM (kg/d) response curves to net energy intake in Scandinavian feed unit (SFU). Each curve from 7,000 to 13,000 kg represents the response curve for a herd with the specific yield capacity. A marginal response of 0.5 kg ECM per SFU for each of the curves is indicated by the points from the dotted line (Modified from Kristensen et al., 2003).

Production responses from literature

From literature previously developed empirical models describing the production responses in lactating cows to changed energy intake levels can be found though the numbers are scarce and the response functions differs a lot in the use of units of both response and explanatory variables. Also the number and types of explanatory variables included in the response functions differ and as does the mathematic terms used for describing the shape of curve. To compile these response functions in a common figure for comparison reasons seems attractive; however, it also seems difficult to get a clear picture.

The responses (outputs) described for milk production can be found for the actual milk yield in kg/d or in a corrected unit such as fat corrected milk (kg FCM/d) and energy corrected milk (kg ECM/d) or the output was given as the milk protein yield (kg MPY/d). For the responses concerning partitioning of the energy intake between milk and body tissues the output was given as milk and tissue energy or as total energy output in MJ or kcal (Moe and Tyrrell, 1975; Agnew et al., 1998); where various conversion factors of milk and body tissue (mobilized or deposited) were applied. The milk production functions were based on total or concentrate dry matter intake and dietary nutrients or energy intake in ME, NE or total digested nutrients for describing the response (Dean et al., 1972; Ferris et al., 1998; Woods et al., 2003). The numbers of and which nutrient variables used varied among the response functions and non-nutritional variables such as DIM and parity were included in some cases (Coulon and Rémond, 1991; Martin and Sauvant, 2002; Hristov et al., 2004, 2005; Huhtanen and Hristov, 2009; Huhtanen and Nousiainen, 2012). Further the estimated energy intakes among the response functions were based on different feed evaluation systems according to origin and date of data and the specific nutrient variables also differed according to the system used. From all these differences among the empirical models of
production responses from literature compiling these for comparison would require many assumptions regarding the nutrient levels used in supplement of the energy intake.

1.3. The hypotheses and aims
The state of the art as presented above has resulted in the following hypotheses on the topic of production responses to energy intake in lactating cows:

- In NorFor, the milk response to net energy intake is linear
- In NorFor, the NEL not found in milk production can be found in live weight gain
- Milk production response to net energy intake do not differ between herds

In order to test these hypotheses the aims for this thesis are following:

- To provide new production responses in terms of milk production and live weight change based on NorFor
- To evaluate the effects of breed, parity and stage of lactation on the production responses
- To compare production responses derived from between herd or within herd data
- To analyze possible herd factors causing a deviance between the predicted milk production in commercial herds from the experimental model estimates and the observed milk production
2. **Brief presentation of methodology**

Empirical modeling of production responses in this thesis was made by use of the meta-analysis method by compiling data from several previous production studies to estimate a common effect of a given parameter e.g. energy intake. The use of the milk production responses modeled was evaluated by use of commercial dairy herd data.

The method of meta-analysis was used in the studies presented in the papers 1, 2 and 3. Initially a study was made for evaluation of the level of data to be used, group versus individual observations, for the analyses of milk responses to increased energy intake. Data for Paper 1 were from two previous Danish production trials comprising all observations on individual cow level. In Paper 2 the milk production responses to increased energy intake were modeled and in Paper 3 the live weight gain responses to increased energy intake were modeled, and in both papers analyses were based on group observation treatment means. The data used for estimation of these response functions were 13 previous production trials from Denmark, Norway and Sweden comprising data on feed intake, live weight and milk production. In Paper 4 the method of evaluating the milk response model was by use of commercial herd data gathered from a database of feeding evaluation registrations (FER) in Danish dairy herds. Also production responses based on individual registrations within herds and based on mean of registrations for each herd were compared using the commercial herd data.

2.1. **Data material**

The trials that provided data for the modeling of production response functions were selected according to the prerequisites that cows were fed ad libitum, the planned ration energy density was independent of recorded milk yield, and that different dietary energy levels were planned within each trial. Furthermore the selection of studies to comprise the total data set was limited to originate from research centers in countries using the NorFor system and the original data on feed intake and milk production had to be accessible for recalculation of ration energy values. This resulted in a selection of 13 production trials.

The trials were completed during 1998 to 2010 at research centers with registrations on actual feed intake of all offered feed, feed residuals, LW, milk production and milk constituents. The individual trials lasted from eight weeks to six years and the study design was for nine of the trials continuous block whereas for four of the trials it was Latin square design. Data from trials that included grazing periods were discarded, due to an estimated feed intake of the grazing. The breeds represented in total data set were Danish Holstein (DH), Danish Red (DR), Danish Jersey (DJ), Norwegian Red (NR) and Swedish Red (SR). Parity of cows was from first to seventh. The total data set was divided into four subsets according to parity and stage of lactation where parity was either primiparous or multiparous and stage of lactation was defined as Early or Mid with DIM 0 to 100 or 101 to 200, respectively. The principle for the early lactation period was based on several trials having data for the early lactation period within DIM 0 to 100 and the long term studies were adjusted with new treatment means for this early period. The data used in milk production and LW gain response analyses were all treatment mean observations from the data subsets.

The energy intake was in the original trials given from different energy systems and units due to previously varying energy evaluation systems between the countries. Therefore to ensure that the same system of feed ration evaluation was used throughout data and as access to original data for all
trials was possible the energy and nutrient intake of all the feed rations was recalculated using NorFor (Volden and Larsen, 2011; Volden and Nielsen, 2011). Feedstuff inputs to NorFor were chemical analyses of individual feedstuffs (Åkerlind et al., 2011b) whenever available, otherwise appropriate feed table values (table, 2012) were used. In the regression analyses it was the energy intake in MJ per day and the ration concentration of nutrients in grams per MJ NEL that was used. The animal inputs to NorFor were breed, parity (primiparous or multiparous), LW (mean of first and last LW in trial period), stage of lactation (DIM) and activity (loose or tied up) (Åkerlind et al., 2011a). Calculations were made using NorFor Development Tool, a program that runs off-line incorporating the NorFor equations used for development, testing and implementing processes (Volden et al., 2011).

In all milk response functions the response variable was the average daily yield of energy corrected milk (ECM, 3.14 MJ/kg) calculated from milk yield and milk composition according to Sjaunja et al. (1991). In the response functions for LW gain the response variable was the daily live weight gain (DG) in kg at three specific stages of lactation; at DIM 30, 60 and 90, these daily live weight gains were found as the slope of the modeled live weight curves for the individual cows. This was to account for an early lactation period having both a mobilization and a deposition phase which is not accounted for by a simple mean of ‘ultimo LW minus primo LW’. The DG was calculated as treatment means from individual LW curves made for the individual cows in each trial.

The commercial herd data used for evaluation of the milk production response function was gathered from the Dairy Management System (DMS) (Anonymous, 2013), a database of i.a. one day feeding evaluation records according to the NorFor system (Volden et al., 2011). The herd data was from the period of December 2012 through November 2013 representing 728 herds with breeds of DH, DR and DJ. The variables for milk production, energy and nutrient intake which were chosen for use in the analyses in Paper 4 were similar to those used for the modeling of milk response functions from the meta-analysis on the production trial data. The herd data was used at two data aggregation levels, between herds and within herds. The between herd data was aggregated by calculating means for the total number of feeding evaluation records for an individual herd resulting in one observation of milk and feed for each herd. The within herd data had various numbers of feeding evaluation records for each herd and thereby various numbers for observations of milk and feed. This allowed for study of milk production responses within individual herds using herd as a random factor.

The study comparing milk response functions from individual versus group data was made prior to the analyses on the total data set. The data selected for this were taken from the total data set from two continuous experiments where the data on individual level were individual cow observations and the data on group level were mean of treatment groups. Each of the trials included 90 multiparous Danish Holstein cows and lasted 12 weeks, from week 3 to 15 after parturition.

2.2. Statistical methods

The applied method of meta-analysis for the empirical modeling of the response functions on the production trial data is more likely to produce relevant prediction estimates for use in production decision tools due to the broader set of conditions e.g. breeds, feedstuffs or production systems that come from inclusion of data from several studies rather than only one (Sauvant et al., 2008). The model type used for the regression analyses of milk and growth on the energy intake was a mixed-
Brief presentation of methodology

effects model with a random effect of trials. The ‘trial effect’ accounts for the possible variance between studies that are not accounted for by other variables in the response model (St-Pierre, 2001). From the use of trials as random factor in the meta-analyses parallels can be drawn to milk responses in a given herd and the varying energy intake levels are represented by the treatment means.

The trials in the total dataset were of both continuous and change over design in order to have an appropriate number of trials that fulfill the prerequisites. The continuous trials are preferred for use in meta-analyses as the characteristic for trials of change over design with short term periods could induce problems of carry-over effect between treatment periods. However, according to Huhtanen and Hetta (2012) the milk production response to change in nutrient supply was not dependent on the experimental design. In relation to growth responses the data from the short periods of registration might not be valid and thereby the Latin square trials are not suitable for modeling response functions.
3. Results

3.1. Paper 1
“Evaluation of individual versus group level observations and different feed ration evaluation systems for estimating milk yield responses”
Evaluation of individual versus group level observations and different feed ration evaluation systems for estimating milk yield responses. C. Jensen\textsuperscript{1,2}, M. R. Weisbjerg\textsuperscript{1}, and S. Østergaard\textsuperscript{1}. \textsuperscript{1}Department of Animal Science, Aarhus University, Blichers Allé 20, 8830 Tjele, Denmark, charlotte.jensen@agrsci.dk; \textsuperscript{2}Knowledge Centre of Agriculture, Cattle, Agro Food Park 15, 8200 Aarhus, Denmark.

Milk production response functions are needed for the economic optimization of energy level in feed rations based on NorFor (Volden 2011), a non-additive net energy (NEL) system. Previous production responses were based on additive Scandinavian feed units (SFU). The objectives were to compare response functions based on: (1) individual cow observations versus treatment means; (2) NEL versus SFU. Data used were from two block experiments; each lasted from 3 to 15 wk after parturition and included 90 multiparous Danish Holstein cows. Treatments were three types of roughages combined with three levels of concentrates as TMR rations. Datasets were 90 individual (idv) or 18 group (grp, treatment means) level observations. A mixed linear effects model with random effect of experiments was used for analyses of energy corrected milk (kg, ECM) response; explanatory variables were energy intake as both a linear effect and transformed by natural logarithm. A declining marginal milk yield response (MR) was found for all scenarios (Fig. 4). At 10, 50 and 90 percentiles of NEL intake the MR were (idv/grp): 0.11/0.24, 0.10/0.11 and 0.09/0.02 kg ECM per MJ, respectively; with SFU the MR were (idv/grp): 0.67/1.15, 0.57/0.48 and 0.50/0.10 kg ECM per SFU, respectively. This shows that at both low and high levels of energy intake, there is a significant difference between using idv versus grp data. To compare MR from NEL and SFU system,

![Fig. 4. (a) and (b) The milk production response in kilograms energy corrected milk per day (kg ECM d\textsuperscript{-1}) to increased net energy intake according to NorFor (MJ d\textsuperscript{-1}) and Scandinavian feed unit (SFU d\textsuperscript{-1}). Observations on individual level (○) and on group level (●). Predicted responses on individual level (— — —) and on group level(-- -- --). (c) and (d) The marginal milk production response (marginal kg ECM per energy unit) to increased net energy intake according to NorFor (MJ d\textsuperscript{-1}) and Scandinavian feed unit (SFU d\textsuperscript{-1}).]
we converted ECM per SFU to ECM per NEL by the factor 0.144 SFU per MJ, which was the calculated mean from idv data. At 10, 50 and 90 percentiles of SFU intake the converted MR (idv/grp) were: 0.10/0.17, 0.08/0.07 and 0.07/0.01 kg ECM per MJ, respectively. This shows a larger MR for the NEL system than the SFU system, though the differences are small. These results demonstrate that different outcomes can be obtained when modelling responses from individual and group-based data, which is particularly important in models such as those targeting optimal feeding levels.

**Key words:** Dairy cows, modelling, response curves

3.2 Paper 2
“A meta-analysis of milk production responses to increased net energy intake in Scandinavian dairy cows”
(Submitted to Livestock Science)
A meta-analysis of milk production responses to increased net energy intake in Scandinavian dairy cows

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ABSTRACT

The objectives of this analysis were to develop empirical prediction models for milk yield based on cow characteristics and dry matter intake (DMI) or net energy intake (NEL) and to evaluate the effect of breed, parity, stage of lactation and the additional prediction value of using NEL estimates versus DMI estimates for incorporation in future economical optimization models of the energy level in dairy cow rations. Previous Danish response models are outdated due to higher yield capacity of cows and the new Nordic feed evaluation system NorFor, a mechanistic non-additive system. A data set with 195 treatment mean observations was compiled from original data of 13 trials from Denmark, Norway and Sweden representing the breeds Danish Holstein, Danish Red, Danish Jersey, Norwegian Red and Swedish Red. Total data were grouped into 4 sub datasets according to parity; either primiparous or multiparous and according to stage of lactation; either DIM 1 to 100 (Early) or DIM 101 to 200 (Mid). All analyzed ration characteristics were calculated from NorFor principles or estimated from NorFor feed table values. Data were analyzed using linear mixed effects model with trials as random effect. Residuals were weighted by number of cows in each treatment mean. Best fit model was by use of linear and natural log transformation of NEL intake rather than DMI in the regression, especially when also including the ration concentration of the individual nutrients (g/MJ NEL), neutral detergent fiber, amino acids absorbed in the small intestine and crude fat, in the model. Breed specific responses were parallel and only differed by their intercept. In early lactation for multiparous cows with a mean NEL intake (136 MJ) the model predicted an ECM response of 35.4 kg and for primiparous cows with mean NEL intake (115 MJ) the model predicted an ECM response of 27.8 kg. Marginal milk response (kg ECM/MJ NEL) decreased more for multiparous cows (from 0.34 to 0.08) than for primiparous cows (from 0.20 to 0.15) within the observation ranges of NEL intake. The developed milk response models can be incorporated and applied to economical optimization of the energy level in feed rations for dairy cows in early stage of lactation.

Keywords: Dairy cow; Energy intake; Meta-analysis; Milk production; NorFor

1. Introduction

Feed is the single most important factor to the economy in the dairy herd and typically constitutes 80% of the variable costs. Increased focus on economic efficient dairy herds as well as frequent fluctuations in feed and milk prices has emphasized an economical approach to feed planning, including optimization of the energy level. New mechanistic physiological models have been developed in recent years to improve formulation of feed rations nutritionally and to improve milk production. NorFor - The Nordic feed evaluation system is a semi-mechanistic non additive feed evaluation system and is implemented in Denmark, Iceland, Norway and Sweden (Volden and Gustafsson, 2011). Feed ration formulation for dairy cows using NorFor requires input of feed characteristics (chemical composition, fractional degradation rates and particle length) and animal characteristics (BW, breed, stage of lactation and planned or potential daily milk production) (Volden, 2011) and includes a cost minimization. Such a feed ration will seldom be economically optimal, and assuming no carry-over effect, economic optimum is where marginal cost of feed equals marginal income from production as
the factor input level should be increased until the marginal value of an additional factor unit equals the unit price of the factor.

Currently determination of the economic optimal feeding level is not available together with NorFor feed ration planning. This is due to lack of new milk production responses that are applicable to contemporary high yielding dairy cows and a non additive ration evaluation system. Introducing mechanistic non additive systems as NorFor and the Cornell Net Carbohydrate and Protein System (CNCPS) (Russell et al., 1992) have markedly changed the classical additive system using static feed values. In these systems the energy value of a feed stuff in a given ration is defined according to interactions between the ration feedstuffs, feeding level and animal characteristics. In the NorFor system this results in a decrease in NEL with increased DMI (Volden and Nielsen, 2011) like the CNCPS, whereas in the classic energy evaluation systems NE per kg DM is constant when increasing DMI. In NorFor the mechanism of reduced NEL with higher DMI is due to an increased passage rate of feed fractions and thereby less nutrients were digested and used by the cow (Volden, 2011).

The objectives of this analysis were to develop empirical prediction models for milk yield based on cow characteristics and dry matter intake (DMI) or net energy intake (NEL) and to evaluate the effect of breed, parity, stage of lactation and the additional prediction value of using NEL estimates versus DMI estimates for incorporation in future economical optimization models of the energy level in dairy cow rations.

2. Materials and methods

2.1. Dataset

A data set with 195 treatment mean observations was compiled from original data of 13 trials from Denmark, Norway and Sweden. Prerequisites for a trial to be included in current analysis were that cows were fed ad libitum, the planned ration energy densities were independent of individually recorded milk yields, and that various energy levels were planned within each trial. The trials were conducted in the years 1998 to 2010 at research centers with registrations on actual feed intake of all offered feed, milk yield and BW. Two-thirds of trials were continuous design and one-third of trials were change-over design. Breeds in data were Danish Holstein (DH) (44%), Norwegian Red (NR) (31%), Swedish Red (SR) (18%), Danish Red (DR) (4%) and Danish Jersey (DJ) (3%). Total data were grouped into 4 sub datasets according to parity; either primiparous (Primi) or multiparous (Multi) and according to stage of lactation; either DIM 1 to 100 (Early) or DIM 101 to 200 (Mid). The principle for the early lactation period was based on several trials having data for the early lactation period within 0 to 100 DIM and the long term studies were adjusted with new treatment means for this early period. DIM for a treatment group was defined by the mean of the trial period. Summary of trials included in data set is shown in Table 1. Feed rations in trials were TMR, partly mixed rations or separate feeding. Roughages were silages of grass, grass clover, corn, alfalfa or whole crop barley, or ammonia treated straw. Concentrates were various combinations of barley, oats, rapeseed cake, peas, dried beet pulp, molasses, or urea. Concentrate share in rations varied from zero to 85% on DM basis. Feed ration characteristics are shown in Table 2.
2.2. Calculations

Dependent response variable was the average daily yield of ECM (3.14 MJ/kg) calculated from milk yield and milk composition according to Sjaunja et al. (1991). Energy values of all rations used in trials were calculated by use of NorFor to obtain consistent energy expression in data opposed to the varying feed evaluation systems used in original analysis of trials. Animal inputs to NorFor were breed, parity, BW (mean of first and last BW in trial period), DIM and activity (loose or tied up). Animal characteristics, milk production and feed intake for Early and Mid of Primi and Multi data are shown in Table 3a and 3b. Feedstuff inputs to NorFor were chemical analyses of individual feedstuffs whenever available, otherwise appropriate feed table values (NorFor Feedtable, 2012) were used. Silage OM digestibility was determined either in vivo with sheep fed at maintenance or in vitro using rumen fluid (Tilley and Terry, 1963) and subsequent recalculated to in vivo according to NorFor (Åkerlind et al., 2011). Content of indigestible NDF (iNDF) was determined either in sacco or by near infrared spectroscopy (Åkerlind et al., 2011). In analysis of the sensitivity of ration energy value to feed characteristics, the iNDF has been found to be one of the most important feed characteristics in NorFor (Volden et al., 2011). If iNDF contents were absent, values were estimated from feed table values on iNDF to NDF ratio. In NorFor calculation of energy supply from feed rations was based on the Dutch NE system developed by Van Es. NEL was calculated by the ME from apparent total tract digestibility of protein, fat and CHO with digestibility of NorFor. The efficiency of ME utilization was then calculated as a function of the ME to GE ratio (Volden and Nielsen, 2011). Metabolizable protein supply was calculated as amino acids absorbed in the small intestine (AAT), which was the sum of dietary AA, microbial AA and endogenous AA digested in the small intestine (Volden and Nielsen, 2011). Protein for microbial growth in the rumen was determined as protein balance in the rumen (PBV) (Volden and Larsen, 2011). Ration concentration of nutrients were calculated as the ratio of total intake in grams per total NEL intake in MJ.

2.3. Statistical Analysis and Parameter Estimation

Data were analyzed using linear mixed effects model procedure in “nlme” package (Pinheiro et al., 2012) in R (R Core Team, 2012). Trials were used as random effect. Residuals were weighted by number of cows in each treatment mean. Inclusion of relevant variables to the model was evaluated by individual screening. The screening was performed on the dataset of Early Multi (subset of data with greatest number of observations), using a model with fixed continuous effect of linear net energy intake and natural logarithm of net energy intake and a fixed categorical effect of breed on ECM response. The model was: ECM = NEL + ln(NEL) + Breed + VAR_m, where VAR_m represents ration concentration of each of the following nutrients (g per MJ NEL); CP, crude fat (CFat), total fatty acids, NDF, starch, sugar, AAT, and PBV or the ration characteristic variables; fill value of ration or concentrate share of ration. In addition to this model all variables with P-value ≤ 0.20 were included in a backward model reduction procedure. Reduction of the nutrient and ration characteristic variables was based on Chi-square tests, Akaike Information Criterion (AIC), and Bayes information criterion (BIC). Possible interactions between NEL intake and the selected nutrients were tested.
Following the screening and model reduction on Early Multi data a final model for ECM response included NEL, NDF, AAT, CFat and breed as independent variables. This model was then applied as the full model to the other data subsets. The model was:

\[
ECM_{ij} = \beta_0 + \beta_1 \text{NEL} + \beta_2 \ln(\text{NEL}) + \beta_3 \text{NDF}_\text{NEL} + \beta_4 \text{AAT}_\text{NEL} + \beta_5 \text{CFat}_\text{NEL} + \beta_6 \text{Breed} + b_i + \epsilon_{ij}
\]

with NEL, AAT\_NEL, NDF\_NEL, CFat\_NEL (continuous) and Breed (categorical) as fixed effects, \(b_i\) as random intercept effect of trials and \(\epsilon_{ij}\) as residual error values with \(b_i \sim N(0, \sigma_i^2)\) and \(\epsilon_{ij} \sim N(0, \sigma^2)\). An ECM response model with DMI as independent variable was also tested:

\[
ECM_{ij} = \beta_0 + \beta_1 \text{DMI} + \beta_2 \ln(\text{DMI}) + \beta_3 \text{Breed} + b_i + \epsilon_{ij}
\]

with same random statement and residual weighting as previously. Following all statistical analyses visual examination of residual plots as the residuals against the model variables was used to assess normality of residuals and homogeneity of variance.

An R-squared statistic \((R^2_\beta)\) was estimated according to Edwards et al. (2008) for the measure of multivariate association between the response variable and the fixed effects in the linear mixed model. The \(R^2_\beta\) is related to an F-test comparing the full model to a null model with all fixed effects deleted except the intercept and retaining the same covariance structure. It assesses the goodness of fit of the fixed effects model (the means model) keeping out the random parts of the entire mixed model. Calculations of \(R^2_\beta\) was made in R (R Core Team, 2012) using the “lme4” package (Bates et al., 2012) and the “pbkrtest” package (Halekoh and Højsgaard, 2012).

The 95% confidence interval for the mean prediction values was calculated by use of SE and 95% prediction interval for new observations was calculated by use of prediction error (PE). The PE for a new observation at given NEL intake in a new trial or herd was given by \(SE^2 + \sigma^2_{\text{trial}}\), where \(\sigma^2_{\text{trial}}\) was the MSE for random effect of trials (Harville and Jeske, 1992).

The marginal responses were derived from the first derivative of the response functions. For the curvilinear models this was calculated by \(\beta_1 + \beta_2 /\text{NEL}\).

3. Results

Data displayed large variation in feed intake and ECM production. For Early Primi and Early Multi (Table 3a) mean NEL intake were 115 MJ (ranged 75 to 154 MJ) and 136 MJ (ranged 95 to 171 MJ); mean DMI were 18.1 kg (ranged 12.0 to 22.7 kg) and 21.7 kg (ranged 15.7 to 26.0 kg); mean ECM were 26.6 kg (ranged 15.3 to 36.1kg) and 33.0 kg (ranged 20.8 to 44.4 kg), respectively. For Mid Primi and Mid Multi (Table 3b) mean NEL intake were 118 MJ (ranged 61 to 166 MJ) and 135 MJ (ranged 81 to 166 MJ); mean DMI were 18.0 kg (ranged 11.1 to 22.5 kg) and 20.8 kg (ranged 13.7 to 25.4 kg); mean ECM were 27.1 kg (ranged 10.3 to 35.9kg) and 29.4 kg (ranged 14.8 to 36.7 kg), respectively.

Depending on the criteria used for model reduction (Chi-square test, AIC or BIC) different models were possible best fit models. Estimates for ECM response models with NEL for multiparous and primiparous cows in early and mid lactation are shown in Table 4. For Early Multi data the full model...
(NUTR-model) including concentration of the nutrients NDF, AAT and CFat was the best fit model according to lowest AIC. Excluding variables AAT_NEL and CFat_NEL from NUTR-model the model including only NDF (NDF-model) was best fit model according to a Chi-square test (test not shown). The model based on natural logarithm of NEL (lnNEL-model) was best fit model according to BIC. For Mid Multi data best fit model was lnNEL-model according to both Chi-square test, AIC and BIC. For Early Primi data and Mid Primi data best fit model was lnNEL-model according to AIC and BIC, whereas a linear response based only on NEL (NEL-model) was best fitting according to Chi-square test. Root mean square error (RMSE) values for ECM response models with NEL intake ranged from 1.38 to 2.50 kg ECM.

Nutrient estimates in NUTR-model were all positive for Early Multi data and Early Primi data. For Early Multi the predicted responses of nutrients were 0.106 kg ECM per g NDF/MJ, 0.402 kg ECM per g AAT/MJ and 0.760 kg ECM per g CFat/MJ; for Early Primi predicted responses of nutrients were 0.041 kg ECM per g NDF/MJ, 0.036 kg ECM per g AAT/MJ and 0.544 kg ECM per g CFat/MJ. There were no interactions between NEL intake and the nutrients. Breed specific intercept estimates relative to DH in NUTR-model for Early Multi were -3.3 for DJ, -3.6 for DR, -6.5 for NR and -0.7 for SR; for Early Primi estimates relative to DH were 0.3 for DJ, -2.8 for DR, -4.6 for NR and 1.8 for SR. There were found no significant interactions between NEL intake and breeds.

Predicted ECM response to a given NEL intake level was higher for multiparous cows than primiparous cows. The ECM responses from NUTR-model for Early Multi data and Early Primi data as a function of NEL intake given the mean level of NDF/MJ, AAT/MJ and CFat/MJ in each data set is shown in Figure 1. From Early data with the NUTR-model and a mean NEL intake for multiparous cows (136 MJ/d) the predicted ECM response was 35.4 kg with a 95 % confidence interval of 33.0 to 37.8 kg and a prediction interval for new observations (e.g. trials or herds) of 28.7 to 42.0 kg. For primiparous cows (115 MJ/d) the predicted ECM response was 27.8 kg with a 95 % confidence interval of 25.5 to 30.1 kg and a prediction interval for new observations (e.g. trials or herds) of 21.5 to 34.1 kg. From Mid data with the NUTR-model and a mean NEL intake for multiparous cows (135 MJ/d) the predicted ECM response was 30.9 kg and for primiparous cows (118 MJ/d) the predicted ECM response was 28.8 kg (result not shown).

Marginal ECM response to increased NEL intake with the NUTR-model decreased more for Early Multi than for Early Primi (Figure 2) when calculated by the functions 0.111+6.6/NEL and -0.247+56.2/NEL for Early Multi and Primi, respectively. For Early Multi it decreased from 0.34 to 0.08 kg/MJ with 0.17 kg/MJ at mean NEL intake whereas for Early Primi marginal ECM response decreased from 0.20 to 0.15 kg/MJ with 0.17 kg/MJ at mean NEL intake. Likewise for Mid Multi it decreased from 0.45 to 0.02 kg/MJ with 0.12 kg/MJ at mean NEL intake whereas for Mid Primi marginal ECM response decreased from 0.06 to -0.02 kg/MJ with -0.01 kg/MJ at mean NEL intake (result not shown).

Regression estimates for ECM response models with DMI as only independent variable for primiparous and multiparous cows in early and mid lactation are shown in Table 5. For Early Multi and Mid Multi data there was a nonlinear effect of DMI (lnDMI-model), whereas for Early Primi and Mid Primi responses of DMI were linear (DMI-model). RMSE values for ECM response models with DMI ranged from 1.52 to 2.59 kg ECM.
The $R^2_\beta$ values were all high and ranged from 0.92 to 0.97 for models based on NEL intake as well as DMI. The best fit models according to Chi-square test also had the highest $R^2_\beta$, only exception to this was for Early Multi where $R^2_\beta$ was 0.93 for both NUTR-model and lnNEL-model.

4. Discussion

Use of the same model reduction process in all sub data sets enabled comparisons of models and estimates between parity and stage of lactation. The Early Multi data was chosen as outline for this model reduction process due to the largest number of observations. Among the ECM response models of Early Multi no single best fit model was determined as it differed depending on selection criteria (Chi-square tests, AIC or BIC), where BIC penalizes larger models heavily compared to AIC (West et al., 2006). In the case of applicability of a model according to relevance or availability of nutrient value of feeds the full NUTR-model or the reduced lnNEL-model might be the most feasible, respectively. When applying models for the data outside the ranges in NEL and nutrient intakes of the original dataset caution should be placed with extrapolation, which is especially important with linear models. However, the advantage of models based on DMI is that they can be used independently of specific feed and energy evaluation systems.

To assess the goodness-of-fit an $R^2_\beta$ statistic for the linear mixed model (Edwards et al., 2008) was used. The $R^2$ known from ordinary linear regression models is usually interpreted as the larger value the better the model fits the data. In this analysis the measure decreased when adding predictors in several cases. However, according to Edwards et al. (2008) “adding a predictor in the fixed effects (between-subject effect) can increase the estimated variance of the random effects (within-subject effect) and hence increase the estimated variance of the response”. This was found to be the case for Early Primi and Mid Primi data.

Feed rations in this analysis represented a large variety of forages but most of the rations included grass or grass clover silage as typical for Scandinavia. All main Scandinavian dairy cow breeds were included in this analysis though with an overweight of DH and NR. Therefore conclusions on specific responses of especially DR and DJ breeds should be cautioned. The design in trials was block, continuous or Latin square designs. This was not considered as a factor in the analysis, as previous analysis (Huhtanen and Hetta, 2012) indicated that there was no interactions between milk production responses and experimental design.

A positive response of DMI on milk production is well known from previous analyses (Hristov et al., 2005; Martin and Sauvant, 2002) and is confirmed in this analysis. For Early Multi data highly significant positive non linear ECM response of DMI was found (Table 5). At a mean DMI of 22.6 kg the predicted ECM response was 35.7 kg. For multiparous cows in early lactation the marginal ECM response decreased from 1.7 to 0.3 kg ECM per kg DMI with increased DMI. Hristov et al. (2005) predicted a linear response of 1.076 kg ECM per kg DMI for combined primiparous and multiparous cows which was inside the range of the ECM responses in this analysis.

Use of NEL intake rather than DMI in the regression model improved prediction of ECM response. The $R^2_\beta$ was slightly higher for the model based on NEL intake than on DMI. The improvement from DMI models to NEL models was smaller than expected. This could be interpreted as imprecise NEL estimation.
in NorFor, however more likely related to a very high correlation between DMI and NEL intake in ad libitum fed cows as the plot of residuals against NEL intake did not indicate any problems with the NorFor NEL parameter (Figure 3). Furthermore the prediction improved when also including individual nutrients in the model. The ration concentration of individual nutrients was used to control correlation between NEL and the nutrients. When rations are fed ad libitum, increased NDF concentration is probably mediated through increased NDF digestibility. Early Multi responded with 0.11 kg ECM per gram NDF/MJ NEL. Assuming that increased NDF feed ration concentrations in the data set is due to increased digestibility of NDF, it can be calculated that a per unit increase in NDF digestibility yielded 0.3 kg ECM with constant energy concentration in the ration. This is in same range of ECM response as found by Oba and Allen (1999) where a one-unit increase in NDF digestibility was associated with a 0.25 kg increase in 4 % fat corrected milk. The significance of the NDF ration concentration parameter in the models indicates the possibility of NorFor not fully including the effect of digestibility of NDF in feed rations. Further the NDF digestibility might change the energy concentration in feed ration. Variation in ration CFat concentration was due to natural fat content in ration feedstuffs as none of the trials were designed to test effect of supplementary fat. Thereby, the variation in crude fat for the roughages can be a result of improved quality related to the stage of vegetation and for the concentrates it can be a result of the main protein source differing in fat content. The CFat estimate of 0.76 kg ECM per gram CFat/MJ tended to be significant (P = 0.06). An increase of 1 gram CFat/MJ in a mean ration of Early Multi data corresponded to 6 gram CFat/kg DM and with the rather low intake of CFat the expected relative ECM response would increase 1 to 2 % (0.33 to 0.7 kg ECM in this dataset) according to Danish requirements (Strudsholm et al., 1999). Numerically the estimate was high but similar high ECM responses to increased FA concentration has been found by Weisbjerg et al. (2008) where an increase in FA of 10 g/kg DM yielded an increase of 1.1 kg ECM. This was from a curvilinear response to FA concentration with marginal responses being particularly higher at low NEL intake levels than high. Also Huhtanen and Nousiainen (2012) found a curvilinear ECM response to increased ration concentration of fat from concentrate feed, though their response was less than found in our analysis.

The model with natural logarithm transformation of NEL intake was superior to a model with quadratic or a linear effect of NEL intake (results not shown). This transformation with natural logarithm was suitable as the response variable increases at a decreasing rate with the independent variable (Dohoo et al., 2003). A diminishing marginal milk response to increased NEL intake in this analysis was in agreement with previous findings (Blaxter, 1966; Huhtanen and Hristov, 2009; Huhtanen and Nousiainen, 2012). In this analysis the production response was defined as average daily ECM production to an increased NEL intake. The estimation of NEL intake in the NorFor system, used in this analysis, includes a correction for reduced digestibility at increased dry matter intake based on feed characteristics and the size of the cow. Thereby the NEL value of a feed ration becomes a more precise estimate of the net energy supplied to the cow as compared to additive feeding systems. The NorFor system predicts a linear milk response of 0.318 kg ECM per NELmilk, where NELmilk is the NEL value of the ration minus basal energy requirement (maintenance, gestation and growth of primiparous cows) corrected for any change in BW (mobilization or deposition)(Åkerlind and Volden, 2011). The NorFor system does not predict the partitioning of NEL between milk yield and gain or mobilization.
Consequently, the NorFor system does not provide a prediction of milk yield as a function of total NEL intake when gain or mobilization is unknown. Therefore, our results of a diminishing ECM production response to increased NEL intake (especially in multiparous cows) do not contradict with the NorFor system and might be explained by a partitioning of net energy towards mobilization or deposition relative to milk yield when NEL intake is increased.

A large difference in marginal ECM response between primiparous and multiparous cows was found in this analysis. This implies that primiparous cows will respond less than multiparous cows to an increased feed level at low levels of intake and vice versa. In an experiment on feeding strategies by Bossen and Weisbjerg (2009) similar difference between parities was found as there was no significant effect of the feeding strategies on milk production within primiparous cows as in contrast to multiparous cows. Primiparous cows require energy for growth (maturing) and therefore they might prioritize energy for growth higher than multiparous cows. In Figure 1, the nearly linear response to energy intake for the primiparous cows indicates that primiparous cows have a partitioning of energy between milk and gain, which is nearly independent of the energy supply (Bossen and Weisbjerg, 2009; Spahr et al., 1993). The marginal ECM response for the primiparous cows (Figure 2) was only slightly decreasing, however considering a potential diminishing return of body weight gain at increasing NEL intake and in particular the increasing marginal cost for increasing the NEL intake, then even a linear NEL effect on ECM does not preclude an economic optimization of NEL intake.

The higher marginal ECM responses of the Early data compared to the Mid data at mean NEL intake levels is in line with previous studies (Blaxter, 1966; Coulon and Rémond, 1991; Kirkland and Gordon, 2001) where it was reported that milk yield responses to changes in ME intake were higher in early than mid and late stage of lactation across varying definitions of early, mid and late. With the natural logarithm transformation of NEL intake in the ECM production response model marginal responses were non linear. In our analysis within the observation range of NEL intake the multiparous cows of Mid data had a lower marginal ECM response at high NEL intake levels than multiparous cows of Early data (result not shown). Primiparous cows were found to have a marginal ECM response close to zero over the range of NEL intake in this study (result not shown). The differences in marginal responses were not tested statistically and the numerically different marginal responses could be due to different range of NEL intake within the data subsets with the small data subsets. However, the range in NEL intake within the data subsets between parity and periods were similar (Table 3a and 3b).

Previous Danish models of ECM responses to increased net energy intake included a covariate effect of milk yield capacity (Kristensen et al., 2003). Different breeds (DH, DR, DJ, NR, and SR) represented in this analysis resulted in an absolute effect of breed on ECM response but no interaction between breed and NEL intake was found. Likewise the use of individual trials as expression of yield capacity or production level showed no interaction between NEL intake and trial. This indicated similar marginal ECM responses to NEL intake independent of yield capacity. In accordance with this Huhtanen and Nousiainen (2012) found no effect of mean milk yield level on ECM responses of increased ME supply. Also earlier studies reported no interactions between genetic merit and diet on milk production responses (Ferris et al., 1999; Veerkamp et al., 1994).
An interaction between NEL intake and breed was also expected due to differences in breed BW but not found in this analysis. The dry matter intake depends on size of the cow, with a higher DMI for cows of higher BW (e.g. DH) than for lower BW (e.g. DJ). Higher BW is followed by a higher requirement of NE for maintenance but NEL from NorFor used in this analysis was a measure of total NEL for maintenance, production and growth. Therefore NEL for maintenance was being diluted with increased energy intake levels. No interaction between NEL intake and breed as found in this analysis is possibly explained by the energy evaluation system in NorFor and the maintenance requirements. In NorFor the rumen fractional passage rate decreases with increased BW for a given feed ration (Volden and Larsen, 2011). This will result in more parallel responses between small and large breeds. Also AAT estimates in NorFor are highly affected as efficiency of microbial synthesis is related to the DMI to BW ratio (Volden and Larsen, 2011).

There was found a quite large uncertainty of the response estimates, which is shown in Figure 1 by the prediction intervals for mean and for new observations. Therefore, an optimization of the energy level in feed ration should not be based only on these production response estimates but also include other nutritional and feeding management criteria. The prediction interval was wider than the confidence interval, at given NEL intake as the prediction interval must take account of the tendency of predicted ECM to fluctuate from its mean value, while the confidence interval simply needs to account for the uncertainty in estimating the mean value (Harville and Jeske, 1992). The prediction interval for new observations was wider than for the mean data, due to response models included a random effect of the trial, which could be an indication of a need for a specific response function for a given herd. This would require coherent data of feed intake and milk production from the herd.

5. Conclusions

Multiparous cows showed higher and nonlinear responses in milk production to increased energy intake compared to primiparous cows with more linear responses. Breed specific responses were parallel. Models based on NEL improved prediction of milk yield compared to DMI. Including NorFor specific nutrient intake variables further improved model fit.

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References


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Figure 1. Predicted milk production response (—) to increased NEL intake for primi- and multiparous cows in early stage of lactation. Dotted lines shows predicted interval for mean (---) and predicted interval for new observations (∙∙∙∙). ECM responses are based on a model including NEL, ln(NEL), NDF/MJ, AAT/MJ, CFat/MJ where the level of nutrients are mean of respective data.
Figure 2. Marginal milk responses to increased NEL intake for primiparous (−) and multiparous (−) cows in early stage of lactation.
Figure 3. Raw residuals (observed – predicted ECM) plotted against NEL intake for data of multiparous cows in early stage of lactation.
## Table 1

Summary of trials included in total data set.

<table>
<thead>
<tr>
<th>Year</th>
<th>Design</th>
<th>Cows</th>
<th>Breed</th>
<th>Early(^b)</th>
<th>Mid(^b)</th>
<th>Feeding(^c)</th>
<th>Roughage</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Block</td>
<td>63</td>
<td>DH</td>
<td>18</td>
<td></td>
<td>TMR</td>
<td>Grass /</td>
<td>Kristensen et al., 2003</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Whole crop /</td>
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<tr>
<td>1999</td>
<td>Block</td>
<td>63</td>
<td>DH</td>
<td>18</td>
<td></td>
<td>TMR</td>
<td>Grass /</td>
<td>Kristensen et al., 2003</td>
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<tr>
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<td></td>
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<td></td>
<td></td>
<td>Whole crop /</td>
<td>Whole crop /</td>
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<td>NH(_3)-straw</td>
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<tr>
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<td>DH</td>
<td>8</td>
<td></td>
<td>PMR</td>
<td>Grass + Corn</td>
<td>Weisbjerg and Munksgaard, 2009</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>DR</td>
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<td></td>
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<td></td>
<td>DJ</td>
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<tr>
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<td>Grass cl. /</td>
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<td></td>
<td></td>
<td>Corn + Alfalfa</td>
<td>Corn + Alfalfa</td>
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<tr>
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<td>Block</td>
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<td>16</td>
<td></td>
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<td>Corn + Alfalfa</td>
<td>Kristensen, unpublished</td>
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<tr>
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<td>Latin sq.</td>
<td>32</td>
<td>NR</td>
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<td>SEP</td>
<td>Grass</td>
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<tr>
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<td>Randby et al., 2012</td>
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<tr>
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<td>Block</td>
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<td>SR</td>
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<td></td>
<td>PMR</td>
<td>Grass + Corn</td>
<td>Spörndly, unpublished</td>
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</table>

*\(^a\)DH = Danish Holstein, DR = Danish Red, DJ = Danish Jersey, NR = Norwegian Red, SR = Swedish Red*

*\(^b\)number of observations (treatment means), where Early = DIM 1 to 100 and Mid = DIM 101 to 200*

*\(^c\)TMR = Total mixed ration, PMR = partly mixed ration with roughage ad lib and concentrate restricted, SEP = separate feeding of roughage and concentrates*
Table 2

Feed ration characteristics in sub dataset of Early (DIM 1 to 100) and Mid (DIM 101 to 200) stage of lactation.

<table>
<thead>
<tr>
<th></th>
<th>Early (n = 135)</th>
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<th></th>
<th></th>
<th>Mid (n = 40)</th>
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<th></th>
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<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Min</td>
<td>Max</td>
<td>Mean</td>
<td>SD</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Ration DM (%)</td>
<td>48</td>
<td>14</td>
<td>30</td>
<td>87</td>
<td>41</td>
<td>10</td>
<td>22</td>
<td>57</td>
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<tr>
<td>OMD b (%)</td>
<td>74</td>
<td>2.3</td>
<td>69</td>
<td>80</td>
<td>76</td>
<td>3.2</td>
<td>65</td>
<td>81</td>
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<tr>
<td>NDFD c (%)</td>
<td>61</td>
<td>6.5</td>
<td>50</td>
<td>80</td>
<td>66</td>
<td>4.8</td>
<td>52</td>
<td>78</td>
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<tr>
<td>Concentrate share (%)</td>
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<td>18</td>
<td>0</td>
<td>85</td>
<td>36</td>
<td>14</td>
<td>5</td>
<td>54</td>
</tr>
<tr>
<td>CP (g/kg DM)</td>
<td>165</td>
<td>18.3</td>
<td>135</td>
<td>226</td>
<td>175</td>
<td>26.9</td>
<td>121</td>
<td>232</td>
</tr>
<tr>
<td>Crude fat (g/kg DM)</td>
<td>38</td>
<td>7.1</td>
<td>24</td>
<td>55</td>
<td>37</td>
<td>7.1</td>
<td>22</td>
<td>51</td>
</tr>
<tr>
<td>NDF (g/kg DM)</td>
<td>371</td>
<td>52</td>
<td>277</td>
<td>520</td>
<td>359</td>
<td>73</td>
<td>219</td>
<td>550</td>
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<tr>
<td>Starch (g/kg DM)</td>
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<td>0</td>
<td>259</td>
<td>138</td>
<td>70</td>
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<td>263</td>
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<td>Sugar (g/kg DM)</td>
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<td>11</td>
<td>140</td>
<td>47</td>
<td>25</td>
<td>3.1</td>
<td>111</td>
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</tbody>
</table>

\(^a\) n = number of observations (treatment means)

\(^b\) OMD = apparent total digestibility of organic matter, NorFor estimate

\(^c\) NDFD = apparent total digestibility of NDF, NorFor estimate
Table 3a

Animal characteristics, production, daily intake and ration concentration for primi- and multiparous cows in early stage of lactation (DIM 1 to 100).

<table>
<thead>
<tr>
<th>Animal characteristics</th>
<th>Primiparous (n(^a) = 66)</th>
<th>Multiparous (n = 69)</th>
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<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
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<tr>
<td>DIM</td>
<td>70</td>
<td>25</td>
</tr>
<tr>
<td>BW (kg)</td>
<td>531</td>
<td>49</td>
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<tr>
<td>Animal production (kg/d)</td>
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<td></td>
</tr>
<tr>
<td>ECM</td>
<td>26.6</td>
<td>4.4</td>
</tr>
<tr>
<td>Milk yield</td>
<td>26.7</td>
<td>4.6</td>
</tr>
<tr>
<td>Protein yield</td>
<td>0.87</td>
<td>0.15</td>
</tr>
<tr>
<td>Fat yield</td>
<td>1.08</td>
<td>0.18</td>
</tr>
<tr>
<td>Intake</td>
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<tr>
<td>DM (kg/d)</td>
<td>18.1</td>
<td>2.6</td>
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<tr>
<td>ME (MJ/d)</td>
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<td>29</td>
</tr>
<tr>
<td>NEL (MJ/d)</td>
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<td>18</td>
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<td>Ration concentration (g/MJ NEL)</td>
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<tr>
<td>CP</td>
<td>26.0</td>
<td>2.6</td>
</tr>
<tr>
<td>AAT (^b)</td>
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<tr>
<td>Fatty acids</td>
<td>4.1</td>
<td>0.9</td>
</tr>
<tr>
<td>NDF</td>
<td>58.4</td>
<td>8.7</td>
</tr>
<tr>
<td>Starch</td>
<td>24.4</td>
<td>9.0</td>
</tr>
<tr>
<td>Sugar</td>
<td>8.4</td>
<td>4.9</td>
</tr>
</tbody>
</table>

\(^a\) n = number of observations (treatment means)

\(^b\) AAT = amino acids absorbed in the small intestine, calculated as sum of dietary AA, microbial AA and endogenous AA digested in the small intestine

\(^c\) PBV = protein balance in rumen, protein for microbial growth in the rumen
Table 3b

Animal characteristics, production, daily intake and ration concentration for primi- and multiparous cows in mid stage of lactation (DIM 101 to 200).

<table>
<thead>
<tr>
<th></th>
<th>Primiparous (n = 29)</th>
<th></th>
<th></th>
<th>Multiparous (n = 31)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Min</td>
<td>Max</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Animal characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIM</td>
<td>133</td>
<td>25</td>
<td>95</td>
<td>155</td>
<td>137</td>
<td>21</td>
</tr>
<tr>
<td>BW (kg)</td>
<td>539</td>
<td>30</td>
<td>420</td>
<td>561</td>
<td>621</td>
<td>33</td>
</tr>
<tr>
<td>Production (kg/d)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECM</td>
<td>27.1</td>
<td>5.6</td>
<td>10.3</td>
<td>35.9</td>
<td>29.4</td>
<td>4.9</td>
</tr>
<tr>
<td>Milk yield</td>
<td>26.2</td>
<td>5.0</td>
<td>11.6</td>
<td>33.6</td>
<td>28.8</td>
<td>4.2</td>
</tr>
<tr>
<td>Protein yield</td>
<td>0.88</td>
<td>0.18</td>
<td>0.33</td>
<td>1.13</td>
<td>1.00</td>
<td>0.18</td>
</tr>
<tr>
<td>Fat yield</td>
<td>1.12</td>
<td>0.25</td>
<td>0.40</td>
<td>1.54</td>
<td>1.19</td>
<td>0.20</td>
</tr>
<tr>
<td>Intake</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM (kg/d)</td>
<td>18.0</td>
<td>2.1</td>
<td>11.1</td>
<td>22.5</td>
<td>20.8</td>
<td>2.5</td>
</tr>
<tr>
<td>ME (MJ/d)</td>
<td>196</td>
<td>29</td>
<td>105</td>
<td>239</td>
<td>225</td>
<td>32</td>
</tr>
<tr>
<td>NEL (MJ/d)</td>
<td>118</td>
<td>18</td>
<td>61</td>
<td>146</td>
<td>135</td>
<td>20</td>
</tr>
<tr>
<td>Ration concentration (g/MJ NEL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude protein</td>
<td>26.8</td>
<td>3.4</td>
<td>21.5</td>
<td>35.6</td>
<td>26.8</td>
<td>3.5</td>
</tr>
<tr>
<td>AAT b</td>
<td>14.7</td>
<td>1.1</td>
<td>12.3</td>
<td>16.9</td>
<td>14.7</td>
<td>1.0</td>
</tr>
<tr>
<td>PBV c</td>
<td>5.0</td>
<td>3.1</td>
<td>1.2</td>
<td>12.4</td>
<td>4.9</td>
<td>3.0</td>
</tr>
<tr>
<td>Crude fat</td>
<td>5.6</td>
<td>1.0</td>
<td>3.5</td>
<td>7.1</td>
<td>5.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Fatty acids</td>
<td>3.4</td>
<td>1.0</td>
<td>2.0</td>
<td>5.2</td>
<td>3.4</td>
<td>1.0</td>
</tr>
<tr>
<td>NDF</td>
<td>54.9</td>
<td>14.2</td>
<td>30.8</td>
<td>99.7</td>
<td>56.0</td>
<td>13.3</td>
</tr>
<tr>
<td>Starch</td>
<td>21.1</td>
<td>10.3</td>
<td>4.7</td>
<td>38.4</td>
<td>20.8</td>
<td>10.0</td>
</tr>
<tr>
<td>Sugar</td>
<td>7.1</td>
<td>4.0</td>
<td>0.6</td>
<td>16.7</td>
<td>7.2</td>
<td>3.8</td>
</tr>
</tbody>
</table>

a n = number of observations (treatment means)

b AAT = amino acids absorbed in the small intestine, calculated as sum of dietary AA, microbial AA and endogenous AA digested in the small intestine

c PBV= protein balance in rumen, protein for microbial growth in the rumen
Table 4

Parameter estimates for ECM response (kg/d) for primi- and multiparous DH cows in Early (1-100 DIM) and Mid (101-200 DIM) stage of lactation based on NEL intake models.

<table>
<thead>
<tr>
<th>Model</th>
<th>Intercept</th>
<th>NEL</th>
<th>ln(NEL)</th>
<th>NDF_NEL</th>
<th>AAT_NEL</th>
<th>CFat_NEL</th>
<th>RMSE</th>
<th>AIC</th>
<th>BIC</th>
<th>R²</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Early Primi</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NUTR</td>
<td>-22.4 ± 55 ns</td>
<td>0.111 ± 0.13 ns</td>
<td>6.6 ± 15 ns</td>
<td>0.041 ± 0.05 ns</td>
<td>0.036 ± 0.27 ns</td>
<td>0.544 ± 0.44 ns</td>
<td>1.606</td>
<td>276.2</td>
<td>300.5</td>
<td>0.917</td>
<td></td>
</tr>
<tr>
<td>NDF</td>
<td>-48.1 ± 50 ns</td>
<td>0.058 ± 0.12 ns</td>
<td>14.1 ± 13 ns</td>
<td>0.044 ± 0.04 ns</td>
<td>1.631</td>
<td>273.1</td>
<td>293.8</td>
<td>0.919</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lnNEL</td>
<td>-27.2 ± 46 ns</td>
<td>0.084 ± 0.11 ns</td>
<td>9.5 ± 12 ns</td>
<td>1.649</td>
<td>267.7</td>
<td>286.4</td>
<td>0.936</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NEL</td>
<td>7.9 ± 2 ***</td>
<td>0.172 ± 0.01 ***</td>
<td></td>
<td>1.673</td>
<td>273.2</td>
<td>289.9</td>
<td>0.952</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Early Multi</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NUTR</td>
<td>-224 ± 84 *</td>
<td>-0.247 ± 0.15 ns</td>
<td>56.2 ± 21*</td>
<td>0.106 ± 0.05 *</td>
<td>0.402 ± 0.23 t</td>
<td>0.760 ± 0.40 t</td>
<td>1.381</td>
<td>277.0</td>
<td>301.9</td>
<td>0.928</td>
<td></td>
</tr>
<tr>
<td>NDF</td>
<td>-322 ± 77 ***</td>
<td>-0.415 ± 0.14 **</td>
<td>82.7 ± 19 ***</td>
<td>0.133 ± 0.05 **</td>
<td>1.462</td>
<td>277.3</td>
<td>298.4</td>
<td>0.923</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lnNEL</td>
<td>-213 ± 70 **</td>
<td>-0.288 ± 0.14 *</td>
<td>58.5 ± 18 **</td>
<td>1.523</td>
<td>278.4</td>
<td>297.6</td>
<td>0.928</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mid Primi</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NUTR</td>
<td>-0.038 ± 79 ns</td>
<td>-0.070 ± 0.16 ns</td>
<td>7.7 ± 21 ns</td>
<td>-0.173 ± 0.10 ns</td>
<td>1.08 ± 0.84 ns</td>
<td>-1.07 ± 0.93 ns</td>
<td>2.023</td>
<td>142.9</td>
<td>153.4</td>
<td>0.923</td>
<td></td>
</tr>
<tr>
<td>NDF</td>
<td>-46 ± 72 ns</td>
<td>-0.130 ± 0.15 ns</td>
<td>20 ± 18 ns</td>
<td>-0.120 ± 0.10 ns</td>
<td>2.236</td>
<td>145.0</td>
<td>154.1</td>
<td>0.942</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lnNEL</td>
<td>-101 ± 56 t</td>
<td>-0.160 ± 0.15 ns</td>
<td>31.6 ± 15 t</td>
<td>2.349</td>
<td>141.6</td>
<td>149.8</td>
<td>0.951</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NEL</td>
<td>12.2 ± 6 *</td>
<td>0.150 ± 0.03 ***</td>
<td></td>
<td>2.504</td>
<td>150.9</td>
<td>158.2</td>
<td>0.956</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mid Multi</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NUTR</td>
<td>-254 ± 105 *</td>
<td>-0.384 ± 0.19 t</td>
<td>67.5 ± 27 *</td>
<td>0.031 ± 0.09 ns</td>
<td>0.654 ± 0.68 ns</td>
<td>-1.03 ± 0.71 ns</td>
<td>1.418</td>
<td>136.9</td>
<td>148.3</td>
<td>0.947</td>
<td></td>
</tr>
<tr>
<td>NDF</td>
<td>-237 ± 72 **</td>
<td>-0.376 ± 0.14 *</td>
<td>64.8 ± 18 **</td>
<td>0.031 ± 0.08 ns</td>
<td>1.494</td>
<td>137.6</td>
<td>147.4</td>
<td>0.966</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lnNEL</td>
<td>-224 ± 63 **</td>
<td>-0.378 ± 0.13 **</td>
<td>62.6 ± 16 ***</td>
<td>1.492</td>
<td>132.6</td>
<td>141.4</td>
<td>0.973</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
a Name of models from specific data set, where Early = 1 to 100 DIM, Mid = 101 to 200 DIM, Primi = primiparous, Multi = multiparous

b P values shown by *** = P \leq 0.001, ** = 0.001 > P \leq 0.01, * = 0.01 > P \leq 0.05, t = 0.05 > P \leq 0.1, ns = P > 0.1

c NEL = Net energy intake (MJ) as total NEL from feed not corrected for maintenance, gestation and growth

d NDF_NEL = neutral detergent fiber, ration concentration (g/MJ NEL intake)

e AAT_NEL = amino acid absorbed in the small intestine, ration concentration (g/MJ NEL intake)

f CFat_NEL = crude fat, ration concentration (g/MJ NEL intake)

g RMSE = root mean square error

h AIC = Akaike’s information criteria

i BIC = Bayesian information criteria

j R^2_\beta = R-squared for mixed models
Table 5

Parameter estimates for ECM response (kg/d) for primi- and multiparous DH cows in Early (DIM 1 to 100) and Mid (DIM 101 to 200) stage of lactation based on DMI models.

<table>
<thead>
<tr>
<th>Model</th>
<th>Intercept</th>
<th>DMI</th>
<th>ln(DMI)</th>
<th>RMSE</th>
<th>AIC</th>
<th>BIC</th>
<th>$R^2_{\beta}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Primi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lnDMI</td>
<td>-26.9 ± 27 ns</td>
<td>0.113 ± 0.86 ns</td>
<td>18.1 ± 15 ns</td>
<td>1.674</td>
<td>271.4</td>
<td>290.1</td>
<td>0.920</td>
</tr>
<tr>
<td>DMI</td>
<td>6.5 ± 2 **</td>
<td>1.159 ± 0.11 ***</td>
<td></td>
<td>1.701</td>
<td>278.1</td>
<td>294.9</td>
<td>0.938</td>
</tr>
<tr>
<td>Early Multi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lnDMI</td>
<td>-173 ± 51 **</td>
<td>-3.18 ± 1.21 *</td>
<td>90 ± 25 ***</td>
<td>1.577</td>
<td>278.1</td>
<td>297.2</td>
<td>0.917</td>
</tr>
<tr>
<td>Mid Primi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lnDMI</td>
<td>-99 ± 48 t</td>
<td>-2.5 ± 1.7 ns</td>
<td>60 ± 27 *</td>
<td>2.425</td>
<td>137.6</td>
<td>145.8</td>
<td>0.945</td>
</tr>
<tr>
<td>DMI</td>
<td>7.9 ± 7 ns</td>
<td>1.24 ± 0.3 ***</td>
<td></td>
<td>2.586</td>
<td>148.7</td>
<td>156.0</td>
<td>0.946</td>
</tr>
<tr>
<td>Mid Multi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lnDMI</td>
<td>-171 ± 56 **</td>
<td>-3.6 ± 1.6 *</td>
<td>91 ± 29 **</td>
<td>1.517</td>
<td>127.3</td>
<td>136.1</td>
<td>0.973</td>
</tr>
</tbody>
</table>

*a* Name of models from specific data set, where Early = 1 to 100 DIM, Mid = 101 to 200 DIM, Primi = primiparous, Multi = multiparous

*b* P values shown by *** = $P \leq 0.001$, ** = $0.001 > P \leq 0.01$, * = $0.01 > P \leq 0.05$, $t = 0.05 > P \leq 0.1$, ns = $P > 0.1$

*c* DMI = Dry matter intake (kg/d)

d RMSE = root mean square error

*e* AIC = Akaike’s information criteria

*f* BIC = Bayesian information criteria

$g$ $R^2_{\beta}$ = R-squared for mixed model
3.3 Paper 3
“Responses in live weight gain to net energy intake in dairy cows”
(Manuscript intended for submission to Livestock Science)
Responses in live weight gain to net energy intake in dairy cows

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1. Introduction

Prediction of the response in live weight gain of lactating dairy cows to increased energy intake level is relevant for ration optimization and feeding economics. Economic optimization of the ration energy level to lactating cows is important and has gained focus by fluctuations in feed and milk prices during recent years. Although the actual energetic value of the live weight change response is numerically small compared to the milk production response, the change in tissue mobilization and later deposition in early lactation is of both direct and indirect economical importance. Furthermore, the excessive negative energy balance that the majority of dairy cows go through during early lactation can cause serious health problems (Collard et al., 2000) and is claimed to be the main cause of decline in fertility (Walsh et al., 2011).

However, published data on live weight change responses to energy intake levels in lactating dairy cows are sparse. Comparable estimates for these responses are difficult to derive from literature because of the individual trials being on different parities, covering different lactation periods, with different breeds and based on different energy evaluation systems. A review by Coulon and Rémond (1991) evaluated 66 feeding trials from 1956 to 1991 with three feeding levels for primiparous or multiparous cows. They found during early lactation (week 8 to 13 of lactation) for the primiparous cows on low and mid feeding level a negative live weight change and on high feeding level a positive live weight change. For the multiparous cows the live weight change was negative on low, mid and high feeding levels, with the weight loss being highest on low feeding level and lowest on high feeding level. From more recent times two trials have shown the same pattern for the live weight changes to different feeding levels. For primiparous cows during early lactation (week 2 to 15 of lactation) the live weight gain was positive at high energy intake level and negative at low energy intake level but no breed differences in live weight gain were found between Holstein-Friesian and Norwegian cows (Yan et al., 2006). A less negative live weight gain was found for multiparous cows during first 8 weeks of lactation.
and during week 9 to 16 of lactation a higher positive live weight gain was found at high compared to low energy intake levels (Andersen et al., 2003).

In previous production responses estimation of live weight changes was done by residual calculation as total energy intake subtracted energy for maintenance and milk production and a correction according to decreased feed efficiency at increased energy levels (Andersen, 1998). Recently a method for estimation of EB solely from changes in BW measured automatically at milking has been developed (Thorup et al., 2013). New updated production response functions for LW change are required to enable the economic optimization of the energy level. Furthermore, use of semi-mechanistic non additive feed planning system like the Nordic Feed Evaluation System (NorFor), which has been implemented in Denmark, Iceland, Norway and Sweden (Volden and Gustafsson, 2011) increases the need for new updated LW responses fitted to the actual energy evaluation system.

In early lactation the typical LW curve includes both a mobilization and a deposition period which makes it complicated to quantify the LW change during the early lactation period. Furthermore, daily LW measurements in cows are highly variable due to rumen and gut fill or relative time to milking. To address this in our study we fitted time series LW curves at the individual cow level and analyzed the energy intake and LW change relationship at different days after calving. The objective of this analysis was to estimate the effect of increased energy intake on daily live weight changes during the first 100 days of lactation of primiparous and multiparous cows.

2. Materials and methods

2.1. Dataset

A data set with 78 treatment mean observations was compiled from original data of 6 trials from Denmark, Norway and Sweden. Prerequisites for a trial to be included in current analysis were that cows were fed ad libitum, the planned ration energy densities were independent of individually recorded milk yields, and that various energy levels were planned within each trial. Further, the trial period should cover most of early lactation stage from 1 to 100 DIM. Trials were all continuous design and were conducted in the years 1998 to 2009 at research centers with registrations at individual cow level of feed intake of all offered feed, milk yield and LW. Breeds were Danish Holstein (DH) (46 %), Norwegian Red (NR) (46 %) and Swedish Red (SR) (8 %). The data were grouped into sub datasets according to parity; either primiparous (Primi) or multiparous (Multi). Summary of trials included in the data set is shown in Table 1.

Feeding principles in trials were TMR, partly mixed rations or separate feeding. Roughages were silages of grass, grass clover, corn, whole crop barley, or ammonia treated straw. Concentrates were various combinations of barley, oats, rapeseed cake, peas, dried beet pulp, molasses, or urea. Concentrate share in rations varied from zero to 85% on DM basis. Feed ration characteristics are shown in Table 2.

Treatment mean data from two additional trials were used as supplemental data sets for this analysis as our study period from parturition to day 100 was only covered partly by these two trials (Table 1). In the two trials DIM were from zero to 56 and from 20 to 70, respectively. The short trial periods were due to subsequent changes in feeding levels within treatments.
2.2. Calculation of energy intake and milk production

Energy values of all feed rations used in the trials were calculated by use of NorFor to obtain consistent energy expression in data opposed to the varying feed evaluation systems used in original analysis of trials. Input of animal parameter values to NorFor were breed, parity, activity (loose or tied barn system) and treatment mean for LW (mean of first and last LW of each cow in trial period) and DIM. Input of feedstuff parameter values to NorFor were chemical analyses of individual feedstuffs whenever available, otherwise appropriate feed table values (NorFor Feedtable, 2012) were used. Silage OM digestibility was determined either in vivo with sheep fed at maintenance or in vitro using rumen fluid (Tilley and Terry, 1963) and subsequent recalculated to in vivo according to NorFor (Åkerlind et al., 2011). Content of iNDF was determined either in sacco or by near infrared spectroscopy (Åkerlind et al., 2011). If iNDF contents were absent, values were estimated from feed table values on iNDF to NDF ratio. Supply of energy and protein from the feed rations was calculated from NorFor as NEL, amino acids absorbed in small intestine (AAT) and protein balance in the rumen (PBV) (Volden and Nielsen, 2011; Volden and Larsen, 2011). Ration concentration of nutrients were calculated as the ratio of total intake in grams per total NEL intake in MJ. Daily yield of energy corrected milk (ECM, 3.14 MJ/kg) was calculated from milk yield and milk composition according to Sjaunja et al. (1991). Animal characteristics, production and feed intake for treatment mean data of primiparous and multiparous cows are shown in Table 3.

2.3. Calculation of live weight gain

In every trial used for this analysis LW was registered by weighing of cows during trial periods. For each trial and parity of cows linear live weight curves were estimated from the individual cow weight registrations available during the trial periods corresponding to the periods for calculation of mean NEL intake. A random regression model was used to determine a LW curve for each cow by fixed linear and quadratic effects of DIM and random effects of cow and DIM. The model used was:

$$LW_{ij} = \beta_0 + \beta_1 \text{DIM}_{ij} + \beta_2 \text{DIM}^2_{ij} + b_i + \epsilon_{ij}$$

with LW$_{ij}$ as the average LW for the $i$th cow and the $j$th treatment, $\beta_1$ and $\beta_2$ as fixed effect of DIM$_i$ and DIM$^2_i$, $b_i$ as random intercept of cow and random regression coefficient of DIM and $\epsilon_{ij}$ as residual error values with $b_i \sim N(0, \sigma^2_i)$ and $\epsilon_{ij} \sim N(0, \sigma^2)$. The smoothing by linear regression was done to obtain similar LW estimates across trials with different frequency in LW registrations and length of trial periods. A quadratic DIM term was included to account for the trial periods in early lactation with both mobilization and deposition. Daily gain (DG) for each cow was then calculated as the difference in LW at DIM$_n$ and DIM$_{n+1}$ where $n$ was set to 30, 60 or 90, respectively. Finally treatment means for DG at DIM 30 (DG30), DG at DIM 60 (DG60) and DG at DIM 90 (DG90) were calculated within each trial and parity.

2.4. Statistical analysis and parameter estimation

The relationship between average daily net energy intake (NEL) during 0 to 100 DIM and DG was analyzed separately for parity (primiparous and multiparous) and stage of lactation (DIM 30, 60 and 90).
Separate analyses for 30, 60 and 90 DIM allowed a test for effect of NEL during 0 to 100 dim on DG at different phases regarding mobilization and deposition rather than just based on the difference in LW between 0 and 100 DIM.

Data were analyzed using linear mixed effects model procedure in “nlme” package (Pinheiro et al., 2012) in R (R Core Team, 2013). Trials were used as random effect. Residuals were weighted by number of cows in each treatment mean. The model used was:

\[ \text{DG}_{ij} = \beta_0 + \beta_1 \text{NEL}_{ij} + \beta_2 \ln(\text{NEL}_{ij}) + b_i + \varepsilon_{ij} \]

with DG$_{ij}$ as the average DG for the $i^{th}$ trial and the $j^{th}$ treatment, $\beta_1$ and $\beta_2$ as fixed effect of NEL$_{ij}$ and ln(NEL$_{ij}$), $b_i$ as random intercept effect of trial and $\varepsilon_{ij}$ as residual error values with $b_i \sim N(0, \sigma^2_i)$ and $\varepsilon_{ij} \sim N(0, \sigma^2)$. To represent a curvilinear relationship between NEL and DG, the ln(NEL) term was chosen over a quadratic term based on best model fit. Relevant variables of nutrient intake were tested for inclusion as linear fixed effects and with interaction to NEL intake in the above model by individual screening of the nutrient variables. With the different breeds represented in the analysis a fixed effect of breed and the interaction to NEL was also tested.

Data of DG at DIM 30 from the supplemental data set were analyzed using the same regression model as above with random effect of trial and residual weighting of number of cows in each treatment mean. The allocation of cows of different breeds (DH, DR and DJ) in these trials allowed an analysis of breed intercept differences and interactions to NEL intakes.

Following all statistical analyses a visual examination of residual plots was used to assess normality of residuals and homogeneity of variance. All model reduction was based on Chi-square tests, Akaike Information Criterion (AIC) and Bayes Information Criterion (BIC).

### 3. Results

There was a considerable variation in treatment means for feed intake and production level used for the analysis (Table 3). For primiparous and multiparous cows mean NEL intake were 116 MJ (ranged 75 to 154 MJ) and 138 MJ (ranged 95 to 171 MJ); mean DMI were 18.0 kg (ranged 12.2 to 22.7 kg) and 21.6 kg (ranged 15.7 to 26.0 kg); mean ECM were 25.6 kg (ranged 15.3 to 34.1 kg) and 31.9 kg (ranged 20.8 to 39.2 kg), respectively. Mean DG$_{30}$ were -0.37 kg (ranged -1.35 to 0.58 kg) and -0.38 kg (ranged -1.02 to 0.21 kg); mean DG$_{60}$ were 0.06 kg (ranged -0.48 to 0.54 kg) and 0.03 kg (ranged -0.41 to 0.36 kg); mean DG$_{90}$ were 0.48 kg (ranged 0.04 to 0.16 kg) and 0.44 kg (ranged -0.26 to 0.78 kg).

Regression models predicting DG at DIM 30, 60 or 90 as linear (NEL) or curvilinear (NEL + ln(NEL)) functions are presented in Table 4. For multiparous cows the curvilinear models were all superior to the linear model by lower AIC and BIC values and significant chi-square tests. The same model reduction was seen for the primiparous cows except for DG prediction at DIM 30 with only a tendency for significant chi-square test ($p=0.07$) for elimination of ln(NEL) term. In Figure 1 is shown the predicted DG based on ‘NEL+ln(NEL)’ models to increased NEL intake for primiparous and multiparous cows. For all prediction models there was an increasing DG with increased NEL intake. For both parities DG at DIM 30 was below zero, whereas DG at DIM 90 was above zero within the NEL intake range. For both parities
DG at DIM 60 and 90 were higher than at DIM 30 with DG at DIM 90 being highest. At mean NEL intake level for primiparous cows (116 MJ) the DG at DIM 30, 60 and 90 were -0.157, 0.137 and 0.435 kg, respectively and for multiparous cows at mean NEL intake (138 MJ) the DG at DIM 30, 60 and 90 were -0.215, 0.098 and 0.413 kg, respectively.

There was no effect of including any of the nutrient intake variables as total intake in grams or as intake in grams per MJ NEL (CP, AAT, NDF, crude fat, fatty acids, starch or sugar) in the statistical models and neither any interaction between single nutrients and NEL intake. There was no effect of Breed when included to the models, and no interactions between NEL intake and breeds.

The marginal DG responses from the curvilinear DG prediction models decreased for primiparous and multiparous to increased NEL intake with primiparous cows having a more rapid decrease than the multiparous cows (Figure 2). For primiparous cows at mean NEL intake (116 MJ) the marginal DG response at DIM 30, 60 or 90 was 0.005, 0.004 and 0.004 kg/MJ, respectively. For multiparous cows at mean NEL intake (138 MJ) the marginal DG response at DIM 30, 60 or 90 was from 0.010, 0.006 and 0.002 kg/MJ, respectively.

From the supplementary data set regression estimates of DG at dim 30 were reduced to linear responses to increased NEL intake, as the curvilinear estimates were highly non significant. For primiparous and multiparous cows the slope of DG at DIM 30 was 0.006 kg per MJ NEL intake (p=0.15 and p=0.10) and the DG responses were below zero within the NEL intake range of the supplementary data set (Results not shown). There were no breed differences regarding intercepts or interactions to NEL intake for neither primiparous nor multiparous cows. In Figure 3 is shown the predicted daily gain at DIM 30 increased NEL intake for primiparous and multiparous cows from total dataset in comparison with supplemental data set.

4. Discussion

**Linear vs. curvilinear response curves for daily gain at dim 30, 60 and 90**

The DG response to increased NEL intake in early lactation had a curvilinear shape. The curvilinear term in the DG regression from the ‘NEL+ln(NEL)’ model was significant (p<0.05) in both parities and at DIM 30, 60 and 90. Only exception was for primiparous cows at DIM 30 where there was only a tendency for curvilinear response (p=0.09). However when deciding on best fit model based on the AIC and BIC values, the curvilinear response functions had lowest values in all cases compared to linear responses. Assuming a diminishing effect of NEL intake we chose ‘NEL+ln(NEL)’ to model the curve. The diminishing marginal DG implies that the effect of extra NEL intake is larger at a low NEL intake level than high level.

**DG responses in primiparous vs. multiparous cows**

The predicted DG responses based on the regression estimates from curvilinear models all increased to increased NEL intake (Figure 1), though between parity the response curves had different shapes. Regardless of DIM the DG were lower for the multiparous cows at minimum NEL intake levels than for the primiparous cows and further more the DG were negative. However, at high NEL intake
levels the DG at DIM 30 and 60 were higher for the multiparous cows than the primiparous cows where as DG at DIM 90 were similar for both parities. Generally the multiparous cows had larger responses to increased energy intake levels throughout early lactation than the primiparous cows likewise other studies (Coffey et al., 2004; Friggens et al., 2007) where multiparous cows typically mobilized more compared to primiparous cows when offered the same ration. Particularly, for the multiparous compared to primiparous cows at DIM 30 there was found a larger increase in DG compared to DIM 60 and 90.

Level of DG response to increased net energy intake

The DG responses for primiparous cows were from -0.67 to +0.08 kg/d and for multiparous cows from -0.11 to +0.45 kg/d at a minimum and maximum NEL intake level, respectively. There were large ranges of DG at minimum or maximum NEL intake levels due to the specific response estimates at DIM 30, 60 or 90. A few studies have reported live weight changes to different energy intake levels during corresponding stages of lactation. In Figure 4 is shown literature values of average DG results to a given energy intake level together with the predicted DG responses at DIM 30, 60 and 90 from our analysis. Yan et al. (2006) examined possible differences in energy partitioning to body tissue in primiparous Holstein-Friesian and Norwegian dairy cows on a low or high concentrate diet. During lactation week 2 to 15 for Holstein-Friesian and Norwegian cows they found live weight changes of -0.24 and -0.13 kg/d on low concentrate diets (158 and 149 MJ ME), respectively. At high concentrate diets (200 and 183 MJ ME) they found live weight changes of 0.15 and 0.28 kg/d for the Holstein-Friesian and Norwegian cows, respectively. However, as the energy intake was given as metabolizable energy a conversion of ME to NE \[NE = 0.76 \times ME\] (McDonald et al., 1995) was done. Comparing these results from week 2 to 15 to the DG response at DIM 60 the LW losses at the low energy levels were below whereas at the high energy level DG results were at same level of DG response.

For multiparous cows Andersen et al. (2003) examined the performance of DH cows in early lactation on a low or high concentrate diet. From parturition to week 8 of lactation cows on diet low (110 MJ NE) and high (144 MJ NE) had different LW loss of -61 and -56 kg, respectively and during lactation week 9 to 16 cows on diet low (127 MJ NE) and high (169 MJ NE) had different LW gain of 8 and 23 kg, respectively. At high compared to low energy intake levels they found less LW loss and higher LW gain during first period and following period, respectively. Contrary to our increased DG response at DIM 30 they found LW losses averaging approximately 1 kg/d at both low and high energy levels (Figure 4). However, their LW gains during week 9 to 16 were similar to our DG response at DIM 90.

DG responses from supplemental data

Supporting the estimates of DG at DIM 30 for primiparous and multiparous cows the supplemental data set showed increasing DG with increased NEL intake and also a difference in level between the parities.

The linear DG responses from supplemental data in comparison to the curvilinear DG responses from total data set are shown in Figure 3. There was no significant curvilinear response in supplemental data as the range of the NEL intake was narrow and for supplemental data calculated as mean across
DIM zero to 56 as opposed to DIM zero to 100 for main data in this analysis. Further NEL intake of supplemental data was within the range in main dataset, with primiparous cows having NEL intake range to the lower side and multiparous cows in the mid of main data set. However both the levels and slopes of DG from supplemental data are in line with DG response curve at DIM 30 for primiparous and multiparous cows.

**Effects of breed on DG response**

The partitioning of energy between milk and body tissue is genetically driven (Friggens and Newbold, 2007) and dairy cows selected primarily for higher milk production also partition less energy into body tissue than do low genetic merit cows (Agnew and Yan, 2000). From this there is reason to expect the growth responses to differ between the breeds in our study. However, with the data available we found no effects of breed on the DG estimates or interaction of breed to the energy intake level. Likewise, there was found no breed differences during early lactation (week 2 to 15) in the trial on energy partitioning within Holstein-Friesian and Norwegian cows (Yan et al., 2006), where the Norwegian cows were comparable with the NR in this study. Contrary the energy balance patterns among the breeds DH, DJ and DR showed significantly higher mobilization of body energy of DH in early lactation compared to DJ and DR (Friggens et al., 2007). These three breeds were also represented in the supplemental data set wherefore the lack of breed effect (Figure 3) was unexpected but possibly due to the low number of observations.

5. **Conclusion**

In this analysis of LW changes in production trials from Denmark, Norway and Sweden empirical prediction models of DG at DIM 30, 60 and 90 were developed specifically to primiparous and multiparous cows. The DG responses to NEL intake level was increasing curvilinear at a decreasing rate for both parities. Though, multiparous cows had larger LW losses at low NEL intake but also a larger response to increased NEL intake than primiparous cows. The LW change to increased NEL intake of multiparous cows at DIM 30 was higher than at DIM 60 and 90 with DG at DIM 90 being lowest. The prediction models included only effect NEL intake as there was no effects of any ration nutrients. In this analysis it was not possible to find any differences in DG estimates between Holstein, Red and Jersey breed.

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**References**


Table 1
Summary of trials included in data set.

<table>
<thead>
<tr>
<th>Year</th>
<th>Design</th>
<th>Cows</th>
<th>Breed</th>
<th>Feeding</th>
<th>Source of silage</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>Block</td>
<td>63</td>
<td>DH</td>
<td>18</td>
<td>TMR</td>
<td>Grass / Whole crop / NH₃-straw Kristensen et al., 2003</td>
</tr>
<tr>
<td>1999</td>
<td>Block</td>
<td>63</td>
<td>DH</td>
<td>18</td>
<td>TMR</td>
<td>Grass / Whole crop / NH₃-straw Kristensen et al., 2003</td>
</tr>
<tr>
<td>1998</td>
<td>Block</td>
<td>36</td>
<td>NR</td>
<td>6</td>
<td>SEP</td>
<td>Grass Schei et al., 2005</td>
</tr>
<tr>
<td>2001</td>
<td>Long term</td>
<td>19</td>
<td>NR</td>
<td>8</td>
<td>SEP</td>
<td>Grass Steinshamn et al., 2004</td>
</tr>
<tr>
<td>2007</td>
<td>Block</td>
<td>66</td>
<td>NR</td>
<td>22</td>
<td>SEP</td>
<td>Grass Randby et al., 2012</td>
</tr>
<tr>
<td>2006⁴</td>
<td>Long term</td>
<td>191</td>
<td>DH</td>
<td>6</td>
<td>PMR</td>
<td>Grass + Corn Bossen et al., 2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DR</td>
<td>6</td>
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<td></td>
<td>DJ</td>
<td>6</td>
</tr>
<tr>
<td>2006⁴</td>
<td>Block</td>
<td>87</td>
<td>DH</td>
<td>8</td>
<td>PMR</td>
<td>Grass + Corn Weisbjerg and Munksgaard, 2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DR</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DJ</td>
<td>7</td>
</tr>
</tbody>
</table>

⁴DH = Danish Holstein, DR = Danish Red, DJ = Danish Jersey, NR = Norwegian Red, SR = Swedish Red

⁵n = number of observations (treatment means)

⁶TMR = Total mixed ration, PMR = partly mixed ration with roughage ad lib and concentrate restricted, SEP = separate feeding of roughage and concentrates

⁷Trial only used as supplemental data for estimates of daily gain at DIM 30
Table 2

Feed ration characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ration DM (%)</td>
<td>51</td>
<td>17</td>
<td>30</td>
<td>87</td>
</tr>
<tr>
<td>OMD (^a) (%)</td>
<td>75</td>
<td>2</td>
<td>69</td>
<td>80</td>
</tr>
<tr>
<td>NDFD (^b) (%)</td>
<td>63</td>
<td>7</td>
<td>52</td>
<td>80</td>
</tr>
<tr>
<td>Concentrate share (%)</td>
<td>48</td>
<td>20</td>
<td>0</td>
<td>85</td>
</tr>
<tr>
<td>CP (g/kg DM)</td>
<td>170</td>
<td>20</td>
<td>135</td>
<td>226</td>
</tr>
<tr>
<td>Crude fat (g/kg DM)</td>
<td>34</td>
<td>6</td>
<td>24</td>
<td>47</td>
</tr>
<tr>
<td>NDF (g/kg DM)</td>
<td>382</td>
<td>59</td>
<td>277</td>
<td>520</td>
</tr>
<tr>
<td>Starch (g/kg DM)</td>
<td>150</td>
<td>64</td>
<td>0</td>
<td>259</td>
</tr>
<tr>
<td>Sugar (g/kg DM)</td>
<td>59</td>
<td>38</td>
<td>11</td>
<td>140</td>
</tr>
</tbody>
</table>

\(^a\) OMD = apparent total digestibility of organic matter, NorFor estimate

\(^b\) NDFD = apparent total digestibility of NDF, NorFor estimate
Table 3
Animal characteristics, production and daily intake for primi- and multiparous cows in early stage of lactation (DIM 1 to 100).

<table>
<thead>
<tr>
<th>Animal characteristics</th>
<th>Primiparous (n(^a) = 39)</th>
<th>Multiparous (n = 39)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>DIM(^b)</td>
<td>60</td>
<td>3</td>
</tr>
<tr>
<td>BW (kg)</td>
<td>532</td>
<td>46</td>
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<tr>
<td>DG30 (kg/d) (^c)</td>
<td>-0.37</td>
<td>0.4</td>
</tr>
<tr>
<td>DG60 (kg/d) (^c)</td>
<td>0.06</td>
<td>0.2</td>
</tr>
<tr>
<td>DG90 (kg/d) (^c)</td>
<td>0.48</td>
<td>0.2</td>
</tr>
<tr>
<td>Animal production (kg/d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECM</td>
<td>25.6</td>
<td>4.7</td>
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<tr>
<td>Milk yield</td>
<td>26.0</td>
<td>4.8</td>
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<tr>
<td>Intake</td>
<td></td>
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</tr>
<tr>
<td>DM (kg/d)</td>
<td>18.0</td>
<td>2.5</td>
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<tr>
<td>ME (MJ/d)</td>
<td>193</td>
<td>28</td>
</tr>
<tr>
<td>NEL (MJ/d)</td>
<td>116</td>
<td>17</td>
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</tbody>
</table>

\(^a\) n = number of observations (treatment means)
\(^b\) DIM for a treatment group is the mean of the trial period
\(^c\) DG = daily live weight gain (kg) calculated at DIM 30, 60 or 90, respectively
Table 4
Parameter estimates of daily live weight gain at DIM 30 (DG$_{30}$), DIM 60 (DG$_{60}$) and DIM 90 (DG$_{90}$) for primiparous or multiparous cows

<table>
<thead>
<tr>
<th>Response</th>
<th>Fixed effect</th>
<th>Intercept</th>
<th>SE</th>
<th>P-value</th>
<th>$X_1$</th>
<th>SE</th>
<th>P-value</th>
<th>$X_2$</th>
<th>SE</th>
<th>P-value</th>
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<th>BIC</th>
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<tr>
<td>DG$_{30}$</td>
<td>NEL</td>
<td>-1.2</td>
<td>0.4</td>
<td>0.002</td>
<td>0.008</td>
<td>0.002</td>
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<td>43.2</td>
<td>49.7</td>
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<td>DG$_{30}$</td>
<td>NEL + ln(NEL)</td>
<td>-14.2</td>
<td>7.4</td>
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<td>NEL</td>
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<td>0.004</td>
<td>0.007</td>
<td>0.002</td>
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<td>NEL + ln(NEL)</td>
<td>-12.1</td>
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<td>-0.02</td>
<td>0.01</td>
<td>0.07</td>
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<td>NEL</td>
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<td>NEL + ln(NEL)</td>
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<td>NEL</td>
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<td>0.01</td>
<td>0.002</td>
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<td></td>
<td>10.4</td>
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<td>NEL + ln(NEL)</td>
<td>-20.2</td>
<td>8.2</td>
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<td>-0.02</td>
<td>0.02</td>
<td>0.14</td>
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<td>0.001</td>
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<td></td>
<td></td>
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<td>4.7</td>
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<td>0.002</td>
<td>5.2</td>
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<td>NEL</td>
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<td>0.001</td>
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<td></td>
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<td>0.01</td>
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<td>1.2</td>
<td>0.000</td>
<td>-37.9</td>
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Figure 1. Predicted daily gain (DG) in kg in response to increased NEL intake in MJ for primiparous and multiparous cows based on regression model with NEL and ln(NEL) as fixed effects. The three curves represent DG at DIM 30 (---), 60 (―) and 90 (∙∙∙).
Figure 2. Marginal daily gain (MR_DG) response (kg/d) to net energy intake (MJ) for primiparous and multiparous cows based on regression model with NEL and ln(NEL) as fixed effects with MR_DG at DIM 30 (---), 60 (―) and 90 (∙∙∙).
Figure 3. Predicted daily gain at DIM 30 (DG_30) in kg to increased NEL intake in MJ for primiparous and multiparous cows from total dataset (—) and from supplemental data set (---). Observations from supplemental data set are shown by breed.
Figure 4. Literature values of average results of DG to a given energy intake level together with the predicted DG responses at DIM 30, 60 and 90 from our analysis.
3.4 Paper 4
“Analysis of milk response to energy intake within and between commercial dairy herds”
(Manuscript intended for submission to Livestock Science)
Milk responses to energy intake estimated within and between commercial dairy herds
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Keywords: commercial dairy herds, energy intake, milk response, within herd

1. Introduction
Information about the amount of milk produced relative to the amount of feed offered in a dairy herd is important for monitoring the production efficiency and eventually for adjusting the feeding. It is well established knowledge that there is a positive response in milk production to increased net energy intake yet with a diminishing marginal milk response (Blaxter, 1966; Moe and Tyrrell, 1975). The decrease in marginal response is due to both a decrease in feed efficiency and a shift in the energy partitioning towards more body tissues and less milk production, and where the magnitude of the decrease in efficiency depends on the energy and feed evaluation system (Coulon and Rémond, 1991).

Milk and feed prices have been varying between herds, year and season in recent years, and with feed constituting the largest variable cost in the dairy production this motivates an economical optimization of the feeding level offered to the milking cows in the individual herd. Therefore, knowledge on the marginal milk production response to an increased energy intake is needed. Within a herd a good prediction of the marginal milk response is more important than the actual milk production when maximizing the profit (Blaxter, 1966).

The current feed evaluation and ration planning system in the Nordic countries is NorFor (Volden, 2011), to which a tool for economic optimization of the energy level is being developed including new milk response functions (Jensen et al., submitted) [Paper 2] for cows in early lactation to fit the mechanistic non-additive models in NorFor. Systematic recording of milk production data have a long tradition. Today 90 % of Danish dairy herds have regularly registration of milk, fat and protein yield, for the individual cow. These recordings along with data for feed and nutrient management, health and reproduction and breeding are gathered in the National Central Danish Cattle Database constituting a comprehensive data set with unique identification of herds and individual cows. This allow for studies on the relationship between energy intake and milk production on field data from commercial dairy herds.

Frequent one-day recording of milk production and feed intake producing a one-day feeding control is commonly used by the dairy herds. The Dairy Management System (DMS) developed during
the last years in Denmark (Anonymous, 2013) is used by the dairy farmers and the farm advisors to optimize nutrients in ration formulations and evaluate feeding efficiency. This system provides a frame for recordings of a large amount of consecutive data within each herd on performance in terms of milk production and energy intake which can be combined with specific information on the individual cows as e.g. breed, DIM and parity. Registrations of feed intake are made on group or herd level with the exception for concentrate intake in automatic milking systems (AMS) or from separate concentrate feeding in stationary feeders. Evaluations of the milk response to feed intake are therefore in commercial dairy herds based on the mean feed intake for the groups of milking cows. Repeated registrations enable analysis of the relationship between milk production and energy intake within a herd and between herds for a large sample of commercial dairy herds. Providing such analysis on both within herd and between herd relationships, and analysis on factors responsible for the deviations between predicted and observed relationships may be valuable for evaluating data on relationship for the feeding and production management in a dairy herd. Further the analysis of within herd milk response to energy intake is valuable for evaluating the perspective of how to apply and interpret herd specific responses estimated on data from the herd itself as opposed to using a general milk response function.

The objectives of this analysis were 1) to study possible factors causing a deviance in predicted ECM production from actual ECM registered in commercial herd data and 2) to evaluate ECM responses to energy intake in commercial dairy herds using either between herds or within herds data.

2. Material and methods

2.1. Commercial herd data

Recordings of feed intake and milk production in commercial dairy herds are used to evaluate feed efficiency by the extension service and are uploaded to the DMS, making it possible to compile a large number of data representing dairy feeding in Denmark. The total number of feeding evaluation records (FER) made during the period from December 2012 through November 2013 was 4,322 and after filtering 2,580 recordings representing 728 herds with a mean of 3.5 FER per herd (ranging from 1 to 18) constituted the DMS data used in the analysis. In the filtering process in total 1,742 FER were deleted either to accomplish prerequisites of data regarding loose housing, no feed ration including grazing and no cross breed herds [1,196 FER] or to have no FER less than 8 days before next FER, no FER from groups of predominantly primiparous cows, no FER with missing data on DIM and no FER from herd used for education [531 FER] or to minimize dubious data by extreme nutrient intake values [15 FER].

Herds were grouped in three breed categories based on the main proportion of genes in the herd, with Danish Holstein (DH) defined by more than 80 % of genotypes being DH and similar for Danish Red (DR), and Danish Jersey (DJ). There were 561 DH, 42 DR and 125 DJ herds. During the period of registration all cows were housed indoor in loose housing system, typically cubicle stables with slatted floor. The milking system was automatic milking system (AMS) in 30 % of the herds, and production system was organic in 8 % of the herds. The FERs were made on groups of milking cows only, of which mean group size ranged from 161 to 238 cows and primiparous cows constituted on average 39 %
(ranging from 21 to 65%). The stage of lactation was on average 196 DIM (ranging from 135 to 272 days).

The total daily milk production, and content of fat and protein, delivered to the dairy factory corrected for usage of milk to calves etc. at the farm was obtained in DMS. From this information on group milk production, daily mean energy corrected milk (ECM, 3.14 MJ/kg) per cow was calculated as described by Sjaunja et al. (1991). Also for each FER the mean herd milk recording per year (kg ECM) was given. Cows were fed total mixed or partial mixed feed rations. Information on feeding was daily amount (kg) of each feed ingredient supplied to the group of lactating cows measured by a scale at the mixer wagon, and composition and feed value of each feed item was based on either feed analysis of the actual batch in commercial feed labs using NIR (most forages), information from the trader (commercial concentrate mixes), or standard values from feed tables (concentrates). The energy value of the ration in MJ net energy lactation (NEL) and ration nutrient content, fill value and chewing time in the rations were calculated by the DMS using NorFor (Volden, 2011).

Descriptive characteristics of data based on mean values of herds for DH, DR and DJ are presented in Table 1 and is in the following referred to as between herd data used for analysis on deviance in ECM prediction. The mean ECM (kg/d) was 30.6 (ranged 20.9 to 42.6), 27.9 (ranged 18.7 to 32.1) and 29.8 (ranged 24.1 to 34.7) for herds of DH, DJ and DR, respectively. The mean NEL intake (MJ/d) was 146 (ranged 113 to 182), 122 (ranged 103 to 144) and 142 (ranged 125 to 163) for herds of DH, DJ and DR, respectively. The mean DIM (days) for the lactating cows was 198 (ranged 137 to 272), 193 (ranged 153 to 250) and 185 (ranged 135 to 224) for herds of DH, DJ and DR, respectively. For herds with repeated FERs the range (maximum – minimum) value for variables on production, intake and stage of lactation of herds for DH, DR and DJ are given in Table 2.

### 2.2. Calculation of predicted ECM and the deviance to actual ECM production for commercial herd data

The predicted ECM production, using the between herd data set, was based on response model estimates derived from production trials of lactating cows in early lactation (Exp$_{model}$) (Jensen et al., submitted). The continuous independent variables in the model were net energy intake as NEL intake in MJ per cow per day and the ration nutrient concentration of neutral detergent fiber (NDF$_{NEL}$), of amino acids absorbed in the small intestine (AAT$_{NEL}$) and of crude fat (CFat$_{NEL}$) given in g per MJ NEL. The nutrients were given as ration concentrations rather than total intake to minimize correlation between NEL intake and respective nutrient intake. Breed was included in the model as a categorical variable [DH, DR or DJ]. For primiparous cows the prediction model was: ECM$_{primi}$ = -22.4 + 0.111*NEL + 6.6*ln(NEL) + 0.041*NDF$_{NEL}$ + 0.036*AAT$_{NEL}$ + 0.544*CFat$_{NEL}$, with breed specific intercept values relative to DH of -2.8 for DR and 0.32 for DJ. For the multiparous cows the prediction model was:

ECM$_{multi}$ = -224 + 0.247*NEL + 56.2*ln(NEL) + 0.106*NDF$_{NEL}$ + 0.402*AAT$_{NEL}$ + 0.760*CFat$_{NEL}$,

with breed specific intercept values relative to DH of -3.6 for DR and -3.3 for DJ.

The between herd data set was adjusted to fit the input to the Exp$_{model}$ by estimating NEL intake separately for primiparous (NEL$_{primi}$) and multiparous (NEL$_{multi}$) cows given the mean NEL intake of all
lactating cows in each herd. It was assumed that primiparous cows had a 20% lower feed intake than multiparous cows (Kristensen et al., 2003). Therefore the equations used were: \(\text{NEL}_{\text{multi}} = \text{NEL} / (0.8 + \text{Multi} \times 0.2)\) and \(\text{NEL}_{\text{primi}} = \text{NEL}_{\text{multi}} \times 0.8\).

Then the \(\text{Exp}_{\text{model}}\) estimates of primiparous and multiparous cows were applied to \(\text{NEL}_{\text{primi}}\) and \(\text{NEL}_{\text{multi}}\) to predict the ECM\(_{\text{primi}}\) and ECM\(_{\text{multi}}\). The mean ration nutrient concentrations were assumed equal independently of parity distribution among group of cows. A correction of breed was made according to the mean genetic ratio of the breeds DH, DJ, DR or crossbreed (CR) in the herd, where it was assumed that CR was made up of 1/3 of each of the other three breeds.

Finally the predicted ECM (ECM\(_{\text{Exp-model}}\)) from using \(\text{Exp}_{\text{model}}\) for each herd was calculated by applying the parity ratio of primiparous (Primi) and multiparous (Multi) cows in the herd by the equation: \(\text{ECM}_{\text{Exp-model}} = \text{ECM}_{\text{primi}} \times \text{Primi} + \text{ECM}_{\text{multi}} \times \text{Multi}\). For each herd the deviance in predicted ECM to actual ECM produced was calculated as: \(\text{deviance}_{\text{ECM}} = \text{ECM}_{\text{Exp-model}} - \text{ECM}_{\text{actual}}\).

The analysis of the calculated deviance\(_{\text{ECM}}\) was made by linear regression of the deviance on the variables from \(\text{Exp}_{\text{model}}\) as well as supplementary variables from the herd data (i.e. DIM, parity ratio, DMI, concentrate share of ration (Conc_share), concentrate intake (Conc_DM), chewing index of ration (CI_DM), fill value of ration (FVL) or ration energy concentration (NEL_DM). Pearson correlation coefficients were calculated between deviance\(_{\text{ECM}}\) and each variable in the regression model for deviance\(_{\text{ECM}}\). Furthermore information on the production system (organic/conventional) and the milking system (AMS/milking parlour) were available in data and tested as categorical explanation variables of deviance\(_{\text{ECM}}\). The \(\text{Exp}_{\text{model}}\) applies to cows in early stage of lactation (DIM 1 – 100), therefore a simple linear regression analysis was made for the effect of DIM on deviance in ECM, as the difference in DIM between these data and data used for \(\text{Exp}_{\text{model}}\) were considerable. Residual plots from the simple linear regression showed the adjusted deviance in ECM by stage of lactation (Residual Deviances in ECM).

2.3. Estimating ECM responses using between and within herd data

ECM response models were made from the data, using either mean FER data for each herd (DMS-between\(_{\text{model}}\)) or using every individual FER data within each herd (DMS-within\(_{\text{model}}\)). The variables used for the ECM response functions were to match those of the \(\text{Exp}_{\text{model}}\) as a cause of relation. Thereby the continuous independent variables were NEL intake in MJ, ration nutrient concentration of NDF\(_{\text{NEL}}\), AAT\(_{\text{NEL}}\) and CFat\(_{\text{NEL}}\) given in g per MJ NEL. Breed was included in the models as categorical variable. Furthermore two independent continuous variables for mean stage of lactation (DIM) and mean ratio of primiparous cows (Primi-ratio) were included in the models. The regression model used for the DMS-between\(_{\text{model}}\) was:

\[
\text{ECM}_i = \beta_0 + \beta_1 \times \text{NEL}_i + \beta_2 \times \ln(\text{NEL}_i) + \beta_3 \times \text{NDF}_i + \beta_4 \times \text{AAT}_i + \beta_5 \times \text{CFat}_i + \beta_6 \times \text{DIM}_i + \beta_7 \times \text{Primi-ratio}_i + \beta_8 \times \text{Breed} + \varepsilon_i
\]  

where ECM\(_i\) is mean ECM from the FERs of the \(i\)-th herd, parameters \(\beta_0\) through \(\beta_8\) represent fixed effects associated with the intercept and the covariates in the model and \(\varepsilon_i\) is residual error values with
\( \varepsilon_i \sim N(0, \sigma^2) \). In the DMS-between model we also tested for interactions to NEL intake (DMS-between-int). There was no interaction between NEL and nutrient variables nor between NEL and primiparous ratio, but for the variables DIM and breed interactions to NEL were found.

For the function response based on the individual FERs of each herd a mixed regression model was used with same independent variables as in [1] and herd was used as random factor in order to model the correlation of FERs within same herd. The DMS-within model with random intercept and slope was:

\[
ECM_{it} = \beta_0 + \beta_1 \text{NEL}_{it} + \beta_2 x \ln(\text{NEL}_{it}) + \beta_3 \text{NDF}_{NEL_{it}} + \beta_4 \text{AAT}_{NEL_{it}} + \beta_5 \text{CFat}_{NEL_{it}} \\
+ \beta_6 \text{DIM}_{it} + \beta_7 \text{Primi-ratio}_{it} + \beta_8 \text{Breed} + b_0 + b_1 + \varepsilon_{it}
\]  

where ECM_{it} is ECM from the the t-th FER in the i-th herd, the parameters \( \beta_0 \) through \( \beta_8 \) represent the fixed effects associated with the intercept, the covariates and the interaction terms in the model, \( b_0 \) is random intercept and \( b_1 \) is random slope of i-th herd and \( \varepsilon_{it} \) is residual error values with \( \varepsilon_i \sim N(0, \sigma^2) \) and \( \varepsilon_{it} \sim N(0, \sigma^2) \). Again interactions between the independent variables and NEL intake were tested in interaction model of within herd data (DMS-within-int). There were no interactions between NEL intake and DIM, breed, primiparous ratio or the nutrients NDF_NEL and CFat_NEL, probably due to the smaller NEL intake range within each herd than in the overall NEL intake range in the between herd data. Only exception was an interaction between NEL and AAT_NEL. The regression analyses were made using the “nlme” package (Pinheiro et al., 2012) in R (R Core Team, 2013).

3. Results

3.1. Deviance in predicted ECM response of between herd data with Experimental prediction model

Applying Exp_{model} regression estimates to between herd data (mean of FER for each herd), resulted in predicted ECM responses that for the majority of herds were higher than the actual obtained ECM production. For DH the mean deviance in ECM was 4.1 kg (ranged -5.0 to 12.0 kg) and the same trend, though numerically lower, was found for DR and DJ with mean deviance in ECM of 1.1 kg (ranged -2.2 to 5.5 kg) and 1.8 (ranged -1.5 to 8.9 kg), respectively (Table 3). The deviance in ECM for DH, DR and DJ in relation to ECM production (kg/d) and NEL intake (MJ/d) are presented in Figure 1. The deviance in ECM decreased with increased ECM yield and was negatively correlated (\( r = -0.61^{***} \)) across all three breeds indicating an overestimation of predicted ECM at low ECM production levels (Table 3). There was no effect of NEL intake on deviance in ECM across all three breeds, however for the individual breeds DH and DR there were negative correlations (\( r = -0.39^{***} \) and \( r = -0.36^{*} \), respectively) between deviance in ECM and NEL intake; contrary to DJ with no correlation.

Stage of lactation for the milking cows in the herds was positively correlated to deviance in ECM (\( r = 0.34^{***} \)), where lower DIM values had lower deviances. From the linear regression including only DIM as independent variable to explain deviance in ECM across all three breeds the regression estimate of DIM (0.05) and intercept value (-6.2) resulted in a zero deviance in ECM at 125 days in milk (data not shown). Using the DIM variable, as sole independent variable, explained 11 % (R^2) of deviance in ECM. The residuals from this simple linear regression (Residual Deviance ECM) were plotted against ECM
(kg/d) or NEL intake (MJ/d) in Figure 2. Adjusting the stage of lactation according to the regression estimate of DIM the deviance in ECM was reduced to about zero at about 30 kg ECM/day.

The correlation analysis across all breeds between deviance in ECM and variables included in Exp_model showed positive correlations to NDF_NEL (r = 0.45*** and CFat (r = 0.07*) and negative correlation to AAT_NEL (r = -0.50***) indicating lower deviances with lower NDF ration concentration and lower deviances with higher AAT ration concentration. When testing other ration nutrients in data (i.e. crude protein, protein balance in rumen, starch or fatty acids) they had low correlations (r < 0.2) or no correlations to deviance in ECM (data not shown). Among the variables for feed ration characters, not included in Exp_model, there were high correlations to deviance in ECM for Ci_DM (r = 0.52***), Conc_share (r = -0.31***) and NEL_DM (r=-0.37***) within data of all three breeds (Table 3). The variables on feed ration characters were all mutually correlated. Ci_DM were highly correlated to Conc_share (r = 0.67***), Conc_DM (r = -0.54***) and FVL (r = 0.39***) as well as NEL_DM (r = -0.58***). Further NDF_NEL was highly correlated to Ci_DM (r = 0.77*** and Conc_share (r = -0.36***).

Including the explanatory variables Ci_DM, Conc_share, Conc_DM, FVL, NEL_DM, DIM, production system and breed in the linear regression of deviance in ECM in (model 1) 47 % of the variation (R^2) was explained (Table 5). The parameter estimates were biologically sensible except for Conc_share, being positive contrary to the negative correlation coefficient between deviance in ECM and Conc_share, due to a high correlation Conc_DM (r=0.88). When further including the energy and nutrient variables from Exp_model (NEL intake, NDF_NEL, AAT_NEL and CFat_NEL), the variable on production system (conventional or organic) became insignificant and was therefore excluded. An interaction between NEL intake and breed was further included. Now model 2 for deviance explained 62 % (R^2) of the deviance in ECM (Table 5).

3.2. ECM prediction from between and within herd data

From the response functions on between and within herd data the ECM responses in all models and for all breeds increased to increased NEL intake (Table 6). There were positive effects on ECM response of the nutrient variables AAT_NEL and CFat_NEL and a negative effect of NDF_NEL. The effect of ratio of primiparous cows was negative with a lower ECM response for herds with a high ratio of primiparous cows. The effect of DIM on ECM response in the DMS-between_model and DMS-within_model was negative with 0.26 and 0.21 kg ECM less per 10 day increased DIM, respectively. The parameter estimates for the breeds DR and DJ relative to DH were negative and lowest for DJ. Further in all models the estimate for DJ was different from the DH whereas the estimate for DR was only different from DH in the DMS-within_model. For the DMS-between_model-int including interaction between NEL intake and breed the increase in ECM response to increased NEL intake for DJ was lower (0.8 kg less ECM per 10 MJ increased NEL intake) than for DH.

The ECM responses from DMS-between_model and from DMS-within_model at mean NEL intake for DH (146 MJ), DR (142 MJ) and DJ (122 MJ) were similar, 30.8, 30.1 and 28.0 kg, respectively (Figure 3A for DH). The ECM responses from DMS-between_model-int at mean NEL intakes and mean DIM values for DH (198 days), DR (185 days) and DJ (193 days) were 35.9, 30.1 and 28.0 kg, respectively. For the DMS-between_model-int with interaction between NEL intake and DIM the ECM response increased at a higher
rate at lower DIM values, resulting in higher ECM responses to increased NEL intake for cows in earlier lactation stages than in later lactation stages. At an earlier DIM (140 days) versus a later DIM (260 days) the difference (early minus late) in ECM response at maximum NEL intake levels were higher than at minimum NEL intake levels. For DH, DR and DJ the differences at maximum NEL intake levels were; 7.5, 5.6 and 3.6 kg ECM, respectively and at minimum NEL intake levels; 0.5, 1.7 and -0.5 kg ECM, respectively (Figure 4).

There was an interaction between NEL and AAT_NEL in the DMS-within$_{model-int}$ which resulted in a larger effect on the ECM response of increasing AAT_NEL at low NEL intake than at high NEL intake levels. The predicted ECM responses from DMS-within$_{model-int}$ at mean NEL intake and mean AAT_NEL values for DH, DR and DJ were 30.7, 29.9 and 28.0 kg, respectively. At a lower AAT_NEL level (-2 g/MJ) versus a higher AAT_NEL level (+2 g/MJ) the difference (high minus low) in ECM response at maximum NEL intake levels were lower than at minimum NEL intake levels. For DH, DR and DJ the differences in response of a higher vs. a lower level of AAT_NEL were at maximum NEL intake levels; 2.8, 3.1 and 3.5 kg ECM, respectively and at minimum NEL intake levels; 4.2, 3.9 and 4.4 kg ECM, respectively (results not shown).

3.3. Comparison of ECM responses from herd data vs. experimental data

The ECM responses by the DMS models were lower than those by the Exp$_{model}$ weighted by the parity ratio of DH (primiparous to multiparous cow ratio of 38:62) (Figure 3A). The weighted Exp$_{model}$ response was extrapolated to include the NEL intake range of the DMS data. For these predictions of ECM responses a mean nutrient concentration as well as a mean ratio of primiparous cows and a mean DIM for DH in data were used for the DMS models. Applying the mean stage of lactation (DIM 70) as reported in the experimental data (Jensen et al., submitted) to the herd data increased the ECM responses from the DMS models to a level similar to that of the weighted Exp$_{model}$ (Figure 3B). However, there was a downward curvature of the response models by the DMS data contradictory to an upward curvature for the response model of experimental data.

The marginal ECM response to NEL intake increased with increased NEL intake for the DMS-between$_{model}$, though at a diminishing rate and with a larger effect of NEL intake than for the DMS-within$_{model}$. While the marginal response to NEL intake decreased for Exp$_{model}$ (Figure 5). For the DMS-between$_{model}$ the marginal ECM response increased from 0.07 to 0.19 kg/MJ with 0.15 kg/MJ at mean NEL intake (146 MJ) within the data range of between herds of DH, and for the DMS-within$_{model}$ the marginal ECM response increased from 0.06 to 0.12 kg/MJ with 0.10 kg/MJ at mean NEL intake (147 MJ) within the data range of within herds of DH. Marginal ECM response from Exp$_{model}$ weighted by parity ratio decreased with increased NEL intake from 0.27 to 0.08 kg/MJ with 0.14 kg/MJ at mean NEL intake (147 MJ) within the data range of within herds of DH. In the DMS-between$_{model-int}$ including interaction between NEL intake and DIM, the marginal ECM response depended on stage of lactation. Therefore, given DIM 140, 200 and 260 the marginal ECM responses were 0.20, 0.15 and 0.10 kg/MJ, respectively and were nearly constant to increased NEL intake (Figure 6).
4. Discussion

4.1. Use of commercial herd data

Validation of data and filtering (sources of error), commercial herd data vs. experimental data

Compiling commercial dairy herd data through DMS produced a data set representative of the dairy industry of the time in terms of production system, size and feeding to study milk yield response to energy intake and evaluate previously developed ECM response functions from experimental data. The 728 herds in data represent 23% of Danish herds with milk yield recordings. From the total number of FER in the DMS 40% was removed in the filtering process, however less than 1% was deleted due to dubious registrations, therefore, the filtering process is not likely to have affected the obtained results. The distribution of herds within breeds was similar to the national distribution of herds between DH (75%), DJ (17%) and DR (8%) (RYK, 2013). The mean yearly ECM production was similar to the national average of October 2012 through September 2013 for DH (9895 kg) and DJ (8850 kg) whereas it was slightly higher for DR (9373 kg) (RYK, 2013). The proportion of herds with AMS was higher (30%) than the national average of 23% whereas the proportion of organic production system was at same level (Knowledge Centre for Agriculture, 2014).

The data set was unique with the systematic and repeated milk recordings combined with the associated feed ration intakes for the lactating group of cows. However, it is more difficult in the commercial herds to control production input variables compared to controlled experiments in research stations, where exact feed intake at cow level is measured and combined with feed analysis of all individual feed stuffs. Though information on production system, housing and milking systems are available in the DMS data the management within herds can vary during the one year period of registration. Several factors in addition to those of nutrition affects herd performance (milk production), like reproduction, genetics, environment and management; factors that cannot specifically be identified in our data from DMS. As much as 56% of the observed variation in milk production (13 kg/d) has been found to be explained by the nondietary factors ‘age at first calving’, ‘presence or absence of feed refusals’, ‘ratio of number of free stall per lactating cow’ and ‘use or no use of feed push up in the feed bunk’ in a study where forty-seven herds were offered the same TMR ration (Bach et al., 2008).

Data from a commercial herd compared to those from an experimental research station lack random allocation of cows to predefined treatment groups. Registered change in feeding level in the herd could be deliberate adjustment according to the herd milk yield, to a new feeding situation e.g. season or due to changes in production restrictions, e.g. milk quota. Within herds with repeated FER there was a considerable variation in NEL intake, the mean range within DH herds was 11 MJ. The mean range in stage of lactation within herds with repeated FER was 19 days and the mean range in ratio of primiparous cows was 0.04. The parity distribution and stage of lactation within a herd do influence the mean feed intake. However, with the small mean range of ratio of primiparous cows (0.04) and small mean range in stage of lactation (19 days) within the DH herds, we presume that these factors are not the primary cause of variation in NEL intake levels within herds. Management factors including the feeding are more likely to be the driving force of changes in energy level of feed rations over time within the herds.
Common practice among the advisory service is to our knowledge that changes in feeding level for the herds in Denmark is mainly driven by the observed milk yield production and not an actual optimization. Thereby use of commercial herd data could tend to overestimate the true milk yield response to increased energy intake, as increased feeding level could be a response to increased milk yield and not opposite as assumed in the response equation. As the EU milk quota will be abolished in 2015, it is also possible that some farmers have been gearing up for the coming no-quota situation and therefore have increased the energy level slightly, even at the risk of exceeding present quota limit with a following fee, due to increasing milk prices obtained and positive price relation between milk and feed during period of FER in this study.

4.2. Sources for deviance in ECM prediction

As expected, stage of lactation contributed to the deviance in predicted ECM as the Exp_{model} was based on early lactation period (mean DIM 70) and the between herd data were from a later period (mean DIM 198). This could explain part of the difference in predicted ECM for the commercial herd data (from 4.1 kg for DH to 1.1 for DR). However, only 11 % of the deviance in ECM was explained by DIM in the regression with DIM as only factor for the deviance. Thereby main part of deviance is to be found in other factors, i.e. nutrient and ration evaluation or general management factors (Figure 2B).

The deviance in ECM prediction decreased with increased NEL intake, though NEL intake is included in the prediction model from experimental data. The prediction model does not account for all the complexity of the interactions of ration characteristics, as example Ci_DM which is given by the sum of eating and rumination time of each feedstuff in the ration (Nørgaard et al., 2012). Both eating and rumination time is determined by NDF, iNDF and particle length of feeds and as such Ci_DM is also found highly correlated to NDF_NEL in these data.

The prediction model tend to overestimate ECM at low NEL intake levels which leads to the consideration that other factors than cow and ration characteristics could explain the deviance at low ECM yields. A possible ‘connection’ between the decreased deviance in ECM at increased ECM yield in the herd might be the fact that high yield is not only achieved by high energy intake but also demands good management or environment (Bach et al., 2008).

Inclusion of the variable for ratio of primiparous cows in the DMS prediction models was well-founded from the Exp model estimates with a curvilinear response for multiparous cows versus a more linear response for primiparous (Jensen et al., submitted) in line with primiparous cows partitioning more of the energy intake towards live weight gain (Friggens et al., 2007). An effect of parity distribution on the ECM response was expected with primiparous cows constituting from 21 to 65 % within the mean herd data.

It is well documented that partitioning of energy intake changes with the stage of lactation where cows in early compared to late lactation show larger milk yield responses to increased intake (Kirkland and Gordon, 2001). Compared to our study a less negative effect of increased DIM on ECM yield (-0.15 kg/10 days increased DIM) was found by Huhtanen and Nousiainen (2012). However their data was generally from earlier parts of lactation (from 38 to 282 DIM) than our data. From the review of Coulon and Rémond (1991) on variation in milk response to energy level there was consistently found an
average response that was higher in early lactation than in mid and for long term studies. Friggens et al. (2007) suggested that this is due to the cows during lactation change their energy partitioning from the present calf (milk production) in early lactation towards prioritizing a future pregnancy (body tissues).

4.3. ECM responses from between and within herd data

Using the repeated registrations within herds to model the ECM response allowed for both within and between herd response functions using a similar structure of response function as the one of Exp\textsubscript{model} for comparison reasons. Estimation of general ECM prediction models based on commercial herd data is vague with non controllable factors as opposed to experimental research data. Nevertheless the herd data were appropriate for the analysis of responses between and within herds.

The larger effect of NEL intake on ECM response of between herd data compared to within herd data demonstrated that the response within herds was less than the response between herds. The responses from the between and the within models were particularly different at high NEL intake levels. Within a specific herd the nutrition and the energy intake is not the sole factor for increasing the herd yield but management and genetics are also important factors. Cows with a higher yield potential will respond more to increased energy intake than cows with a lower yield potential (Veerkamp et al., 1994; Ferris et al., 1999). This shows the importance of using herd specific response curves in relation to optimization of the feeding level within a herd. An adaptive dynamic model for online estimation of milk yield response to concentrate intake for the individual cow has been developed (André et al., 2011). However, as concentrates are not the only costs of feeding, considering the roughage part of the ration would be a more complete approach (André et al., 2010).

However, for the herd data the marginal ECM responses of both between and within herd astonishingly showed an increased effect of NEL intakes. Given the use of same variables as in the Exp\textsubscript{model} the estimates for the curvature, ln(NEL), that were negative and caused an increased marginal response. Though the estimate was not significant in the within herd models nor in the between herd model including an interaction between stage of lactation and NEL intake. Further the DMS data could be influenced by non controllable factors like management as opposed to experimental data.

4.4. Perspectives on future feed and milk registrations

In times with widespread use of IT communication and online data collection of daily production and feed consumption it could be possible with ration planning and optimization to an individual herd level. In an observational study on 4 research farms the milk yield responses to concentrate intake differed systematically between farms and there was a random variation between the individual cows on each farm (André et al., 2010). Also more precise registrations of the nutrient contents of the individual feedstuffs could provide a set up for precision feeding at an individual level, however this would require an estimate of the forage intake variation between cows if not the exact forage intake of each cow. The use of specific nutrients intake rather than DM intake to predict milk yield responses is supported in a meta-analysis by Hristov et al. (2005) which compared response models based on DM intake versus nutrients intake from either NRC or CPM dairy model.
5. Conclusion

The deviance in ECM between prediction estimates of experimental data and actual ECM in commercial herd data was of considerable size, though mainly for DH with plus 4 kg ECM whereas for DR it was plus 1 kg ECM and for DJ plus 2 kg ECM. The main factors explaining this deviance were stage of lactation, feed ration characteristics as amount and share of concentrate intake and the chewing index. Of the deviance 47% was explained by factors not attributed directly to the energy and nutrient variables in the prediction model. There was a larger effect of increased NEL intake on ECM response for the between herd data than the within herd data and for the between herd data there was a larger response for DH than DJ. The response curves for increased NEL intake of herd data were downwards curvilinear, yielding increasing marginal responses to increased energy intake, contrary to the decreasing marginal response from experimental data, possibly due to factors originating from the commercial herd compared to controllable experiments like management and genetic potential in the herds. The difference in the response curves of between and within herd data and not least difference to experimental data, indicates good reason for further work at herd specific ECM prediction models based on herd data.

Acknowledgements

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References


Knowledge Centre for Agriculture, 2014. Antal AMS.


Table 1
Summary of commercial herd data based on mean herd data from group of lactating cows, sampled during December 2012 to November 2013 for Danish Holstein (DH), Danish Red (DR) and Danish Jersey (DJ)

<table>
<thead>
<tr>
<th></th>
<th>DH (n=561)</th>
<th>DR (n=42)</th>
<th>DJ (n=125)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Min</td>
</tr>
<tr>
<td>Herd size</td>
<td>205</td>
<td>110</td>
<td>28</td>
</tr>
<tr>
<td>DIM</td>
<td>198</td>
<td>16</td>
<td>137</td>
</tr>
<tr>
<td>Parity ratio</td>
<td>0.38</td>
<td>0.05</td>
<td>0.24</td>
</tr>
<tr>
<td>ECM, kg/d</td>
<td>30.6</td>
<td>3.1</td>
<td>20.9</td>
</tr>
<tr>
<td>Intake per day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM, kg</td>
<td>22.6</td>
<td>1.5</td>
<td>17.8</td>
</tr>
<tr>
<td>NEL, MJ</td>
<td>146</td>
<td>10</td>
<td>113</td>
</tr>
<tr>
<td>NDF, g/MJ NEL</td>
<td>51.8</td>
<td>4.1</td>
<td>41.2</td>
</tr>
<tr>
<td>AAT, g/MJ NEL</td>
<td>14.4</td>
<td>0.8</td>
<td>11.0</td>
</tr>
<tr>
<td>CFat, g/MJ NEL</td>
<td>6.9</td>
<td>0.8</td>
<td>4.5</td>
</tr>
<tr>
<td>Ration character</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CI, min/kg DM</td>
<td>35</td>
<td>3.2</td>
<td>25</td>
</tr>
<tr>
<td>Concentrate, %</td>
<td>36</td>
<td>6.2</td>
<td>16</td>
</tr>
<tr>
<td>Concentrate, kg/d</td>
<td>8.2</td>
<td>1.6</td>
<td>3.1</td>
</tr>
<tr>
<td>FVL, FV</td>
<td>8.4</td>
<td>0.55</td>
<td>6.7</td>
</tr>
<tr>
<td>EC, MJ/kg DMI</td>
<td>6.5</td>
<td>0.17</td>
<td>5.8</td>
</tr>
</tbody>
</table>

a Number of herds
b Number of lactating cows
c Ratio of primiparous cows out of total milking cows
d Energy corrected milk, 3.14 MJ/kg calculated according to Sjaunja et al., 1991
e Net energy lactation calculated according to Volden et al., 2011
f Amino acids absorbed in the small intestine, calculated as sum of dietary AA, microbial AA and endogenous AA digested in the small intestine
g Crude fat
h Chewing index of total ration in minutes per kg DM
i Concentrate share in ration in % of DM
j Intake of fill value units (arbitrary) per day
k Energy concentration of ration in MJ NEL per kg DMI
Table 2
Summary of range (maximum – minimum) in stage of lactation (DIM), DMI, NEL intake and ECM within herds with repeated feed evaluation registrations for Danish Holstein (DH), Danish Red (DR) and Danish Jersey (DJ)

<table>
<thead>
<tr>
<th>Range</th>
<th>DH (n=500)</th>
<th>DR (n=30)</th>
<th>DJ (n=111)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>3.8</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>Parity ratio</td>
<td>0.04</td>
<td>0.03</td>
<td>0.00</td>
</tr>
<tr>
<td>DIM</td>
<td>19</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>ECM</td>
<td>2.2</td>
<td>1.5</td>
<td>0.0</td>
</tr>
<tr>
<td>DMI</td>
<td>1.9</td>
<td>1.3</td>
<td>0.0</td>
</tr>
<tr>
<td>NEL</td>
<td>11</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

- **N**
  - Number of herds with more than one FER
- **Parity ratio**
  - Ratio of primiparous cows out of total milking cows
- **DIM**
  - Day in milk
- **ECM**
  - Energy corrected milk
- **DME**
  - Daily milk energy
- **NEL**
  - Net energy lactation

- a Number of herds with more than one FER
- b Number of repeated FER within a herd
- c Ratio of primiparous cows out of total milking cows
- d Energy corrected milk, 3.14 MJ/kg calculated according to Sjaunja et al., 1991
- e Net energy lactation calculated according to Volden et al., 2011
Table 3
ECM production predicted by experimentally based estimates and deviance between predicted and actual ECM in between herd data for Danish Holstein (DH), Danish Red (DR) and Danish Jersey (DJ)

<table>
<thead>
<tr>
<th></th>
<th>DH (n=561)</th>
<th>DR (n=42)</th>
<th>DJ (n=125)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Min</td>
</tr>
<tr>
<td>$ECM_{\text{Exp-model}}^a$, kg</td>
<td>34.7</td>
<td>1.5</td>
<td>26.7</td>
</tr>
<tr>
<td>$\text{devianceECM}^c$, kg</td>
<td>4.1</td>
<td>2.3</td>
<td>-5.0</td>
</tr>
</tbody>
</table>

$^a$ Number of herds

$^b$ Predicted ECM production in between herd data by prediction estimates of $\text{Exp}_{\text{model}}$ by Jensen et al., submitted

$^c$ Deviance in ECM response in between herd data calculated as $ECM_{\text{Exp-model}} - ECM_{\text{actual}}$
Table 4
Correlation coefficients\( ^a \) between deviance in ECM (predicted by Exp\(_{\text{model}} \) – actual ECM) and variables on production, feed and nutrient intakes, ration characters or herd characteristics of mean herd data for all breeds, Danish Holstein (DH), Danish Red (DR) and Danish Jersey (DJ)

<table>
<thead>
<tr>
<th>Variable</th>
<th>All breeds</th>
<th>DH</th>
<th>DR</th>
<th>DJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herd characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIM</td>
<td>0.34***</td>
<td>0.30***</td>
<td>0.21( ^c )</td>
<td>0.26**</td>
</tr>
<tr>
<td>Parity ratio( ^b )</td>
<td>0.08*</td>
<td>0.08( ^c )</td>
<td>-0.19( ^c )</td>
<td>-0.14( ^c )</td>
</tr>
<tr>
<td>Production</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECM(^c), kg/d</td>
<td>-0.61***</td>
<td>-0.88***</td>
<td>-0.82***</td>
<td>-0.72***</td>
</tr>
<tr>
<td>Intake per day</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM, kg</td>
<td>0.12***</td>
<td>-0.24***</td>
<td>-0.26( ^c )</td>
<td>0.23**</td>
</tr>
<tr>
<td>NEL(^d), MJ</td>
<td>0.02( ^c )</td>
<td>-0.39***</td>
<td>-0.36*</td>
<td>0.13( ^c )</td>
</tr>
<tr>
<td>NDF, g/MJ NEL</td>
<td>0.45***</td>
<td>0.46***</td>
<td>0.64***</td>
<td>0.19*</td>
</tr>
<tr>
<td>AAT(^e), g/MJ NEL</td>
<td>-0.50***</td>
<td>-0.45***</td>
<td>-0.50***</td>
<td>-0.41***</td>
</tr>
<tr>
<td>CFat(^f), g/MJ NEL</td>
<td>0.07*</td>
<td>0.13**</td>
<td>0.42**</td>
<td>0.29***</td>
</tr>
<tr>
<td>Ration characters</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CI(^g), min/kg DM</td>
<td>0.52***</td>
<td>0.51***</td>
<td>0.67***</td>
<td>0.27**</td>
</tr>
<tr>
<td>Concentrate share, %</td>
<td>-0.31***</td>
<td>-0.38***</td>
<td>-0.32*</td>
<td>0.06( ^c )</td>
</tr>
<tr>
<td>Concentrate intake, kg DM</td>
<td>-0.23***</td>
<td>-0.43***</td>
<td>-0.34*</td>
<td>0.13( ^c )</td>
</tr>
<tr>
<td>FVL(^h), FV/d</td>
<td>0.25***</td>
<td>-0.03( ^c )</td>
<td>-0.05( ^c )</td>
<td>0.24**</td>
</tr>
<tr>
<td>EC(^i), MJ/kg DMI</td>
<td>-0.37***</td>
<td>-0.41***</td>
<td>-0.42**</td>
<td>-0.24**</td>
</tr>
</tbody>
</table>

\( ^a \) ns P>0.05, * 0.05>P>0.01, ** 0.01>P>0.001, *** P<0.001

\( ^b \) Ratio of primiparous cows out of total milking cows

\( ^c \) Energy corrected milk, 3.14 MJ/kg calculated according to Sjaunja et al., 1991

\( ^d \) Net energy lactation calculated according to Volden et al., 2011

\( ^e \) Amino acids absorbed in the small intestine, calculated as sum of dietary AA, microbial AA and endogenous AA digested in the small intestine

\( ^f \) Crude fat

\( ^g \) Chewing index of total ration in minutes per kg DM

\( ^h \) Intake of fill value units (arbitrary) per day

\( ^i \) Energy concentration of ration in MJ NEL per kg DMI
Table 5
Regression estimates for models on deviance in ECM (predicted by \( \text{Exp}_{\text{model}} \) – actual ECM) of mean herd data for Danish Holstein (DH), Danish Red (DR) and Danish Jersey (DJ)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Model 1 (( R^2 = 0.47; \text{RSE} = 1.8 ))^\text{a}</th>
<th>Model 2 (( R^2 = 0.62; \text{RSE} = 1.5 ))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value</td>
<td>SE</td>
</tr>
<tr>
<td>Intercept</td>
<td>1.4</td>
<td>5 ns</td>
</tr>
<tr>
<td>NEL\text{\textsuperscript{c}}</td>
<td>0.15</td>
<td>0.04</td>
</tr>
<tr>
<td>NDF_NEL\text{\textsuperscript{d}}</td>
<td>0.13</td>
<td>0.03</td>
</tr>
<tr>
<td>AAT_NEL\text{\textsuperscript{e}}</td>
<td>-1.0</td>
<td>0.08</td>
</tr>
<tr>
<td>CFat_NEL\text{\textsuperscript{f}}</td>
<td>0.40</td>
<td>0.08</td>
</tr>
<tr>
<td>CI\text{\textsuperscript{g}}</td>
<td>0.18</td>
<td>0.04</td>
</tr>
<tr>
<td>Conc_Share\text{\textsuperscript{h}}</td>
<td>0.27</td>
<td>0.07</td>
</tr>
<tr>
<td>Conc_DM\text{\textsuperscript{i}}</td>
<td>-1.1</td>
<td>0.30</td>
</tr>
<tr>
<td>FVL\text{\textsuperscript{j}}</td>
<td>0.70</td>
<td>0.3</td>
</tr>
<tr>
<td>EC\text{\textsuperscript{k}}</td>
<td>-2.6</td>
<td>0.5</td>
</tr>
<tr>
<td>DIM</td>
<td>0.04</td>
<td>0.004</td>
</tr>
<tr>
<td>System\text{\textsuperscript{l}}</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>DR\text{\textsuperscript{m}}</td>
<td>-2.5</td>
<td>0.3</td>
</tr>
<tr>
<td>DJ\text{\textsuperscript{m}}</td>
<td>-2.2</td>
<td>0.3</td>
</tr>
<tr>
<td>NEL * DR\text{\textsuperscript{n}}</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>NEL * DJ\text{\textsuperscript{n}}</td>
<td>0.12</td>
<td>0.02</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Multiple R squared and residual standard error of the model

\textsuperscript{b} ns P > 0.05, * 0.05>P>0.01, ** 0.01>P>0.001, *** P<0.001

\textsuperscript{c} Net energy intake (MJ)

\textsuperscript{d} Neutral detergent fiber, in g/MJ NEL intake

\textsuperscript{e} Amino acid absorbed in the small intestine, in g/MJ NEL intake

\textsuperscript{f} Crude fat, in g/MJ NEL intake

\textsuperscript{g} Chewing index of total ration in minutes per kg DM

\textsuperscript{h} Concentrate intake in share of total intake

\textsuperscript{i} Concentrate intake in kg DM

\textsuperscript{j} Intake of fill value units (arbitrary) per day

\textsuperscript{k} Energy concentration of ration in MJ NEL per kg DMI

\textsuperscript{l} Intercept estimate for herds with organic production system relative to conventional

\textsuperscript{m} Intercept estimate for Danish Red or Danish Jersey relative to Danish Holstein

\textsuperscript{n} Interaction estimates between NEL intake (MJ) and Danish Red or Danish Jersey
### Table 6
Regression estimates in ECM response functions for lactating cows based on mean herd data (DMS-between) without or with interactions (int) or based on repeated registrations within herd data (DMS-within) without or with interactions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DMS-between&lt;sub&gt;model&lt;/sub&gt; (R&lt;sup&gt;2&lt;/sup&gt; = 0.74)</th>
<th>DMS-between&lt;sub&gt;model-int&lt;/sub&gt; (R&lt;sup&gt;2&lt;/sup&gt; = 0.75)</th>
<th>DMS-within&lt;sub&gt;model&lt;/sub&gt; (R&lt;sup&gt;2&lt;/sup&gt; = 0.68)</th>
<th>DMS-within&lt;sub&gt;model-int&lt;/sub&gt; (R&lt;sup&gt;2&lt;/sup&gt; = 0.68)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value</td>
<td>SE</td>
<td>P&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Value</td>
</tr>
<tr>
<td>Intercept</td>
<td>145.9</td>
<td>43</td>
<td>***</td>
<td>-20.0</td>
</tr>
<tr>
<td>NEL&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.394</td>
<td>0.08</td>
<td>***</td>
<td>0.321</td>
</tr>
<tr>
<td>ln(NEL)</td>
<td>-36.3</td>
<td>11</td>
<td>***</td>
<td>-0.552</td>
</tr>
<tr>
<td>NDF_NEL&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-0.166</td>
<td>0.02</td>
<td>***</td>
<td>-0.167</td>
</tr>
<tr>
<td>AAT_NEL&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.45</td>
<td>0.07</td>
<td>***</td>
<td>1.43</td>
</tr>
<tr>
<td>CFat_NEL&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.320</td>
<td>0.07</td>
<td>***</td>
<td>0.323</td>
</tr>
<tr>
<td>Parity ratio&lt;sup&gt;f&lt;/sup&gt;</td>
<td>-3.83</td>
<td>1.1</td>
<td>***</td>
<td>-3.85</td>
</tr>
<tr>
<td>DIM</td>
<td>-0.026</td>
<td>0.004</td>
<td>***</td>
<td>0.091</td>
</tr>
<tr>
<td>DJ&lt;sup&gt;g&lt;/sup&gt;</td>
<td>-2.5</td>
<td>0.32</td>
<td>***</td>
<td>8.0</td>
</tr>
<tr>
<td>DR&lt;sup&gt;g&lt;/sup&gt;</td>
<td>-0.43</td>
<td>0.3</td>
<td>ns</td>
<td>5.2</td>
</tr>
<tr>
<td>NEL*DIM&lt;sup&gt;h&lt;/sup&gt;</td>
<td>-0.001</td>
<td>0.0003</td>
<td>**</td>
<td>0.003</td>
</tr>
<tr>
<td>NEL*DR&lt;sup&gt;h&lt;/sup&gt;</td>
<td>-0.040</td>
<td>0.026</td>
<td>ns</td>
<td>0.03</td>
</tr>
<tr>
<td>NEL*DJ&lt;sup&gt;h&lt;/sup&gt;</td>
<td>-0.080</td>
<td>0.03</td>
<td>**</td>
<td>0.005</td>
</tr>
</tbody>
</table>

<sup>a</sup> ns P > 0.05, * 0.05>P>0.01, ** 0.01>P>0.001, *** P<0.001
<sup>b</sup> Net energy intake in MJ
<sup>c</sup> Neutral detergent fiber, in g/MJ NEL intake
<sup>d</sup> Amino acid absorbed in the small intestine, in g/MJ NEL intake
<sup>e</sup> Crude fat, in g/MJ NEL intake
<sup>f</sup> Ratio of primiparous cows out of total milking cows
<sup>g</sup> Intercept estimate for Danish Red or Danish Jersey relative to Danish Holstein
<sup>h</sup> Interaction estimates between NEL intake (MJ) and DIM (day), breed or AAT_NEL
Figure 1. Deviance ECM (kg/day) [predicted – actual] for DH (○), DR (+) and DJ (∆) in relation to A) ECM (kg/day) or B) NEL intake (MJ/day), where predicted ECM was calculated by $\text{Exp}_{\text{model}}$.

Figure 2. Residual Deviance ECM (kg/day) [residuals from the linear regression including only DIM as independent variable to explain deviance ECM] for DH (○), DR (+) and DJ (∆) in relation to A) ECM (kg/day) or B) NEL intake (MJ/day). The deviance ECM was calculated as predicted ECM – actual ECM, where predicted ECM was calculated by $\text{Exp}_{\text{model}}$. 
Figure 3. ECM responses (kg/d) to NEL intake (MJ/d) based on DMS models of between herd data (---) and within herd data (---) or based on experimental model estimates (—) using a parity ratio of 38:62 for primiparous to multiparous cows. Nutrient levels and parity ratio used for prediction were means for DH. A) Stage of lactation for the DMS models were mean 198 DIM as in between herd data and B) mean 70 DIM as in experimental model.

Figure 4. Effect of stage of lactation [DIM 140 (-----), 200 (---) and 260 (—)] on predicted ECM responses (kg/day) to NEL intake (MJ/day) based on the interaction model DMS-betweenmodel-int for DH. Nutrient levels and parity parameters used for prediction were means for DH.
Results: Paper 4

Figure 5. Marginal ECM responses (kg/MJ NEL) to increased NEL intake (MJ/day) for DH by the DMS-between\textsubscript{model} (---) or by DMS-within\textsubscript{model} (----) along with marginal ECM response (kg/day) for DH from Exp\textsubscript{model} (——) using a primiparous to multiparous cows ratio of 38:62 and an extrapolation of response area to cover the NEL intake range of DMS data.

Figure 6. Marginal ECM response (kg/MJ NEL) to increased NEL intake (MJ/day) for DH by DMS-between\textsubscript{model} (---) compared to marginal ECM response of prediction model DMS-between\textsubscript{model-int} with interaction between NEL intake and DIM, where stage of lactation was given by DIM 140 (--) and 260 (——).
4. General discussion

The overall aim for this thesis was to improve knowledge on production responses in terms of milk and growth to feed energy intake based on the NorFor feed evaluation system and net energy for lactation (NEL). It was the intention that this new knowledge on the production responses can be incorporated in a model for economical optimization of the feed energy level in dairy cow feed rations within a specific herd and thereby will be one among other tools for optimizing the production economy for the dairy farmer. To approach the aim for the thesis meta-analyses of milk and growth responses to increased NEL intake (Paper 2 and 3) were performed and further to evaluate the application of the milk production response function the similar modeling approach was applied to commercial herd data (Paper 4). The consequences of using data (observations) from individual level (cow) versus group level (treatment mean) from production trials for the modeling of response functions was analyzed in a study prior to the meta-analyses (Paper 1). It is the intention with the general discussion to relate the results of this study to the most state-of-the-art work within the field and to put it into a broader perspective.

4.1. Milk and growth responses to increased net energy intake

Prediction models of milk and growth responses to increased energy intake levels based on the NorFor feed evaluation system were produced by meta-analyses on the compiled data of previous production trials from Denmark, Norway and Sweden. Curvilinear response functions for daily ECM production was found for primiparous and multiparous cows in early (DIM 0 to 100) and mid (DIM 101 to 200) stage of lactation whereas the curvilinear response functions for daily live weight gain was found for primiparous and multiparous cows at the specific stages of lactation of DIM 30, 60 and 90. For the milk response functions also the effect of the specific nutrients NDF, AAT and crude fat were included and breed specific response levels were given.

The predicted ECM responses in early stage of lactation for primiparous and multiparous DH cows with a mean NEL intake and mean ration concentration of NDF, AAT and crude fat for cows were 27.8 and 35.4 kg, respectively. In mid stage of lactation these ECM responses for primiparous and multiparous were 28.8 and 30.9 kg, respectively. The curvilinear effect of NEL in the ECM prediction model resulted in the marginal ECM responses to NEL intake in early stage of lactation for DH primiparous and multiparous cows decreased from 180 to 156 g/MJ NEL and from 241 to 81 g/MJ NEL, respectively. In mid stage of lactation the marginal ECM responses decreased from 5 to -16 g/MJ NEL and from 156 to 22 g/MJ NEL for primiparous and multiparous, respectively.

The predicted daily live weight change (DG) in early stage of lactation for DH cows with a mean NEL intake at DIM 30, 60 or 90 were -157, 137 and 435 g, respectively for primiparous and the DG were -215, 98 and 413 kg, respectively for multiparous. The marginal DG with mean NEL intake at DIM 30, 60 or 90 were 5, 4 and 4 g/MJ, respectively for primiparous cows and marginal DG with mean NEL intake were 10, 6 and 2 kg/MJ, respectively for multiparous cows.
4.2. Effects of parity and stage of lactation on production responses

Parity

The parity of the cow has an effect on the production response as well as the marginal response. Generally the primiparous cows respond less in terms of milk production and more in terms of live weight gain to increased energy than multiparous cows. The pronounced parity difference in marginal ECM response from the prediction models in this study with the primiparous cows having nearly no response to increased energy intake, was in line with results by Bossen and Weisbjerg (2009) where milk production in primiparous cows was not affected by changes in feeding strategies (energy level) compared to a clear effect in multiparous cows. Significant differences in marginal milk responses were also found in a review by Coulon and Rémond (1991) where primiparous versus multiparous cows responded with 0.73 kg and 1.06 kg milk per increased feed unit. Milk production responses in Coulon and Rémond (1991) were linear and therefore marginal responses were constant likewise the nearly constant marginal responses of the primiparous cows in Paper 2 (from 200 to 170 g/MJ NEL). This response to energy intake for the primiparous cows indicates that primiparous cows have a partitioning of energy between milk and gain, which is nearly independent of the energy supply (Spahr et al., 1993; Bossen and Weisbjerg, 2009).

Primiparous cows prioritize growth (maturing) more than the multiparous cows and thereby partition more of the feed energy towards live weight gain (Friggens et al., 2007). This was also the picture in Paper 3 where the primiparous cows either had less negative daily gain or higher positive daily gain in LW than the multiparous cows. Increasing the NEL intake in early lactation for primiparous cows therefore result in weight gain rather than increased ECM production as for the multiparous cows. However, the decreasing marginal DG response was similar between parities as opposed to the distinctive differences in marginal ECM response between parities.

The parity effects on production responses prompted the need for addressing the response functions according to the ratio of primiparous to multiparous cows when used on commercial herd data, where the data were averages across all lactating cows in the herd (Paper 4). The ratio of primiparous cows constituted from 21 to 65 % of cows in the herds (Paper 4) and including this, the parity ratio, as a parameter estimate in ECM response functions was highly significant (p<0.001) for the herd data.

Stage of lactation

Previous studies have reported that milk yield responses to changes in ME intake were higher in early than in mid and late stage of lactation across varying definitions of early, mid and late (Blaxter, 1966; Coulon and Rémond, 1991; Kirkland and Gordon, 2001). In line with this the marginal ECM responses at mean NEL intakes levels were higher in Early than Mid period data for both parity groups (Paper 2). However, the differences were not tested statistically. A reason for the numerical different marginal responses could be different ranges of NEL intake between the data subsets of early and mid lactation. Though in the production trials data the ranges in NEL intake were similar for primiparous or multiparous cows with +6 and +9 MJ, respectively for mid compared to early stage of lactation.
The responses in daily gain were analyzed only with data of early stage of lactation due to lack of data with LW registrations in mid stage of lactation (Paper 3). The DG responses to increased NEL intake were modeled at DIM 30, 60 and 90 where the daily LW gain were found as the slope of LW curves for the individual cows. Few studies have reported LW changes to varying energy intake levels during corresponding stages of early lactation. Though in the study by Andersen et al. (2003) they examined the performance of multiparous DH cows in early lactation on a low or high concentrate diet. From parturition to week 8 of lactation cows on diet low (110 MJ) and high (144 MJ) had LW loss of 61 and 56 kg, respectively and during lactation week 9 to 16 cows on diet low (127 MJ) and high (169 MJ) had LW gain of 8 and 23 kg, respectively. At high compared to low energy intake levels they found less LW loss and higher LW gain during first and following period, respectively. Contrary to our DG response at DIM 30 of -215 g/d at mean NEL intake of 138 MJ (Paper 3) they found very large LW losses, averaging approximately -1 kg/d. However, during week 9 to 16 their LW gain increased averaging approximately 316 g/d and were similar to our positive DG response at DIM 90 of 413 g/d.

In the evaluation of the application of the ECM prediction model used on the commercial herd data (Paper 4) it was expected that stage of lactation had an effect on ECM responses as the production trial data (Paper 2) had mean DIM 70 whereas the herd data had mean DIM 198. However, from the analysis of sources to the deviances between predicted ECM and actual ECM production in the herds only 11% was explained by DIM; where the DIM values in herd data were not corrected to same stage of lactation as in production trial data. Still for the analysis of the milk production responses using between or within herd data (Paper 4) the effect of DIM on ECM was included in the response functions resulting in parameter estimates of -0.26 and -0.21 kg ECM/10 d increased DIM. Compared to our study a less negative effect of increased DIM on ECM yield (-0.15 kg/10 days increased DIM) was found by Huhtanen and Nousiainen (2012). Also these results underline that stage of lactation plays an essential role in production responses of the dairy cow. It has been suggested that this is due to the cows during lactation change their energy partitioning from the present calf; the milk production in early lactation towards prioritizing a future pregnancy; the body tissues (Friggens et al., 2007).

4.3. Prediction variables; DMI, NEL and nutrients

*Milk responses to energy intake versus dry matter intake*

The perspective of developing the new milk production responses was incorporation within an economical optimization of the energy level for feed rations based on the NorFor ration evaluation system. Prediction models based on the responses to NorFor NEL intake was therefore the obvious approach. Though for comparison reasons and for the benefit of a broader application of the results the ECM prediction models were also made using DMI intake as explanatory variable. Results of previous meta-analyses on the relationship between DMI and milk yield showed moderate to high correlations (Martin and Sauvant, 2002; Hristov et al., 2004). In Paper 2 ECM prediction models based on the NorFor NEL improved prediction of milk yield compared to DMI, though only with small numerical differences in the RMSE values of NEL versus DMI models. It was expected that the models based on NEL and nutrient intakes were considerably better than the DMI models. Thereby the lack of improvement from DMI models to NEL intake models could be interpreted as imprecise NEL estimation in NorFor; however it is
more likely related to a high correlation between DMI and NEL intake as the feed rations from the production trials (Paper 2) were formulated for ad libitum feeding. Furthermore from a plot of residuals [observed-predicted ECM] against NEL intake there was no indications of problems with the NorFor NEL parameter.

A curvilinear diminishing ECM response to DM intake for multiparous cows in early lactation was found with a marginal decrease from 1.7 to 0.3 kg per kg DMI within data range of DM intake. The primiparous cows in early lactation had a marginal ECM response of 1.2 kg per kg DM intake from a linear response model. The same pattern of a diminishing curvilinear ECM response for multiparous and an increasing linear response for primiparous was found for the data in mid stage of lactation. A marginal response of 1.1 kg ECM per kg DM intake was found by Hristov et al. (2005) for primiparous and multiparous cows together.

The use of nutrients intake rather than DM intake to predict milk yield responses is supported in a meta-analysis by Hristov et al. (2005), where they compared prediction models based on DM intake versus nutrients intake from either NRC or CPM dairy model. This is in line with our study, where the use of NEL intake rather than DMI in the prediction models of ECM across parities and stage of lactation improved prediction of ECM response. Furthermore the prediction models were tested when also including the individual nutrients NDF, AAT and crude fat in the model together with the NEL intake. Particularly for the ECM responses of the herd data (Paper 4) the parameter estimates for these same nutrients were highly significant, whereas in the model based on production trials it was only for the multiparous cows in early period of lactation the individual nutrients had an effect. This difference in significance of nutrients for the ECM response models might be due to a larger variation within the respective nutrient intake levels for the herd data as opposed to the controlled data of the production trials. However in Paper 2, the ECM prediction models with nutrient parameters only tending significance (p-value < 0.1) were kept for comparison reason between the sub dataset. This was done as variables with general biological effect, as seen for data of multiparous cows in early lactation, was expected to also be of value in prediction models of other sub data set. For use in practice the estimates are also relevant as seen in herd data (Paper 4). For the prediction models of daily gain (Paper 3) none of the nutrients were included, as they were statistically insignificant. This indicates that gain is more dependent on energy intake per se than on specific nutrient intake.

Shape of response curves

Within animal science, often the response variable increases at a decreasing rate with the increase of the independent variable which in prediction model can be fitted by the \( \ln(\text{independent variable}) \) (Dohoo et al., 2003). Accordingly, in the regression analysis of ECM response to energy intake the curvilinear model using the term of natural logarithm to NEL intake \( \ln(\text{NEL}) \) was superior to a model with quadratic or linear effect of NEL intake. However, most previous literature on diminishing marginal milk responses was made by use of quadratic prediction models (Blaxter, 1966; Huhtanen and Hristov, 2009; Huhtanen and Nousiainen, 2012). Comparing the ECM prediction models (Paper 2) with the ECM production responses from the herd data (Paper 3) an unexpected shape of the curve was seen. For the herd data the marginal ECM responses of both between and within herd showed an increased effect of
NEL intakes. Given the use of same variables as in the ECM prediction models (Paper 2) the negative parameter estimates for ln(NEL) in herd data caused an increased marginal response. Though for the within data a model including interaction between stage of lactation and NEL intake the estimate was not significant. However, the responses in herd data were most likely influenced by non-controllable factors like management as opposed to experimental data.

Likewise the curvilinear ECM prediction models the prediction models of daily gain to increased NEL intake in early lactation had a curvilinear shape for both primiparous and multiparous cows at DIM 30, 60 and 90. The decreasing marginal response in daily gain which implies that the effect of extra NEL intake is larger at low NEL intake levels than at high levels was not expected (Paper 3). Contrary to this an increased marginal daily gain with increased NEL intake from a downwards curvilinear response was expected; as it was shown by Agnew et al. (1998) where low ME intake resulted in small responses and high ME intake resulted in large responses within ME intake ranging from 120 to 240 MJ/d. However, composition of body tissue gain (e.g. muscle versus fat) will greatly influence the response and explain the different responses obtained.

4.4. Genetic and management factors

The partitioning of energy between milk and body tissue is partly genetically driven (Friggens and Newbold, 2007) and dairy cows selected primarily for higher milk production also partition less energy into body tissue than do low genetic merit cows (Agnew and Yan, 2000). In the previous Danish model of the ECM response to increased net energy intake an effect of milk yield capacity was also included, where the expression yield capacity is influenced of both genetics and environment (Kristensen et al., 2003). From this, differences in the responses to energy intake were expected between the breeds in our analyses. Though, with the data used from the production trials (Paper 2) only the intercept values differed between the breeds with no interactions between breed and NEL intake resulting in the same marginal ECM responses within the breeds.

In the data set used for estimating the prediction models of daily gain (Paper 3) where only the breeds DH, NR and SR were included, there was no effect of breed on the daily gain estimates or interaction of breed to the NEL intake level. Likewise, there was found no breed differences during early lactation in a trial on energy partitioning within Holstein-Friesian and Norwegian cows (Yan et al., 2006), where the Norwegian cows were comparable to the NR breed in our study. Though, breed differences among DH, DR and DJ for live weight changes has been found. In a study on energy balance patterns DH cows showed significantly higher mobilization of body energy in early lactation compared to DJ and DR (Friggens et al., 2007).

Cows with higher LW have a higher requirement of NE for maintenance; however, the NEL from NorFor used in our analyses was a measure of total NEL and not corrected for requirements of maintenance and growth. In order to correct the NEL intake for growth there was a lack of data, as live weight registrations in trials with Latin square design were not appropriate for calculating daily gain. There would also be a need for assumptions on the energy values of growth in terms of deposition or mobilization which were not obviously available. Also when the cow eats more and produces more milk, the total energy use, especially milk energy output, increases and the energy needed for maintenance is
In Paper 2 the analysis of different ECM responses to increased NEL intake between the breeds there was no interaction between NEL intake and breed. This is possibly explained by the energy evaluation system in NorFor and maintenance requirements. In NorFor the rumen fractional passage rate decreases with increased LW for a given feed ration (Volden and Larsen, 2011). This will result in more parallel responses between breeds; especially between the breeds with higher vs. lower LW (e.g. DH vs. DJ). In Paper 2 only different intercept values for breed specific ECM prediction models was found. Also AAT estimates in NorFor are highly affected as efficiency of microbial synthesis is related to the DMI to BW ratio (Volden and Larsen, 2011).

The effect of genetic merit on milk responses as taken into account in the previous Danish milk production response function (Kristensen et al., 2003) was also tested in the ECM prediction models (Paper 2). This was done by using the individual trials within the data set as an expression of yield capacity (production level). However the analyses of an ECM prediction model including the interaction between NEL intake and trial showed no effect. This indicated similar marginal ECM responses to NEL intake independently of yield capacity or too little variation between trials regarding yield capacity. In accordance with this Huhtanen and Nousiainen (2012) found no effect of mean milk yield level on ECM responses of increased ME supply. Also earlier studies reported no interactions between genetic merit and diet on milk production responses (Veerkamp et al., 1994; Ferris et al., 1999).

The effect of genetic merit on milk production responses was to some degree substantiated with the analysis of the ECM production responses in the herd data by the larger effect of NEL intake from between herd data compared to within herd data (Paper 4). The ECM responses to NEL intake from the between herd and the within herd models were particularly different at the high NEL intake levels. This suggests that using a herd specific response curve in relation to optimization of the feeding level within a herd would be appropriate. As in previous milk response models a mean herd yield level could be the factor controlling which level of response curves to use. Another possibility might be to use coherent registrations of energy intake and milk production in the specific herd as the herd data used in Paper 4. These herd specific registrations are expected to be generally available in near future for the Danish dairy farmers using NorFor and with these data adapting the general ECM production function (Paper 2) to a response function for the specific herd (Jensen, 2013). A method for the herd specific calibration is to use the principle of dynamic linear modeling where the ECM response parameters are sequentially estimated as new observations becomes available and recent observations will weigh more than older ones (Kristensen, unpublished).

Nutrition and genetics are not the sole factors for affecting the herd yield within a specific herd, as management is also a very important factor. As much as 56 % of the observed variation in milk production (13 kg/d) has been found to be explained by the nondietary factors like ‘age at first calving’, ‘presence or absence of feed refusals’, ‘ratio of number of free stall per lactating cow’ and ‘use or no use of feed push up in the feed bunk’ in a study where forty-seven herds were offered the same TMR ration (Bach et al., 2008). In commercial herds it is more difficult to control production input variables compared to controlled experiments in research stations, where exact feed intake at cow level is measured and combined with feed analysis of all individual feed stuffs. Though information on production system, housing and milking systems were available in the herd data (Paper 4) the...
management of each herd could have varied during the one year period of registration. Therefore, when analyzing the deviance between actual and predicted ECM in commercial herd data (Paper 4) using the ECM prediction models of Paper 2 the management of the herds might be a possible factor of explanation. A possible ‘connection’ between the decreased deviance in ECM at increased ECM yield in the herd might be the fact that high yield is not only achieved by high energy intake but also demands a high level of management, thereby both milk yield and management level has increased with increased energy intake. This was related to the effect of yield capacity in previous milk production responses (Figure 1) where a change to a higher placed response curve was obtained by genetic and/or environmental changes and not by just increasing the energy intake level. In the study by Kristensen et al. (submitted) comparing efficiency measures, milk production and feed intake for lactating cows also in commercial herds it was found that only 8% of variation in net energy efficiency could be explained by differences in feeding where the net energy efficiency was defined as total energy requirement in percent of net energy intake. Furthermore among the herds with high or low energy efficiency (top or bottom 25%) it was also found that the effect of NEL intake on ECM production was higher for the high efficiency herds (Kristensen et al., submitted).

4.5. Production response in terms of milk and growth

Dairy cows rely upon both increased feed intake and mobilized body tissue to meet their energy needs during early lactation. Quite large changes in live weight of the cow can be found due to variation in size of lipid stores and thereby in their potential to mobilize in early lactation. The physiological mechanisms that enable the cow to achieve greater yields of milk almost always include a period of negative energy balance and thereby possible suppressed immune and reproductive performance (Collard et al., 2000; Ingvartsen et al., 2003; Walsh et al., 2011).

The traditional calculation of the energy balance by energy input minus energy output (Friggens et al., 2007) can give a rough estimate of the energy balance for the cows. When the energy balance is zero, the net energy from feed intake equals the sum of energy for milk production, growth, gestation, maintenance and activity. In NorFor the net energy value for maintenance and activity, growth in primiparous cows, milk production and daily gain as mobilization or deposition is calculated by application of these energy requirements (Nielsen and Volden, 2011):

\[
\begin{align*}
NE_{\text{maint+act}} &= 0.29256 \times LW^{0.75} \times 1.1 \\
NE_{\text{growth}} &= 0.00145 \times LW + 12.48 \times DG + 0.68 \\
NE_{\text{milk}} &= ECM \times 3.14 \\
NE_{\text{dep}} &= DG \times 31 \\
NE_{\text{mob}} &= DG \times 24.8
\end{align*}
\]

where \(NE_{\text{maint+act}}\) is energy requirement for maintenance and activity in MJ NE/d; \(LW\) is live weight of cow in kg; \(NE_{\text{growth}}\) is energy requirement for growth in primiparous cows in MJ/d; \(DG\) is daily live weight gain in g/d; \(NE_{\text{milk}}\) is energy requirement for production of ECM in MJ NEL/d; \(ECM\) is energy corrected milk yield in kg; \(NE_{\text{dep}}\) is the energy deposited in MJ/d and \(NE_{\text{mob}}\) is energy mobilized in MJ/d.

The equations given above were used to combine the milk and growth responses from Paper 2 and Paper 3 in terms on net energy by computation based on the prediction models of milk and growth.
responses. The predicted ECM production at a given NEL intake level was calculated using the ECM prediction models for primiparous and multiparous cows, respectively. Likewise, the predicted daily gain at given NEL intake was calculated using the daily gain prediction models at the stages of lactation with DIM 30, 60 or 90 for primiparous and multiparous cows, respectively. Calculation of requirements for maintenance and activity used the mean LW of DH in data from early lactation period for primiparous (547 kg) and multiparous (611 kg) cows. In NorFor there is no assumption of growth in multiparous cows. There is no energy requirement for gestation in first 150 days of gestation. Therefore the energy requirement for gestation was not included in the calculations, as the data was from early period of lactation assuming that no cows were at 150 days of gestation during the trial periods. The energy used for maintenance and production in terms of milk and live weight change at minimum, mean and maximum NEL intake levels were summed up and the difference to the NEL intakes were calculated at DIM 30, 60 and 90, due to the DG predicted at these specific stages of lactation. In Table 1 the calculated energy expenditures are shown from the production responses in milk and live weight gain in early lactation for DH multiparous and primiparous cows at mean, minimum and maximum NEL intake levels from data range.

Overall the predicted net energy output of both primiparous and multiparous was higher than the net energy intake, indicating an overestimation in the production responses. At the mean NEL intake levels the difference in energy expenditure was from -20 to -3 MJ (3 to 17 %) for primiparous cows and from -23 to -6 MJ (4 to 16 %) for multiparous cows. At the maximum NEL intake levels at DIM 30 and 60 only the energy difference was positive. Among the daily gain at DIM 30, 60 and 90 the energy differences reflects the DG responses as discussed in Paper 2. In general the difference in the calculated energy expenditures to the NEL intake can originate from several factors like the use of means in calculations for feed intake through trial periods or the assumptions used for the calculations.

The assumptions of energy requirements for mobilization and deposition are to a large degree uncertain in that body tissue consists of lipid, protein as well as bone tissue and that 1 kg of live weight change in muscle requires lot less energy than 1 kg of fat as fat consists almost of no water contrary to muscle tissue consisting of 75 to 80 % water. The diminishing responses in daily live weight changes were modeled from +/- kg per day as output where the LW change with an energy unit as +/- MJ per day as output from specific conversion factors was another possible use of the LW registrations. From a production response in MJ deposited or mobilized the produced response curve might have supplemented the milk response curve to yield a linear response in energy use to increased energy intake. Also the measured live weight changes (Paper 3) were as total body weight with no correction as to empty body weight with adjustment for gut fill. In relation to the prediction models for daily gain they were fitted on a smaller data set than the ECM prediction models as the Latin square trials were excluded. Further the calculation of daily gain as deposition and mobilization can be vague as the data of daily gain as treatment means in data are estimated by linear regressions. Though the method of estimating the LW by linear regression for the individual cows was much preferred compared to a simple mean of LW at ultimo and primo of trial periods. However, with these data it is not possible to give a certain explanation as to whether the differences found in the energy expenditure was related to energy evaluation of the feed rations, prediction models of the daily gain or the maintenance
requirements. The NorFor system utilizes a linear milk response of 0.318 kg ECM per MJ NEL to milk production (Åkerlind and Volden, 2011). The NorFor system does not predict the changes in partitioning of NEL between milk yield and deposition/mobilization due to increased energy intake but utilize a standard curve for LW change according to parity and stage of lactation.

Table 1. Energy expenditure by production responses in milk and live weight gain in early lactation for DH primiparous and multiparous cows at mean, minimum and maximum NEL intake levels from within data range. Milk production (ECM) is average ECM prediction during early lactation, daily live weight gain (DG) is predicted daily gain at DIM 30, 60 and 90 (DG30, DG60 and DG90) and the balance between energy input (NEL intake) and energy output (Maint+ECM+DG) is given at DIM 30 (Diff30), DIM 60 (Diff60) and DIM 90 (Diff90).

<table>
<thead>
<tr>
<th>NEL intake, MJ</th>
<th>Primiparous</th>
<th>Multiparous</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Min</td>
</tr>
<tr>
<td>Maint, MJ</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>ECM, MJ (kg)</td>
<td>90 (28.6)</td>
<td>77 (24.4)</td>
</tr>
<tr>
<td>DG30, MJ (g)</td>
<td>-3.4 (-138)</td>
<td>-8.0 (-324)</td>
</tr>
<tr>
<td>DG60, MJ (g)</td>
<td>+4.7 (+152)</td>
<td>+0.1 (+4)</td>
</tr>
<tr>
<td>DG90, MJ (g)</td>
<td>+13.9 (+448)</td>
<td>+10 (+322)</td>
</tr>
<tr>
<td>Diff30, MJ</td>
<td>-3</td>
<td>-9</td>
</tr>
<tr>
<td>Diff60, MJ</td>
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<td>-17</td>
</tr>
<tr>
<td>Diff90, MJ</td>
<td>-20</td>
<td>-27</td>
</tr>
</tbody>
</table>

4.6. Methodological considerations

Data material and trials used

For establishing production responses to increased energy intake it is necessary to have production trials providing data where the energy level is an independent variable. And further, the trial designs should include a relevant range of energy intake. In the prerequisites for the trials included in the meta-analyses the energy levels within the trials was not determined according to previous obtained milk yields. This reduced the number of trials for inclusion. Especially the number of Swedish trials was reduced as there has been and to some degree still is a tradition of adjusting the energy level according to previous milk yield recording. Also several trials with changing levels of nutrients in rations were discarded due to lack of difference in energy levels between treatments within a trial. A broad survey of published literature would most likely have resulted in a larger number of trials but from those access to original data would not have been possible as was possible within the trials from Denmark, Norway and Sweden.

For all trials used in the meta-analyses the original data were accessible in order to recalculate treatment means separately for primiparous and multiparous cows and for some trials a cut off or a split of data for long term trials was made to fit the defined data periods of early and mid stages of lactation. These similar groups of parity (primiparous and multiparous) as well as the stages of lactation as early,
mid and late was used in the review of Coulon and Rémond (1991) based on 66 trials, however parity was only split in early period data. The trial design was considered not to have an effect on the milk production responses (Huhtanen and Hetta, 2012) wherefore both trials of block, continuous and Latin square design were included. For the growth responses the Latin square trials were not included, as the LW was not considered unaffected by carry-over effects of previous period treatments and the short period in Latin square trials for obtaining a change in live weight gain.

Modeling procedure

Use of the same model reduction process in all sub data set enabled comparisons of models and estimates between parity and stage of lactation. The Early Multi data was chosen as outline for the model reduction process due to the largest number of observations. Among the ECM response models of Early Multi no single best fit model was determined as it differed depending on selection criteria (Chi-square tests, AIC or BIC), where BIC penalizes larger models heavily compared to AIC (West et al., 2006). In the case of applicability of a model according to relevance or availability of nutrient value of feeds the full NUTR-model or the reduced lnNEL-model might be the most feasible, respectively. Using a model including both energy and nutrients intake will enlarge the probability of a valid response in the case of extrapolation. However, the use of prediction models based on DMI implies independence of specific feed and energy evaluation systems.

To assess the goodness-of-fit a coefficient of determination (R²β statistic) for the linear mixed model (Edwards et al., 2008) was used as the R² usually used with linear regression is not applicable with mixed models. The R²β statistic compares the full model with a null model with all fixed effects deleted except typically the intercept. The R² known from ordinary linear regression models is usually interpreted as the larger the R² value the better the model describes data, which is also the principle used for the R²β statistic. In the regression analyses on ECM prediction models (Paper 2) the R²β statistic decreased when adding predictors in several of the models. However, according to Edwards et al. (2008) “adding a predictor in the fixed effects (between-subject effect) can increase the estimated variance of the random effects (within-subject effect) and hence increase the estimated variance of the response”. This was found to be the case for Early Primi and Mid Primi data.”

Data level, individual versus group and between versus within herd

The motives for modeling within animal science can be several, such as to obtain additional understanding of a system like a ruminant digestion model, to enhance in filtering of data or to optimize management decisions in a production. The data material to be used in the modeling is often determined by the type of model produced. The new prediction models on production responses produced in this thesis were intended for use in an optimization of the feed energy level for a group of lactating cows. It was chosen that the data used for the modeling were at group level by using treatment means contrary to using individual cow observations for the input – output relationship. The general acceptance of a diminishing response curve for lactating cows has been questioned in relation to individual cows within a group contrary to the response for the group as one (Friggens et al., 1995; Agnew et al., 1998). This was the topic in the first study (Paper 1) where a profound difference in the
marginal ECM responses to energy intake between data of individual cows and data of treatment means was found. For the individual data the ECM response was nearly linear and thereby an almost constant marginal response which was found similarly in Paper 4 with the between herd data having only a slight increased marginal response to energy intake. Considering a potential diminishing return of the live weight gain at increasing NEL intake and in particular the increasing marginal cost for increasing the NEL intake, then even a linear NEL effect on ECM does not preclude an economic optimization of NEL intake from these response curves. In the meta-analysis the number of cows producing the treatment means varied between the trials, this was why the regression models included a term of weighting by the number of cows for each treatment. However, Agnew et al. (1998) did find curvilinear milk responses in a study with four cows and four ME intake levels (120 to 240 MJ). The decision to develop response functions based on group means was based on the typical feeding planning situation (group feeding) and to improve the 'dose-response' characteristics of the function. The dose-response characteristics can be questioned to a larger extent by analyzing individual cow data, where energy intake can also be a consequence of the actual milk yield. The weighting values applied to the treatments take account for the fairly low number of trials and heterogeneous number of cows to give more weight to the data from treatments with more cows behind leading to better accuracy.
5. **Conclusion**

The main findings of the thesis were:

- Empirical prediction models of milk production responses and live weight changes were developed specific to parity, stage of lactation and breed.
- The milk production responses from the between herd data were different from the within herd data with a larger effect of NEL intake on ECM response.
- The non-nutritional factors stage of lactation, feed ration characteristics and chewing index influenced the deviance between predicted ECM by estimates of experimental data and actual ECM in commercial herd.

In the meta-analysis there was found diminishing curvilinear ECM responses to increased NEL intake. Parity differences were found in models based on DMI as well as NEL intake. For multiparous cows the ECM response was higher than for primiparous cows. Breed specific responses were parallel and only differed by their intercept. Models based on NEL slightly improved prediction of milk yield compared to DMI. Including the nutrient intake variables NDF, AAT and crude fat further improved model fit. The marginal ECM responses to increased energy intake decreased diminishingly.

In the analysis of live weight changes in production trials of DG at DIM 30, 60 and 90 empirical prediction models were developed. The DG responses to NEL intake level was increasing curvilinear at a decreasing rate for both primiparous and multiparous cows. Though, multiparous cows had larger LW losses at low NEL intake but also a larger response to increased NEL intake than primiparous cows. The LW change to increased NEL intake of multiparous cows at DIM 30 was higher than at DIM 60 and 90 with DG at DIM 90 being lowest. The prediction models included only effect of NEL intake as there were no effects of any ration nutrients. It was in this analysis not possible to find any breed differences in DG estimates.

In the analysis of deviance in ECM between prediction estimates of experimental data and actual ECM in commercial herd the main factors explaining this deviance in DH, DR and DJ of plus 4, 1 and 2 kg, respectively, were stage of lactation, feed ration characteristics and chewing index. Of the deviance 47% could be explained by these factors not attributed to the energy and nutrient variables in the prediction model. ECM response functions based on between or within herd data showed similar response levels to increased NEL intake as compared to ECM response from experimental derived model when correcting stage of lactation in herd data to match an early lactation period (DIM 70). There was a larger effect of NEL intake on ECM response in the between herd data than the within herd data and for the between herd data there was a larger response for DH than DJ. The difference in the response curves of between and within herd data indicates that further work herd with specific ECM prediction models is required.

In the analysis on use of individual versus group level data, the results substantiated the work of modeling the production responses of milk and growth based on group level data in terms of treatment means of the previous production trials. The developed prediction models with new response estimates of ECM and daily gain are valid within the limits of application according to stage of lactation and range of NEL and nutrients intake.
Based on these conclusions of the analyses on the data of previous production trials and commercial herd data there does not seem to be basis for a linear ECM response to increased NEL intake in the NorFor system neither does the ECM and live weight change responses imply that the NEL not found in the ECM produced can be found in the live weight change. Finally both the study on individual cow versus group level data and the study on between versus within herd data does provide the basis for differences in milk production responses to differ between herds.
6. Perspectives

The overall aim for the dairy producer must be a production that constantly achieves highest possible revenue. This thesis contributes to knowledge on milk and growth responses to increased energy intake based on the non-additive feed evaluation system NorFor. It is with this thesis suggested that the prediction models for milk production in early lactation specific to primiparous and multiparous cows can improve the basis for a model of economic optimization of the feeding level to dairy cows. Especially in combination with development of a method of calibration to a herd specific response function to also take into account the differences among herds in management and genetics. Further investigations are necessary to analyze possible carry over effects of the energy intake level in one period on the following period, where the periods could be different parity but most likely different stages of lactation within same parity to give basis for an effective implementation of how and when to use the optimization.

In general the times for using a model of economic optimization is whenever the prices of either feedstuffs or milk changes. However, the production response functions are intended for use in optimizing the feeding level at regular intervals, when making feed budgets or when changing feed stuffs such as the use of new roughage or use of new supplemental feed stuff. In practice there are still some challenges in obtaining valid live weight registrations or estimating live weight changes, also possibly by use of model for estimating empty body weight. With high numbers of automatic milking systems the live weight registrations are easily accessible. Along with the automatic milking system registration of and controlling the concentrate feeding is possible or using stationary concentrate feeders to differentiate the concentrate feeding which is pointing in the direction of individual optimization of feeding level. As for the herd specific calibration of the milk response function based on coherent registrations of feed intake and milk output these registrations on individual concentrate feeding and milk production could also be used in dynamic modeling of milk yield response to concentrate intake for the individual cow.

Finally in relation to implementation of the model of economical optimization the question is still about the overall aim for the dairy producer – what about a quite settled desire or tradition to produce the highest possible amounts of milk and in the light of the future with no EU quota on milk production?
7. References


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