



Predictions for voluntary dry matter intake in dairy cows

Skattning av dagligt torrsustansintag hos mjölkkor

by Sofia Arnerdal



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Examensarbete 211

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**Supervisor: Torsten Eriksson, Inst f husdjurens utfodring och vård, SLU
Anders H Gustafsson, Svensk Mjolk**

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Abstract

The objective of this thesis was to compare and evaluate five different dry matter intake (DMI) models and to find factors important for DMI prediction based on data from studies conducted in Sweden, Norway, Denmark and Finland. Differences between intake models and the input factors used for calculation of dry matter intake for lactating dairy cows are described. Five different systems for calculation of the dry matter intake (DMI) for dairy cows were evaluated. The systems described and evaluated are LFU (Lantmännen feed division), CNCPS (Cornell Net Carbohydrate and Protein System), NRC (National Research Council), DFFS (Danish Fill Factor System) and NAAT (Norwegian AAT). The data used in the evaluation part originated from Sweden, Denmark, Finland and Norway. The data used in the meta-analysis was compiled for use in the development process of the new common Nordic feed evaluation system named NorFor.

The DMI prediction systems were compared using linear regression between DMI observed and DMI predicted by the different systems. Correlation analysis was used to select the factors' relationships.

The most important factors for DMI prediction, based on correlation analysis, are milk yield, week of lactation, concentrate proportion of feed and Neutral Detergent Fibre (NDF) content of feed. A conclusion from this work is a recommendation to the NorFor project group to choose the DFFS system as a basis to further develop their feed evaluation system, NorFor Plan.

Sammanfattning

Syftet med detta arbete var att jämföra och utvärdera fem olika modeller för skattning av dagligt torrsbstansintag hos mjölkande kor baserat på nordiska data samt att undersöka vilka faktorer som är viktiga för beräkningarna. Fem olika modeller för beräkning av torrsbstansintag utvärderades och sambanden mellan faktorer som påverkar dagligt torrsbstansintag undersöktes. Modellerna som utvärderades var LFU (Lantmännens FoderUtveckling), CNCPS (Cornell Net Carbohydrate and Protein System), NRC (National Research Council), DFFS (Dansk FyllnadsFaktorSystem) och NAAT (Norsk AAT).

Utvärderingen baseras på data från försök utförda i Norge, Danmark, Sverige och Finland. Systemen har jämförts med hjälp av linjära regressioner mellan observerat och skattat intag. De olika faktorernas inbördes förhållanden har undersökts med hjälp av korrelationer.

Resultatet blev en rekommendation att vidareutveckla det danska systemet, DFFS, för att användas i det kommande Nordiska fodervärderingssystemet, NorFor Plan. De viktigaste faktorerna för skattning av dagligt torrsbstansintag enligt korrelationsanalysen på detta dataset var: mjölkavkastning, laktationsvecka, andel koncentrat i foderstaten samt totala NDF-halten i foderstaten.

Abbreviation list

ADF	Acid Detergent Fibre
cii	Corrected SDMI
CNCPS	Cornell Net Carbohydrate and Protein System
CP	Crude Protein
DFFS	Danish Fill Factor System
DM	Dry Matter
DMI	Dry Matter Intake
ECM	Energy Corrected Milk
eNDF	Effective Neutral Detergent Fibre
FCM	Fat Corrected Milk
FE _m	Feed unit for lactating cows (Norwegian)
FF _L	Fill Factor for lactating dairy cows
FU	Danish Feed Unit
IVDOM = VOS	In Vitro Digestible Organic Matter = Vomvätskelöslig organisk substans (Swedish method)
K _L	Intake capacity (Danish)
LFU	Lantmännens feed division
ME	Metabolizable Energy
MSPE	Mean Square Prediction Error
MW	Metabolic live weight
NAAT	Norwegian AAT model
NDF	Neutral Detergent Fibre
NRC	National Research Council
OMD	Organic Matter Digestibility
PDM	Proportion of feedstuff in dry matter
PMR	Partly Mixed Ration
RMSPE	Root Mean Square Prediction Error
SDMI	Silage Dry Matter Intake index
TMR	Total Mixed Ration
VFA	Volatile Fatty Acids

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Introduction

NorFor was planned during 2001 and started off as a project in 2002 with a mission to convert the different feed evaluation systems in the Nordic countries to one common system. The idea was that one common system in these countries, Denmark, Iceland, Norway and Sweden, would facilitate communication and use of research resources, which in turn would lead to increased efficiency and revenue. The advisory organisations that participate in this project are TINE (Norway), Svensk Mjök (Sweden), Dansk Kvæg (Denmark) and Bændasamtök Íslands (Iceland). The NorFor feed evaluation system is to be introduced in the autumn of 2005 (Gustafsson and Udén, 2004).

During the process of developing a common system, there was a demand to obtain more information about the different intake models that are used today for lactating dairy cows in the region. The group also wanted to evaluate other models that could be possible to apply in this area. In the new system the intake model should be adapted to the region's specific feeds, breeds and climate. Choosing the system is however difficult. There are several candidates for the new common system for example models based on regression such as NRC (National Research Council), CNCPS (Cornell Net Carbohydrate and Protein System) and more complex models based on fill values such as those used in Denmark and France today.

Another important issue is the relative importance of the input parameters used in each model for DMI (Dry Matter Intake) of lactating dairy cows. More knowledge of the factors that influences dairy cow DMI is vital for farmers' economy and also for the environment. Better diets to dairy cows can lower eutrophication emissions of nitrogen and phosphorus from the farms (Faverdin *et al.*, 1995). There will also be lower methane emissions if the diets are well balanced. Methane is one of the more potent green house gases and emissions of methane therefore speed up the climatic changes.

The objective of this thesis was to evaluate the five intake models of LFU (Lantmännen feed division), CNCPS, NRC, DFFS (Danish Fill Factor System) and NAAT (Norwegian AAT) in a meta-analysis with data from studies conducted in Sweden, Norway, Denmark and Finland. This thesis was intended to be used as discussion material in the decisive process of choosing an intake model that will be further developed in the Nordic co-operation.

Literature study

Factors affecting intake

There are several factors influencing the DMI of lactating dairy cows and knowledge of these factors is therefore vital when developing an intake model. Since it is not always possible to measure or obtain an exact value for each factor it is important to know how these factors interact and if they are correlated in any way which, in turn, could give possibilities to exclude one or more factors that are strongly correlated. Table 1 shows an overview of the parameters that may influence the DMI of lactating dairy cows.

The feed intake is regulated on both a long- and short-term basis. The short-term regulation consists of stretch and mechanical receptors of the rumen wall, hormonal signalling *etc.* (Faverdin *et al.* 1995). In long-term regulation the most important factors are nutritional requirements and body reserves (Faverdin *et al.* 1995). The long-term regulation factors are most often found among the animal factors (Table 1). The short-term regulation factors are often found among the dietary factors. These factors indicate the importance of knowing the feed composition and gastrointestinal functions of the dairy cow.

Table 1. Factors affecting the voluntary intake of dairy cows (modified after Ingvarsen, 1994 and Kjos, 2002)

Animal factors	Dietary factors	Environmental factors
Breed	Diet composition	Duration of access to feed
Genetic potential	Chemical composition	Frequency of feeding
Live weight	Digestibility	Separate vs. Complete feed
Age	Degradation profiles	Tie stalls vs. Loose housing
Parity	Rate of passage	Area per animal
Milk yield	Physical form	Space at manger
Stage of lactation	Conservation	Photoperiod
Gestation	DM content	Temperature
Previous feeding	Fermentation quality	Humidity
Body condition	Palatability	
Fatness	Mineral salts, alkaline agents	
Eating velocity	Food additives	
Rumen activity		
Health status		
Anabolic agents		

Animal factors

Long-term regulation is often represented in the intake equations by body condition score, production level and energy efficiency. These types of factors are often referred to as animal factors when discussing intake regulation.

The main factor affecting daily DMI is the energy requirement. The energy requirement depends on the ambient temperature, physical activity of the animal and the milk yield (Faverdin *et al.*, 1995). The milk yield is probably the most obvious factor affecting the energy requirements of the dairy cow.

Milk yield measurements as variable for prediction of DMI are used differently in different models. LFU and NAAT use total milk; NRC and CNCPS use fat corrected milk; and DFFS uses energy corrected milk. Roseler *et al.* (1997) stated that milk yield accounted for up to 45% of the variation in DMI during early lactation. Among the measures of total milk, energy corrected milk, fat corrected milk and milk protein yield, milk protein yield showed the strongest correlation with DMI. Total milk and energy corrected milk were correlated with DMI at a similar level, 0.61 and 0.62, respectively and fat corrected milk was slightly less correlated with DMI (0.58) whereas protein yield showed a higher correlation (0.69) with DMI (Roseler *et al.*, 1997).

According to NRC (2001) the intake capacity is dependent upon the milk yield, not *vice versa*. This is based upon lactation studies with bovine somatotropin where DMI followed the milk production (Etherton and Bauman, 1998). Friggens *et al.* (1998) performed a changeover study where dairy cows were fed a ration with a high proportion of concentrate until day 153 in milk when they received a feed ration with a low proportion of concentrate and *vice versa*. At the time of change from the high to the low concentrate proportion ration, the milk yield did not decrease to the same level as that when the experiment was initiated at a low concentrate proportion. The DMI however, decreased to the same level of the cows fed a low proportion of concentrate. That is, the DMI was not related to the milk yield at that point. These investigators also found that the stage of lactation did not affect the DMI with the low concentrate proportion. For cows fed rations with a high concentrate to roughage ratio the DMI declined with the days in milk.

Nevertheless, the DMI more or less follows the milk yield of the dairy cow. This is depicted in Figure 1 showing the milk yield and the DMI over the lactation period. The diagram also supports the results of Friggens *et al.* (1998) as it shows converging curves for the intake of cows fed rations with a high protein content.

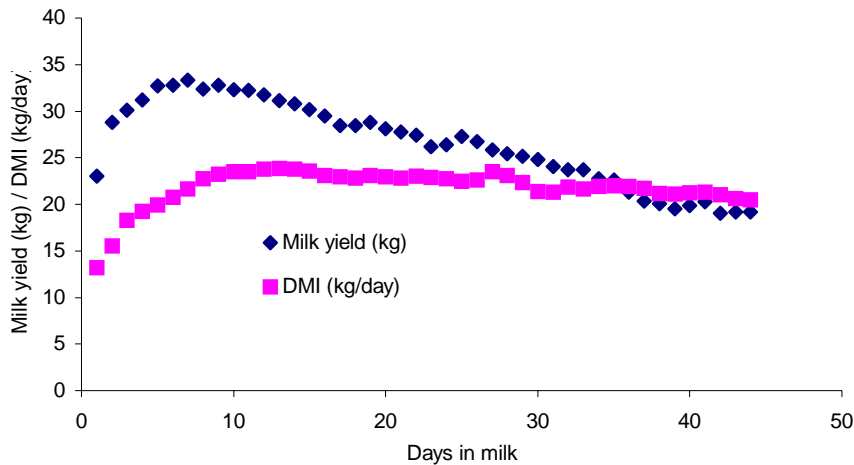


Figure 1. The average DMI of dairy cows fed a high-protein diet together with the average milk yield. Based on data kindly supplied by Ingvarsten and Jensen (2001).

The maximum DMI capacity for the lactating cow is reached during the 10th - to 14th week of lactation whereas the peak milk yield is reached at 4- to 8 weeks after parturition (National Research Council, 1989). The lag is longer with roughage diets and usually longer for heifers than for multiparous cows (Forbes, 1986). This means that there will be a gap in energy demand unless the energy concentration of the diet is adapted to the needs of the cow. In intake prediction models this is often taken care of by a lag-function, which increases the DMI exponentially depending on lactation week or days in milk in the intake equation. This concept is used in the CNCPS and NRC equations whereas some other systems do not consider this factor. One reason for not considering this factor is that during the first weeks of lactation, high-yielding cows are commonly fed highly concentrated, highly digestible feeds to satisfy their energy needs.

In late lactation, the intake is severely decreased due to low milk yield and the growing foetus (calf) is requiring more space, so that the rumen volume is diminished. This effect should be more apparent in cows that are fed bulky rations consisting solely of roughage. However experimental cows that were fed only concentrates also decreased their intake in late pregnancy (Forbes, 1986). Another explanation could be an effect of high levels of oestrogen in late pregnancy. Cows that were given progesterone subcutaneously increased their intake, but these animals experienced a prolonged gestation period (Forbes, 1986).

When using metabolic live weight ($MW = \text{live weight}^{0.75}$) and assuming that the DMI is a constant per kg MW, intake is generally underestimated at low live weights and overestimated at high live weights (McDonald *et al.*, 2002). It would render a better fit if allometric or logarithmic dependencies on weight were used (Ingvarsten, 1994).

Dietary factors

Different feedstuffs have different impacts on digestion in cows. These variables *e. g.* concentrate proportion, digestibility, NDF (Neutral Detergent Fibre), NH₃-N and fermentation acids are often referred to as dietary factors. The dietary factors can be divided into digestibility/fill and palatability properties of the feed.

Many attempts have been made to find a simple measurable factor for the digestibility/fill of the feed. The filling effect of the feedstuff is often described by the fibre fraction represented by NDF, effective NDF, crude fibre or other analysable fractions related to fibre. Van Soest (1965) showed that the voluntary intake of cows is negatively correlated with the content of cell wall structures in the feed and that the fibre fraction of the feed becomes limiting at concentrations around 50- to 60% of the forage dry matter. Mertens (1980) showed that NDF was highly correlated to the fill or bulk density of feeds. On the other hand, Roseler *et al.* (1997) concluded that the filling factors (for example NDF) are not limiting when cows are fed high energy, highly digestible diets. In their study, on the development and evaluation of feed intake predictions for Holstein dairy cows, NDF accounted for less than 1% of the variation.

NDF is important for rumination, saliva flow, ruminal buffering and health of the rumen wall. It is also important to have an adequate intake of NDF for dairy cows as it prevents depression of milk fat. The total NDF fraction does not affect the rumen activity and the milk fat content; the particle size of the fibre fraction is also important. NDF particles larger than >1.18 mm do not continue passage to the *omasum* directly as do smaller particles. Instead these particles are delayed in the *rumen* for rumination. These larger particles are referred to as effective NDF (eNDF) a factor used in CNCPS calculations for example. (Fox *et al.*, 1992 and Eriksson, 1998). Hence, eNDF has been suggested as a better predictor of the rumen fill (physical limitation) than NDF (Fox *et al.*, 1992).

The proportion of concentrate or total amount of concentrate per day in the ration is used in several DMI prediction calculations (Mertens, 1987; Rook *et al.*, 1991). Ingvarsten (1994) presented these and many others in an overview of voluntary food intake predictions.

The palatability of a feed is a common expression for the willingness of the animal to eat a specific feedstuff. The word palatability means tastiness, which is a factor that is very difficult to measure. What is possible to measure is feed intake and feed preferences, but these factors are in many studies referred to as palatability. It is sometimes represented by the fermentation quality of a silage but other factors affecting the palatability of a feedstuff can include thorns and faecal contamination (McDonald *et al.*, 2002). Palatability may also be used in a broader sense in association with high digestibility.

The palatability of the roughage (silage) is often represented by its content of acids and nitrogenous compounds, referred to as fermentation quality. Silages with a high concentration of nitrogenous compounds or organic acids related to propionate production in the ensiling process result in decreased palatability (Huhtanen *et al.*, 2002). According to these researchers, the main fermentation factor that affects the DMI of silage is the amount of total acids, which in their meta-analysis of 234 experimental diets accounted for approximately 0.40 of the variation in the studies included. Lactic acid and ammonia N followed. On the other hand, Ingvarsen (1994) stated that no scientific results confirm a causal relationship between increased concentration of butyric acid and reduced silage intake. Nevertheless he found it appropriate to include this factor when calculating DMI as butyric acid seems to be related to some yet unknown fermentation product that decreases the DMI, probably due to changed palatability or chemical signals in the rumen. Huhtanen *et al.* (2002) concluded that the smell or taste of a feedstuff may impact the choice of a meal or the termination of the meal, but the mechanisms controlling the DMI of the silage are more complicated and involve metabolic mechanisms.

Apart from palatability there are other feed factors that influence the DMI, for example metabolites. Infusion of VFA (volatile fatty acids) into the rumen decreases the DMI in lactating cows though the effect is less evident in dry cows. The sensitivity to VFA seems to increase with the level of DMI. A proposed explanation for the increased sensitivity to VFA is that high-producing animals could have problems enduring nutrient supplementation due to adaptation problems in the liver and the digestive tract (Faverdin *et al.*, 1995). It seems as if the animals need time to adapt their gastric functions to the increased level of nutrient supplementation (Faverdin *et al.*, 1995). According to McDonald (2002) the effect of infusion of VFA on DMI is less evident if the cows are on a roughage-based diet, which is often the case for dry cows.

Environmental factors

Examples of environmental factors are housing conditions, climate, photoperiod, feeding frequency *etc.* According to Faverdin *et al.* (1995), a satiated animal can be induced to eat more if a new portion with fresh forage is presented. Stables with loose housing result in a somewhat higher DMI than tie stalls since the cows move around more (Hvelplund and Nørgard, 2003). McDonald *et al.* (2002) reported that the photoperiod did not affect DMI of cattle.

Different approaches to developing dry matter intake equations

Regression

A model that is developed with simple or multiple regression analysis has several drawbacks. It is only possible to implement the model very specific and identical circumstances. It can be stated that a regression model is based on empirical data, measured in a specific group of animals. The circumstances could include factors

such as type of feed, feed management, breed, parity, housing conditions and climate. DMI predictions based on regression do not represent the regulation system of the animal; instead these demonstrate a correlation between variables and food intake. Therefore these models do not explain the underlying factors and functions of the biological system, but can nonetheless be a good predictor of DMI within specific populations (Yearsley *et al.*, 2001). On the other hand regression models are easy to understand and can yield good predictions when used under identical circumstances. However, when the models are used outside of their own ranges precision is often impaired. Four of the systems evaluated in this thesis are based on regression calculations.

Fill values

The fill unit systems in Denmark and France are additive systems that can be used under varying circumstances. The fill unit systems predict the amount of the feedstuffs the animal will eat voluntarily based on the feedstuffs' fill values. The intake capacity of the animal is a regression of the energy requirement based on the expected milk yield. It is calculated separately and corrected for animal factors such as breed, weight and production level. The dry matter intake is then calculated by dividing the intake capacity with the total fill value of the fed portion. $DMI = \text{intake capacity} / \sum pDM_i \times FF_{Li}$ where pDM_i is the proportion of the feed i included in the diet and FF_{Li} is the fill factor (value) per kg dry matter of feed i . The problem is that it is complicated to make a correct estimate of the feed's fill value. Other feed properties than its actual rumen volumetric fill are often included in the fill value, for example palatability. The fill value is also a measurement of the feed's energy concentration.

Dynamic models

Dynamic mechanistic models often describe interactions between the different feeds in the animal and also the metabolic signals. These models can be very complex and require many input variables. Therefore, these models are more appropriate for research use than on the farm according to Faverdin *et al.* (1995). However, increasing computer capacity has improved the possibilities to develop dynamic and mechanistic models for practical use. The vision for the dynamic model development is to be able to simulate different feed alternatives in a herd and predict the production level. Karoline is a dynamic model that is developed for the Nordic countries and will be a part of the NorFor system (NorFor, 2004). Future development of the Karoline model involves an intake model.

About the different intake equations

The DMI has been calculated according to five different methods:

- LFU Feeding recommendations by Lantmännen (Lindgren *et al.*, 2001)
- CNCPS Cornell Net Carbohydrate and Protein System (Fox *et al.*, 2004)
- NRC National Research Council (National Research Council, 2001)
- DFFS Danish Fill Factor System (Hvelplund and Nørgard, 2003)
- NAAT Norwegian AAT-model (Volden, 2001)

Among these models LFU, CNCPS and NRC are somewhat simpler than the other two as fewer factors are considered. These three are based on knowledge about the physical and physiological limitations for DMI of dairy cows. The calculations do not consider the feed characteristics and are all based on regression analyses. DFFS and NAAT take animal and feed factors into consideration. DFFS uses an additive model where feed factors such as digestibility, energy concentration and DM content are totalled to obtain a fill value for each feed. NAAT uses NDF and silage quality (NH₃-N and fermentation acids) as feed factors.

Table 2 shows those factors presented in Table 1 that are actually used in the different calculations.

*Table 2. Factors included in the calculations for each model are shown in **bold text**. Factors possible to use in the model but not included in calculations presented in this study are shown in regular text*

Model	LFU	CNCPS	NRC	DFFS	NAAT
Factors included in the model	- Milk yield	- Live weight - FCM - Days in milk	- Live weight - FCM - Days in milk	- Parity - Days in milk - Expected milk yield - Race - Energy density - Legume content - Silage DM - FF₁/FU* - TMR - Stable type	- Live weight - Milk yield - Days in milk - Feed NDF content - Silage fermentation quality

*Fill value of lactating dairy cows to energy density ratio

When using a model with fewer factors, the excluded factors are considered to contribute very little to the total intake and/or are strongly correlated with those included. Hence, it is possible to use fewer parameters. The drawback of this exclusion is that the model loses in adaptability.

LFU

LFU is a system for feed evaluation developed by the major Swedish feed producer, Lantmännen (Feed division). In the development of this system simplicity was an important aspect and therefore the equation for DMI for lactating dairy cows is very simple. It consists of a simple regression where total milk is used as the only regressor. This was done since a strong relationship between DMI and total milk yield was found when developing this system. A relationship between energy supply and milk production was also found, but this relationship was much weaker than that between DMI and production. The LFU system is based on the intake capacity of the dairy cow and the content and quality of the feed nutrients. It is not based on energy- or AAT/PBV-calculations. According to the LFU system, it is not certain if DMI is triggered by milk production or *vice versa* (Lindgren *et al.*, 2001).

CNCPS

CNCPS (Cornell Net Carbohydrate and Protein System) is a system for feed management developed in the United States at Cornell University. The intake equation for this system is based on the weight of the animal and the fat corrected milk yield. There is a lag factor connected to this equation which takes into consideration the fact that maximum milk yield is reached before the intake capacity maximum is reached. CNCPS includes ambient temperature and the “muddiness” of the pen as factors. The complete formula has not been used in this evaluation since the environmental parameters were not recorded in the experiments. In Fox *et al.* (1992) possible corrections for the intake equation of CNCPS are presented. Corrections for age, breed, empty body fat, food additives, ambient temperature and mud are shown as multipliers for the basic calculation. These corrections have not been considered in this evaluation.

NRC

NRC is a net energy system developed for North America by the National Research Council based on data from Holstein cows and its latest revision was done in 2001 (National Research Council, 2001). The DMI equation of NRC contains only animal factors that are easily measured or known. The reason for not using dietary factors is that a DMI prediction is most often used to calculate the requirements of the animals before the actual feed ingredients are known. The NRC development group considered equations containing dietary factors were best used to evaluate the consumption observed rather than to predict the consumption in advance (National Research Council, 2001). In this system, the DMI is dependent on milk yield (fat corrected milk) and the weight of the cow. There is also, as for CNCPS, a lag factor included.

DFFS

The Danish system is a bit more complex than the three models presented above. As shown in Table 2, the system uses approximately 10 different factors when determining the DMI. The DFFS is based on the Fill Factor (FF) per kg DM of the feed, *i. e.* the feed's filling capacity. There are different calculations for lactating dairy cows (FF_L, fill factor for lactating dairy cows) and fattening cattle. The fill value is not only a measurement of the concentration in the feed, but also considers the DM content and the proportion of legumes in silages (Hvelplund and Nørgard, 2003). When calculating the intake it is necessary to have a great deal of data from the farm regarding the management system, animals and the different feeds as corrections are made for a broad spectrum of factors.

NAAT

In this system, developed mainly in Norway, the total DMI is calculated based on the NDF intake per kg live weight. The system is based on a model presented by Mertens (1987). Mertens found that the intake was regulated by either the fill of the feed or by the energy regulation of the animal. In this model a fixed level of NDF intake of 1.1% of the body weight is used. In the NAAT system, the NDF intake is a continuous variable. Other input variables are milk yield, cow weight and week of lactation. It also considers the quality of the silage using an adapted version of the Finnish Silage Dry Matter Intake index (SDMI) which is referred to as corrected intake index (cii) and corrects for content of acids and NH₃-N in silage. In the corrected intake index the energy term is omitted from the original equation to avoid redundancy when the model is solved with the aim to achieve energy balance.

The intake capacity formula included in the NAAT system today uses the feed ration as input parameter and must be solved numerically. When numerically solving the physical limitations part of the model for maximum forage intake, the aim is energy balance and the NDF intake per kg live weight is constrained to vary ± 0.1 g from the value calculated from the model (Kjos, 2002). Kjos' (2002) original proposal for the DMI estimation in the NAAT model contained two parts; one that calculates the DMI based on physical limitations and one based upon physiological limitations (energy satiation). Maximum forage intake was found at the intersection of the two calculations that allowed for numerically solving the equations in the applied model. In this thesis the emphasis is on the physical limitations, but the physiological results are also presented, because the intake of many of the evaluated diets may not have been physically restricted.

Material and methods

The data set

The data used in this project has been collected mainly for the development project of Karoline, a dynamic mechanistic model for feed evaluation (Internal name NKJ 111). Part of the data set was generated during the evaluation work in the NorFor project. There are 143 different observations from 26 different studies conducted in the Nordic countries. Unfortunately all parameters needed for the calculation of DMI according to the evaluated models were not collected in every study thus entailing much effort in searching for more parameters to include in the data set. An overview of the different studies and the models that have been applied to the different subsets is shown in Appendix I together with a review of the different studies and references.

All animals in the studies were fed roughage *ad libitum*. TMR (total mixed ration), PMR (partly mixed ration) and separate feeding methods have been used in the different experiments. No consideration has been taken to differences in feeding methods. Orts have been measured in all experiments. An overview of the different studies, milk yields and feed properties are presented in Table 3.

The average week of lactation for the experiments included in the study was 18, ranging from week 6- to 47 for the individual observations. The data has been analysed in MS Excel 97 and SAS v8 (SAS/STAT, 1999).

Table 3. Overview of the composition of the feed rations and the milk yield in the different studies, average values and range are presented. Modified from NorFor (2004)

Feed rations								Milk production			
Trial no	Dominating ¹ Roughage	DMI kg/day	Concentrate DM kg/day	Crude protein g/kg DM	NDF, g/kg DM	Starch g/kg DM	Kg milk/day	Kg ECM/day	Protein, g/kg milk	Fat, g/kg milk	
1	GH, GS	17	10	177	331	258	24	26	35	47	
2	LS, GS	21	7	202	349	52	29	28	30	42	
3	LS, GS	22	7	193	337	50	30	30	32	44	
4	LS	20	6	175	356	103	23	24	32	46	
5	GS	16	7	171	398	196	27	25	32	36	
6	GS	17	9	171	430	202	27	26	31	35	
7	GS	16	10	186	331	256	27	27	36	38	
8	GS	18	7	179	459	92	25	24	32	40	
9	GS	15	6	165	396	202	23	23	32	40	
10	GS	15	8	166	377	244	22	21	32	37	
11	GS	19	9	151	267	185	27	27	31	40	
12	GS	19	8	157	388	158	26	27	32	43	
13	GS	19	7	142	466	150	26	29	33	50	
15	GS	21	9	159	438	164	28	32	33	49	
14	GS	20	12	175	407	220	29	30	32	40	
16	GS, GH, WCB,	10	0.1	134	546	54	3	3	39	43	
17	GS, GH, WCB,	15	6	156	348	281	18	19	34	45	
18	GH, LH, MS, PS	15	6	193	306	217	19	20	34	43	
19	GH, LH, MS	10	0.2	170	512	0.4	8	8	33	41	
20	GS, MS	18	11	211	275	228	33	30	31	34	
21	GS, WCB, NHS	21	14	173	333	150	34	33	32	38	
22	MS	23	11	150	343	247	34	33	33	38	
23	GS	21	12	180	317	148	32	35	34	46	
24	GS	21	11	180	319	141	30	33	34	46	
25	GS	16	9	182	373	76	28	28	31	41	
26	GS	17	13	166	242	248	29	27	32	34	

1) Dominating roughage is the roughage that is dominating in any treatment within study. Roughages not listed can also be part of the treatments but in lesser portions.

GH = Grass Hay, GS = Grass Silage, LS = Legume Silage (lucerne/clover), WCB = Whole Crop Barley silage, MS = Maize Silage, PS = Pea Silage, NHS = NH₃-treated Straw

Calculations

All calculations were executed on spreadsheets in MS Excel 97.

LFU

The intake estimation is based on simple regression from the milk yield (Calculation 1) (Lindgren *et al.*, 2001).

$$[1] \text{ DMI (kg/day)} = 5.7 + 0.43 \times \text{kg milk}$$

CNCPS

Instead of the complete formula¹ a simplified version [2] was used. The lag-factor did not have any impact (range from 0.9989- to 1.0 since no observations were made during the first weeks of lactation) on the curve and was therefore not included. The environmental parameter, MUD1, was not considered applicable in the Nordic climate or for the management systems that are used. The temperature (TEMP1) was not recorded in the different studies, but probably no extreme values would have been recorded. In Fox *et al.* (1992) possible corrections for the intake equation of CNCPS are presented. Corrections for age, breed, empty body fat, food additives, ambient temperature and mud are shown as multipliers of the basic calculation. No consideration has been taken to these corrections in this thesis.

$$[2] \text{ DMI (kg/day)} = 0.0185 \times \text{live weight} + 0.305 \times \text{fat corrected milk}$$

$$\text{where fat corrected milk (4\%)} = 0.4 \times \text{kg milk} + 15 \times \text{kg milk} \times \text{fat content}$$

¹ $\text{DMI (kg/day)} = ((0.0185 \times \text{live weight} + 0.305 \times \text{fat corrected milk} \times \text{TEMP1} \times \text{MUD1}) \times \text{lag}$

MUD1 is a correctional factor that accounts for muddiness in the pen.
TEMP1 is a correctional factor that accounts for the ambient temperature and humidity.

If week of lactation ≤ 16 :

Lag = $1 - \exp[-(0.564 - 0.124 \times \text{PKMK}) \times (\text{week of lactation} + \text{P})]$ otherwise use Lag = 1.
P = 2.36 for PKMK = 1 or 2, and P = 3.67 for PKMK = 3.

Note that CNCPS 5.0 uses PKMK=2 as a default value, as it is not used as an input-parameter.

PKMK = month post partum when maximum milk yield is reached.

NRC

The complete NRC model was used in this thesis.

$$[3] \text{ DMI (kg/day)} = (0.372 \times \text{fat corrected milk} + 0.0968 \times \text{live weight}^{0.75}) \times (1 - e^{(-0.192 \times (\text{week of lactation} + 3.67))})$$

where *fat corrected milk (4%)* = $0.4 \times \text{kg milk} + 15 \times \text{kg milk} \times \text{fat content}$

DFFS

The intake capacity, K_L (FF_L per day), of the cow is calculated and the basic intake capacity calculation considers parity and week of lactation. The intake index is then corrected for milk yield, TMR, loose housing and other factors. Then, the analysed feed composition is recalculated into a fill factor (FF_L per kg DM, 1 for lactating). The calculations for total DMI estimation are shown in detail in Calculations 4 through 12 and are described in Hvelplund and Nørgard (2003). An overview of the calculations is presented in Appendix III.

$$[4] \text{ DMI (kg/day)} = \text{Intake capacity} / \sum \text{FF}_{Li} \times \text{part of total feed DM}_i$$

Intake capacity (K_L) for multiparous cows is estimated according to Calculation 5. All observations in the data set have an average parity of more than one therefore all intake capacities were calculated according to Calculation 5.

$$[5] \text{ Intake capacity} = K_L = 7.08 - 2.95 \times e^{(-0.047 \times \text{days in milk})} - 0.0033 \times \text{days in milk}$$

When $\text{FF}_L/\text{FU} < 0.35$, *i. e.* for feedstuffs that are energy-dense, the intake capacity, K_L , was corrected according to Hvelplund and Nørgard (2003) using $K_{L \text{ corr}} = K_L \times (-0.68 + 8.3 \times \text{FF}_L/\text{FU} - 10 \times (\text{FF}_L/\text{FU})^2)$. This was due to the fact that the metabolism of the animal restricts the DMI.

The intake capacity, K_L , was also corrected for the milk yield of the cows. In this model the default milk yield is 6500 kg ECM. For every 1000 kg ECM exceeding or falling below 6500 kg ECM the K_L was either increased or decreased with the term 0.3 (Hvelplund and Nørgard, 2003).

If total mixed rations (TMR) are offered to the cows, K_L should be increased by a factor of 1.05, *i. e.* $K_L = K_L \times 1.05$. This was not done in the calculations as this was recently found to be not applicable, instead under specific circumstances when separate feeding is used, the fill factor of the feed is increased as described below. When there is more than 60- to 70% easily digested feedstuffs in the feed ration, the intake will be lower than expected if the feedstuffs are fed twice or fewer times per day. The fill factor should then be increased by 10- to 15% (Hvelplund and Nørgard, 2003). This correction was not used in the calculations.

If the cows are loose housed or grazed, the K_L should be increased by 0.15. $K_L = K_L + 0.15$ (Hvelplund and Nørgard, 2003). This was not included in the calculations due to lack of information from the different experiments.

The fill factor, FF_L , for roughages is calculated based on the digestibility and nutrient value of the feedstuff. Concentrates, minerals and additives have FF_L per kg DM = 0.22 which is based on their filling volume in the rumen. The only feedstuffs in the present data set with a different FF_L was fodder beets and potatoes that had FF_L per kg DM = 0.25. The FF_L values for concentrates and additives are found in the Danish feedstuffs table (Møller, 2000).

For hay, ley silage and whole crop silage with a dry matter content below 25%, FF_L is calculated according to Calculation 6 where FU/kg DM is the energy concentration in Danish Feed Units (Hvelplund and Nørgard, 2003).

$$[6] FF_L = 0.74 - 0.32 \times FU/kg DM$$

The FF_L is then corrected for its legume content (Calculation 7) and thereafter for its DM content provided that its DM content is below 30% (Calculation 8) (Hvelplund and Nørgard, 2003).

$$[7] FF_{L\text{ legume}} = FF_L / (1 + 0.002 \times \text{legume}\%)$$

$$[8] FF_{L\text{ DM}} = FF_{L\text{ legume}} / [1 - (30 - DM\%) \times 0.015]$$

For whole crop barley with a DM content exceeding 25%, FF_L is calculated as in Calculation 9 and 10, where (10) is a correction for the legume content (Hvelplund and Nørgard, 2003).

$$[9] FF_L = 0.69 - 0.32 \times FU/kg DM$$

$$[10] FF_{L\text{ legume}} = FF_L / (1 + 0.0005 \times \text{legume}\%)$$

If no table values or recorded values are available for the energy concentration (FU) in the Calculations 6 and 9 above the FU can be calculated according to the following equations (11 and 12). The energy concentration of the feed is expressed in Danish Feed Units (Calculation 11) (Møller, 2000). In the Danish observations (observations 92 to 128) the energy concentration of the feed had already been calculated (Larsen, personal communication, 2004) and these values were used in the calculations.

$$[11] FU/kg DM = -0.369 + 0.0989 \times \text{digestible energy (MJ/kg DM)} - 0.347 \times \text{crude fibre (kg/kg DM)}$$

If crude fibre values were unavailable but acid detergent fibre (ADF) values were reported, ADF replaced crude fibre in Calculation 11. ADF is more commonly used than crude fibre and the values are reasonably comparative and ADF can therefore

be used as a substitute for crude fibre analysis in the calculations (Personal communication: Udén, 2004; Larsen, 2004).

Digestible energy is calculated as in Calculation 12. The sugar part of the original equation (Møller, 2000) was omitted since there were no roughage feedstuffs with a sugar content above 20%.

$$[12] \text{ digestible energy (MJ/kg DM)} = 24.237 \times \text{digestible crude protein (kg/kg DM)} + 34.116 \times \text{digestible crude fat (kg/kg DM)} + 17.3 \times \text{digestible carbohydrates (kg/kg DM)}$$

where

$$\begin{aligned} \text{digestible crude protein (kg/kg DM)} &= (0.93 \times \text{crude protein \% of DM} - 3) / 100 \\ \text{digestible crude fat (kg/kg DM)} &= (0.96 \times \text{crude fat \% of DM} - 1) / 100 \\ \text{digestible carbohydrates (kg/kg DM)} &= (\text{digestibility coefficient organic matter} / 100) \times (100 - \text{crude ash \%}) / 100 - \text{digestible crude protein} - \text{digestible crude fat} \end{aligned}$$

The digestibility coefficient of the organic matter was calculated differently depending on analyses that were available.

If D-values were available: $\text{dig coeff OM} = \text{OMD} \times 100$ (Finnish and Norwegian data) where $\text{OMD} = \text{D-value} / (1 - \text{ash})$

If IVDOM-values were available: $\text{dig coeff OM} = \text{legume content} \times (0.62 \times \text{IVDOM} + 23) + (1 - \text{legume content}) \times (0.9 \text{ IVDOM} - 2)$ (Spörndly, 1999) (Swedish data).

NAAT

In this system the dry matter intake is calculated based on the NDF intake per kg live weight (Calculation 13 and 14). This model is dependent upon milk yield, cow weight, week of lactation and the NDF content of the feed. It also considers the quality of the silage process through its corrected intake index (cii) which corrects for content of acids and NH₃-N in silage (Calculation 15).

As mentioned earlier, this model is based on Merten's model, but in this work, the emphasis was on the fill limitation, physical DMI. The main calculations in the analysis were on this part of the model, the physiological part is described further on in the text. The physical limitation calculation is a way of maximising forage intake when optimising the model aimed at energy balance.

$$[13] \text{ Physical DMI (kg/day)} = \text{NDF (g/kg DM)} / 1000 \times \text{live weight} / 1000$$

$$[14] \text{ NDF intake (g/kg Live weight)} = (6.99 + 0.0698 \times \text{kg milk} - 0.1563 \times \text{week of lactation} + \ln(\text{week of lactation}) \times 2.49 + 0.007455 \times \text{NDF content of forage (g/kg DM forage)} - 545 + 0.0102 \times \text{NDF content of concentrate (g/kg DM conc)} - 214) \times \text{corrected intake index} + \text{amount of NDF from concentrate (g/day)} / \text{live weight} \times (1 - \text{corrected intake index})$$

When two different forages were used in the diet, they were named forage 1 and forage 2. The corrected intake index was weighted for forage 1 and forage 2 when silage was used in both fractions.

$$[15] \text{ Corrected intake index} = (100 + (80 - \text{products of fermentation}) \times 0.11 + (50 - \text{NH}_3\text{-N}) \times 0.07) / 100$$

To define the physiological limits of the DMI, the energy concentration of the feed, live weight and milk yield in ECM must be known in order to calculate the energy requirement. The equations below (Calculation 16 and 17) are described in Kjos (2002). FEm is the Norwegian energy unit “feed unit for lactating cows” (Sundstøl and Ekern, 1992).

$$[16] \text{ Energy requirements (FEm per day)} = 0.0424 \times \text{live weight}^{0.75} + 0.44 \times \text{ECM} + 0.0007293 \times \text{ECM}^2$$

The physiological limited DMI is found by dividing the energy requirement of the cow with the energy concentration of the feed.

$$[17] \text{ Physiological limit for DMI} = \text{Energy requirement} / \text{Energy concentration}$$

To determine the DMI according to the NAAT, model the lesser of the physical and the physiological DMI is chosen (Kjos, 2002). This is, however, a simplification of the calculation. When evaluated in Norway, the DMI is numerically solved from the physical limitations part of the model with maximum forage intake, the aim is energy balance and the NDF intake is constrained to vary ± 0.1 g/kg live weight from the value calculated from the model (Kjos, 2002).

Statistical analyses

The different models were compared using linear regression between observed DMI and DMI predicted by the different equations. When performing the comparison only the observations that were possible to calculate for all five models were used. In total 73 observations out of 143 were used. If no other figures are stated the data set used in the statistical analyses consist of 73 observations. The LFU, CNCPS and NRC models were also evaluated using the total data set, N = 143. For more detailed information on the studies or observations used in the analyses, refer to Appendix I.

The Mean Square Prediction Error (MSPE), the Root Mean Square Prediction Error (RMSPE) and the absolute and relative bias were calculated for the different models.

$$\text{MSPE} = \sum (\text{predicted DMI}_i - \text{observed DMI}_i)^2 / N$$

$$\text{RMSPE} = \sqrt{\text{MSPE}}$$

$$\text{Absolute bias} = [\sum (\text{predicted DMI}_i - \text{observed DMI}_i) / N]$$

$$\text{Relative bias} = [\sum (\text{predicted DMI}_i - \text{observed DMI}_i) / N] / [\sum (\text{observed DMI}_i) / N]$$

As the data used in this thesis originated from different studies, it was interesting to see if the results of the calculations were similar if a correction of the data for the effect of study was used. A method for this was developed by St-Pierre (2001) and was adapted and used in this study. If the study effect is not considered, the results of the calculations can be biased. With this method, the study effect and its interacting effects are looked upon as random components of a mixed model. The regression between observed predicted DMI was adjusted for the effect of study with a random intercept and random slope according to St-Pierre (2001) for all models.

To identify factors inter-correlated or correlated to the observed DMI the function PROC CORR of SAS was used. If several factors had a higher correlation to each other than | 0.8 | only one factor was included in the following stepwise regression to avoid redundancy (Hristov *et al.*, 2004). The factors included in the PROC CORR matrix are listed in Table 4. The observed DMI was also included in the PROC CORR matrix.

The function PROC REG with the extension stepwise in SAS was then used to find the relative importance of factors when calculating DMI. Only animal and dietary factors were examined (Table 4). The OMD and the ME parameters used in these calculations are outputs from simulation calculations of the mechanistic part of the NAAT system.

Table 4. Factors examined with PROC CORR and PROC REG in SAS.

Animal factors	Dietary factors
Week of lactation	Concentrate (in proportion to feed)
Live weight	NDF (g/kg DM)
Metabolic weight	Roughage (NDF g/kg DM)
Milk yield kg	Concentrate (NDF g/kg DM)
Milk yield ECM	CP (g/kg DM)
Milk yield FCM	Starch and sugars (g/kg DM)
Protein yield	OMD
Fat yield	ME (MJ/kg DM)
	Products of fermentation (g/kg DM)
	NH ₃ -N (g/kg DM)

Four different stepwise regressions were performed, with different variables included. The variables included in each execution are presented in Table 5. Variables were allowed to enter the model and to be retained if $p < 0.15$. The

number of observations varies since there was information missing about the fermentation products and the NH₃-N.

Table 5. The different factors included in each stepwise regression performed and number of observations (N)

	Animal factors	Dietary factors	N
Stepwise 1	Week of lactation + metabolic weight + ECM	Concentrate proportion of feed + NDF + roughage NDF + concentrate NDF + crude protein + fermentation products + NH ₃ -N+ ME	60
Stepwise 2	Week of lactation + metabolic weight + ECM	Concentrate proportion of feed + NDF + ME + roughage NDF + concentrate NDF + crude protein	73
Stepwise 3	Week of lactation + metabolic weight + ECM	Concentrate proportion of feed + NDF + ME + crude protein	73
Stepwise 4	Week of lactation	Concentrate proportion of feed + ME + NDF + crude protein + fermentation products + NH ₃ -N + (fermentation products) ²	60

Stepwise 1 contains all parameters that showed any correlation to observed DMI in the PROC CORR execution.

Stepwise 2 contains the same parameters as in stepwise 1 except for silage fermentation products and ammonia.

Stepwise 3 is the most obvious attempt to make a regression for practical use. The parameters are easily measurable and all 73 observations were possible to use.

Stepwise 4 is an attempt to use only dietary factors and the week of lactation as parameters for the regression. The parameters were chosen because these were all known prior to feeding. The fermentation products-square was tested since it is a part of the current Finnish Silage Dry Matter Index.

Results

It was possible to calculate the DMI for all 143 observations in the data set according to the LFU, CNCPS and NRC models since there was information available for all input parameters. Information was lacking for DFFS and NAAT. For DFFS, it was only possible to calculate the DMI for 76 of the observations. For NAAT it was possible to calculate DMI for 114 of the observations. Observations 18 to 44 were not used since these were used for developing the NAAT model. To obtain a balanced data set, all observations where one or more models were missing (not possible to calculate) were excluded from most of the analyses. Details on observations that were included are listed in Appendix I. The main evaluation used a data set of 73 observations. However, other data sets were used in some sub-evaluations such as comparisons between the three simplest models, LFU, CNCPS and NRC. The results of these sub-evaluations are presented at the end of the results section.

The results of the calculations are shown in Table 6 together with MSPE, RMSPE and bias for the different models. A diagram showing the differences between predicted and observed DMI for each of the 73 observations is presented in Appendix II.

Table 6. The unadjusted regression between observed and predicted DMI and the regression adjusted for the study effect (St-Pierre, 2001), Mean Square Prediction Error, Root Mean Square Prediction Error and bias for the five evaluated DMI models (N=73)

		LFU	CNCPS	NRC	DFFS	NAAT
Intercept	Unadj	0.92	7.89	8.36	3.06	1.14
	Adj	8.98	11.7	12.1	10.2	11.2
Slope	Unadj	0.85	0.61	0.67	0.87	1.04
	Adj	0.4	0.39	0.47	0.45	0.41
R ²	Unadj	0.77	0.89	0.87	0.71	0.53
	Adj	0.93	0.93	0.93	0.83	0.87
MSPE ¹	Unadj	6.43	3.29	7.82	4.92	16.95
RMSPE ²	Unadj	2.54	1.81	2.80	2.22	4.12
Bias (kg)	Unadj	-1.76	0.66	2.32	0.59	1.78
Bias %	Unadj	-9.6	3.6	12.7	3.2	9.7

¹Mean Square Prediction Error

²Root Mean Square Prediction Error

Figure 2 shows the regression between DMI predicted by the five models and observed DMI. The figures are based on the 73 observations where data was available for calculating predicted intake for all five models.

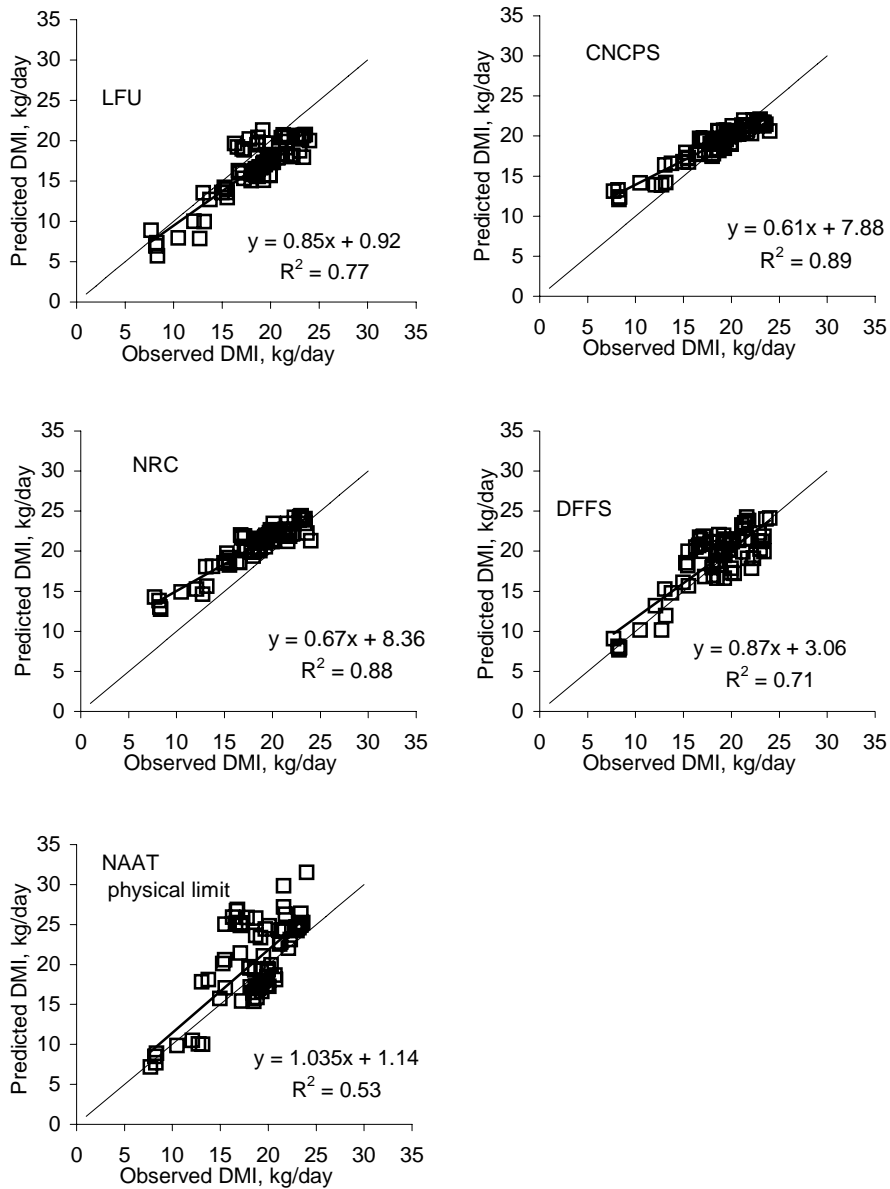


Figure 2. The linear regression between observed DMI and the DMI predicted by the different models. The NAAT is presented with only the physical limitations (NDF intake capacity) of the equation. (N=73).

Since it was possible to calculate the intake according to LFU, CNCPS and NRC for all observations in the data set the regression on predicted and observed DMI for the complete data set is shown in Figure 3.

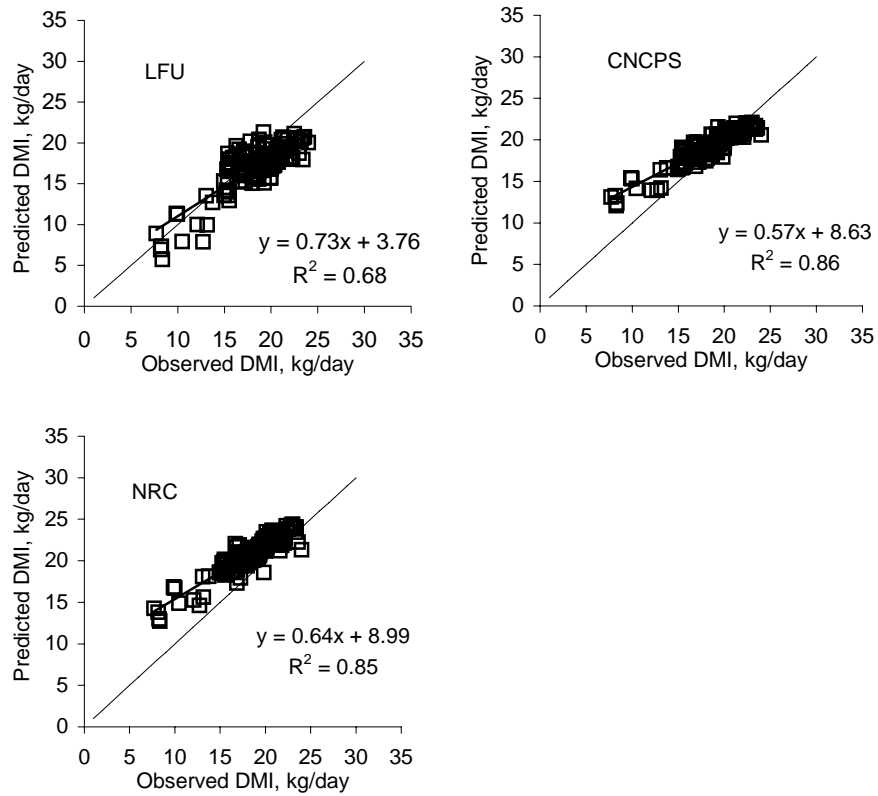


Figure 3. The linear regression between observed DMI and predicted DMI for the models LFU, CNCPS and NRC based on the total data set (N = 143).

The NAAT model in Figure 2 shows only the physical limitation (bulkiness of the feed expressed as NDF) and does not incorporate the physiological limitations of the cow. This is instead shown in Figure 4.

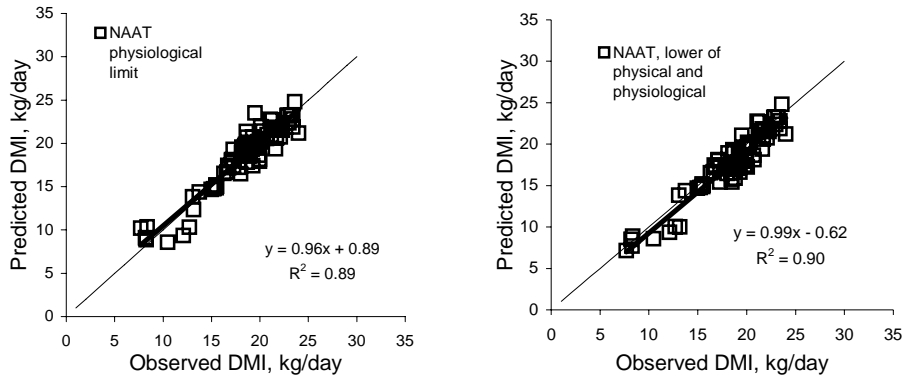


Figure 4. The left-hand diagram shows the linear regression between observed DMI and the physiological limit (energy requirements fulfilled) of the DMI intake according to NAAT. The right-hand diagram shows the linear regression between observed DMI and the DMI predicted by the NAAT model if the lower of the two alternative results from physical (Figure 2) and physiological (left diagram of this figure) calculations is chosen. (N=73).

The results from the PROC CORR execution are found in Table 7 and presented as correlation to observed DMI. Inter-correlations $> | 0.8 |$ to other variables are also shown in the table.

Table 7. Correlation of different factors to the observed DMI, Probability, N = number of observations. The column "Inter-correlated to" lists the factors with a correlation $> |0.8|$. The factor in the inter-correlated column replaced the factor of the first column in the stepwise regressions that followed

Factor	Correlation with observed DMI	Prob $> r $	N	Inter-correlated to $> 0.8 $
Weight	-0.06	0.61	73	Metabolic weight
Metabolic weight	-0.06	0.62	73	
Week of lactation	-0.73	<0.0001	73	(Total milk)
Total milk	0.88	<0.0001	73	ECM
ECM	0.91	<0.0001	73	
FCM	0.91	<0.0001	73	ECM
Protein yield kg/day	0.89	<0.0001	73	ECM
Fat yield kg/day	0.90	<0.0001	73	ECM
NDF g/kg DM	-0.47	<0.0001	73	
Starch and sugar g/kg DM	0.43	0.0001	73	NDF
CP g/kg DM	0.18	0.13	73	
ME MJ/kg DM	0.25	0.03	73	
Concentrate proportion of feed	0.57	<0.0001	73	
Roughage NDF g/kg DM roughage	-0.26	0.03	73	
Concentrate NDF g/kg DM concentrate	0.79	<0.0001	73	
Products of fermentation g/kg DM	-0.32	0.011	60	
NH ₃ -N g/kg N	0.18	0.14	65	
OMD	0.16	0.17	73	ME

The parameters that were inter-correlated (weight, total milk, FCM, OMD, starch and sugar) were excluded from the regression analyses that followed.

The stepwise regressions performed based on the results from the PROC CORR execution resulted in the regression models presented in Tables 8 to 11.

Table 8. The parameter estimates, standard errors, significance levels partial R^2 and model R^2 retrieved from the stepwise regression (1) based on week of lactation, metabolic weight, concentrate proportion of feed, ECM, NDF, ME, roughage NDF, concentrate NDF, crude protein, fermentation products, NH_3 -N (N=60). Parameter estimates and standard errors are from the complete model with all significant factors ($P < 0.15$) in the table whereas partial R^2 is the increment in model R^2 from addition of each factor to the model

Variable	Parameter estimate	Standard error	Pr > F	Partial R^2	Model R^2	Model R^2 adjusted
Intercept	9.8	5.1	0.06			
ECM	0.46	0.04	< 0.0001	0.77	0.77	0.77
Metabolic weight	0.12	0.03	< 0.0001	0.10	0.88	0.88
Concentrate NDF g/kg DM concentrate	0.019	0.0028	< 0.0001	0.030	0.91	0.91
NDF g/kg DM	-0.05	0.0068	< 0.0001	0.0081	0.92	0.91
ME MJ/kg DM	-1.4	0.23	< 0.0001	0.014	0.93	0.93
Week of lactation	0.17	0.03	< 0.0001	0.011	0.94	0.94
Roughage NDF g/kg DM roughage	0.025	0.0047	< 0.0001	0.0074	0.95	0.94
Concentrate proportion of feed	-8.4	2.0	< 0.0001	0.013	0.96	0.96
Fermentation products	-	-	> 0.15	-	-	-
NH_3 -N	-	-	> 0.15	-	-	-

Table 9. The parameter estimates, standard errors, significance levels, partial R^2 and model R^2 retrieved from the stepwise regression (2) based on week of lactation, metabolic weight, proportion of concentrate, ECM, NDF, ME, roughage NDF, concentrate NDF, crude protein (N=73). Parameter estimates and standard errors are from the complete model with all significant factors ($P < 0.15$) in the table whereas partial R^2 is the increment in model R^2 from addition of each factor to the model

Variable	Parameter estimate	Standard error	Pr > F	Partial R^2	Model R^2	Model R^2 adjusted
Intercept	24.2	5.39	< 0.0001			
ECM	0.42	0.05	< 0.0001	0.82	0.82	0.82
Metabolic weight	0.055	0.025	0.033	0.056	0.88	0.88
ME MJ/kg DM	-1.4	0.25	< 0.0001	0.026	0.91	0.90
NDF g/kg DM	-0.030	0.0042	< 0.0001	0.014	0.92	0.92
Concentrate NDF g/kg DM concentrate	0.012	0.0027	< 0.0001	0.015	0.93	0.93
Concentrate proportion of feed	-8.1	2.0	0.0001	0.0026	0.94	0.93
Roughage NDF g/kg DM roughage	0.0094	0.0026	0.0006	0.012	0.95	0.94
Crude protein g/kg DM	-0.012	0.0062	0.051	0.0034	0.95	0.95
Week of lactation	0.039	0.026	0.14	0.0016	0.95	0.95

Table 10. The parameter estimates, standard errors, significance levels, partial R^2 and model R^2 retrieved from the stepwise regression (3) based on week of lactation, metabolic weight, Proportion of concentrate, ECM, NDF, ME, crude protein (N=73). Parameter estimates and standard errors are from the complete model with all significant factors ($P < 0.15$) in the table whereas partial R^2 is the increment in model R^2 from addition of each factor to the model

Variable	Parameter estimate	Standard error	Pr > F	Partial R^2	Model R^2	Model R^2 adjusted
Intercept	23.7	6.21	0.0003			
ECM	0.54	0.031	< 0.0001	0.82	0.82	0.82
Metabolic weight	0.055	0.029	0.065	0.056	0.88	0.88
ME MJ/kg DM	-1.65	0.28	< 0.0001	0.026	0.91	0.90
NDF g/kg DM	-0.015	0.0030	< 0.0001	0.014	0.92	0.92
Concentrate proportion of feed	-3.51	1.27	0.0073	0.0094	0.93	0.92
Crude protein g/kg DM	-0.013	0.0071	0.069	0.0040	0.93	0.93
Week of lactation	0.049	0.031	0.12	0.0025	0.94	0.93

Table 11. The parameter estimates, standard errors, significance levels, partial R^2 and model R^2 retrieved from the stepwise regression (4) based on week of lactation, proportion of concentrate, NDF, ME, crude protein, fermentation products, NH_3 -N, (fermentation products)² (N=60). Parameter estimates and standard errors are from the complete model with all significant factors ($P < 0.15$) in the table whereas partial R^2 is the increment in model R^2 from addition of each factor to the model

Variable	Parameter estimate	Standard error	Pr > F	Partial R^2	Model R^2	Model R^2 adjusted
Intercept	37.4	5.8	< 0.0001			
Week of lactation	-0.28	0.039	< 0.0001	0.47	0.47	0.46
ME MJ/kg DM	-1.22	0.50	0.019	0.057	0.52	0.51
Concentrate proportion of feed	-	-	> 0.15	-	-	-
Crude protein g/kg DM	-	-	> 0.15	-	-	-
NDF g/kg DM	-	-	> 0.15	-	-	-
Fermentation products (Fermentation products) ²	-	-	> 0.15	-	-	-
NH_3 -N	-	-	> 0.15	-	-	-

Discussion

The area of feed intake predictions involves vast and complex issues. Numerous studies have been carried out to find the one and only perfect fitting equation. However, the biological systems involved are still not possible to explain mathematically.

The dairy cow feed ration formulation is complicated due to the varying energy requirements ranging from the extremely demanding needs during early lactation to the other extreme at the end of lactation and dry period when the DMI is intentionally reduced to decrease the milk yield. Normally, lactating cows are offered high-energy concentrates totalling more than 50% of the total DMI during the first part of lactation. The proportion of concentrate is then successively decreased until the dry period when the cows are offered mostly roughage.

The diagrams in Figure 5 illustrate the complexity of predicting the intake during the different lactation stages. These are based on data from a study where the DMI was measured during the entire lactation period. The groups were offered diets with either low or high energy content.

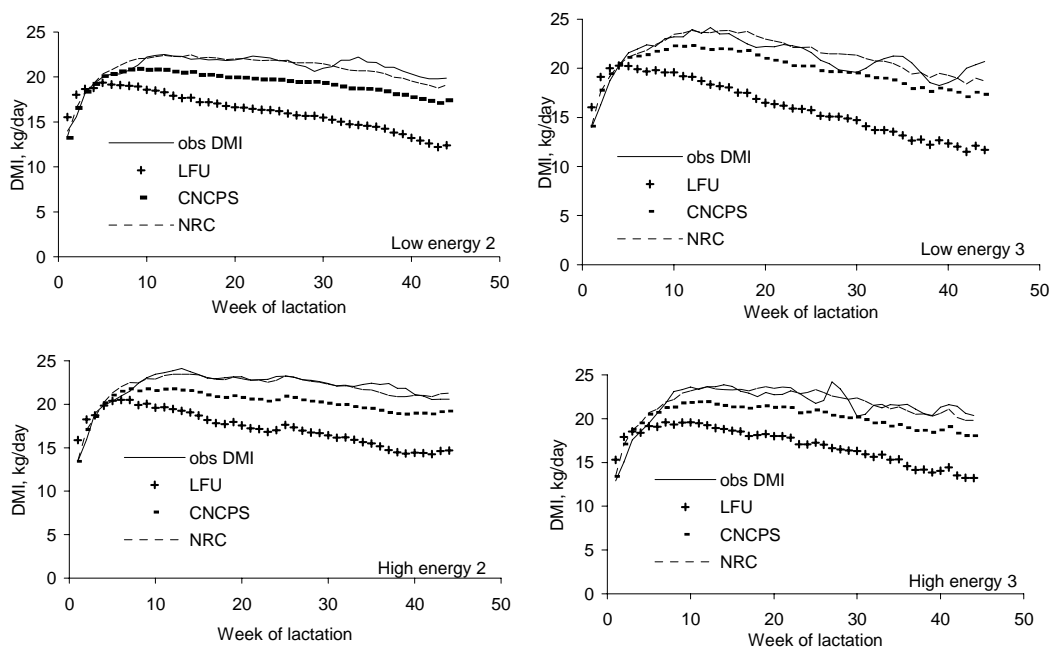


Figure 5. The predicted and the observed DMI during lactation for dairy cows fed a diet with either high or low energy content. Based on data from MEMO (Ingvarsten and Jensen, 2001).

There are a number of questions to answer before developing a new intake model: What is the objective of the new intake model? Is it a model for prediction of the DMI or evaluation of diets fed? Is it meant to work for a group or an individual?

Will it be used for the complete lactation period or just part of it? What are the main feedstuffs available and in the rations? Is it important to find a diet that maximises forage intake?

When the feed rations are calculated for a group of animals, the homogeneity of the herd must be of great importance for economical feed management; The fewer variations from the norm, the better. The most expensive animals to keep should be the ones that have a very high or a very low milk yield. These animals will have problems maintaining their body condition score and health. If the feed system is TMR, it is difficult to keep such animals within the same groups.

The most common method for calculating the DMI is regression. Most often the predicted milk yield is used to find the energy requirement of the dairy cow. This often results in a good prediction provided that the population upon which the regression is developed and the population to which it is applied have similar characteristics such as breed, climate, feedstuffs, feed additives, management *etc.*

A problem with using milk yield as input parameter is that it is always a qualified guess, as the milk yield is never known in advance. However, milk production uses the most energy and is therefore important to use when calculating intake capacity.

Factors affecting intake

In this study, both correlation and regression evaluations indicated that the most important factor is the milk yield. The feed property factors were found to be much less important to the total DMI in the present study.

The animal factors that had the strongest correlation to DMI were milk yield parameters (ECM, FCM, total milk, protein yield, fat yield) and week of lactation. The metabolic weight and the weight of the animal were not correlated to the DMI in this study. The week of lactation was strongly correlated to total milk (-0.89). This parameter is, however, often included in different regressions for calculation of DMI together with the milk yield. This could present problems with redundancy, according to Hristov *et al.* (2004) who stated that if factors are correlated to $> |0.8|$, only factor should be used in a regression analysis. However, these two parameters are not as similar as ECM and FCM for example. Perhaps there is no danger of redundancy when including lactation week and total milk in the calculations.

Roseler *et al.* (1997) found that protein yield better correlated to DMI than total milk, ECM and FCM. However, the data set of the present study shows that both FCM and ECM are correlated best to DMI (0.91) followed by protein yield (0.89) and total milk (0.88).

Some of the dietary factors were significantly correlated to the DMI. Not surprisingly, the factors that were related to NDF content of the diet were the best. The highest correlation (0.79) was recorded for the NDF concentration of the

concentrate. This was an unexpected outcome and is probably not possible to use for predictions of DMI. Instead it could perhaps be useful in diet evaluation. The strong effect was probably due to ration composition effects. If roughage with low NDF was used, the concentrate needed more NDF in order to balance the ration.

The proportion of concentrate in the diet was also strongly correlated to DMI (0.57) and should be applicable for use in prediction calculations.

Silage quality factors represented by $\text{NH}_3\text{-N}$, fermentation acids and the square of fermentation acids (TA^2) were weakly correlated to total DMI. It could be that these factors are better correlated to roughage DMI. However, because the feed rations in these studies consisted of both roughages and concentrates it was not a simple task to find the voluntary intake of roughage since it was always affected by the concentrate intake.

Regression analyses of observed to predicted DMI

The linear regressions between observed and predicted DMI in the different models showed some differences in precision and variation.

The three models, LFU, CNCPS and NRC were quite accurate in terms of R^2 0.77, 0.89 and 0.88, respectively unadjusted and when adjusted for study effect 0.93, 0.93 and 0.93 in relation to the rather simple designs. The feed rations in the different studies were not that extreme in choice of feedstuff or management. The regressions were simply based on populations very similar to that in the present study. But how will these regressions respond if a new feedstuff is introduced, or if the energy efficiency of the animals changes radically? Then it might be necessary to recalculate the regression on a new basis. When the total data set was used ($N = 143$), the R^2 values decreased for all three models (0.68, 0.86 and 0.85, respectively). The R^2 of the LFU system decreased more than the other two models. This could partly be due to the different milk yield parameters used; LFU uses total milk and the other two FCM.

LFU does not consider the milk composition. Its accuracy would probably be lower for cows with elevated fat and protein contents as it considers only total milk yield in kg. There were no observations from the first six weeks of lactation. This might lead to an overestimation of the accuracy for the LFU system since it does not have any lag factor included in the DMI equation. Nevertheless, it was reasonably accurate in terms of R^2 and MSPE (6.43) in this population, which would have been expected as the model was developed in Sweden and most rations in these studies consist of typical Swedish feedstuffs and lactation levels.

The CNCPS is presented without its lag factor, as this did not add any value to the equation. The weeks of lactation for the observations in the data set were too high (weeks 6 to 47) to generate a lag factor that differed from 1. The lag factor was included in the NRC calculations. The slope of the curves in Figure 2 and 3 indicates that there is a problem for the NRC equation to predict DMI. Fox *et al.*

(1992) evaluated the NRC and CNCPS equations on a lactating Holstein cow population. They found that SE was 1.5 and 1.7 kg respectively, with a bias of -5% and +6% with R^2 values of 0.43 and 0.49, respectively. The data set in this study showed a much higher R^2 for the two equations of 0.89 (NRC) and 0.87 (CNCPS) when adjusted for study effect (St-Pierre, 2001). The differences can perhaps be explained by the differences in the lactation week and the farming systems. Another explanation for the relatively high values found are the observations of study 16 and 19 where low DMI and low milk yield were measured in a late lactation (week 47). If these observations are excluded from the data set, the R^2 values will decrease notably for all models evaluated (Table 12).

Table 12. The R^2 of the observed to predicted DMI with a data set of 73 observations compared to a data set with 68 observations where the DMI > 12.1 kg/day

	R^2 (N = 73)	R^2 (N = 68)
LFU	0.77	0.60
CNCPS	0.89	0.80
NRC	0.88	0.77
DFFS	0.71	0.47
NAAT (physical)	0.52	0.29

As seen in Figure 4, the DMI calculated by NAAT using the physiological limiting calculations is much more accurate than using the physical (fill) limiting calculations. If the lesser of the two results from the calculations is chosen the diagram resembles that of the physiological intake, also shown in Figure 4. Therefore when using the current data set, it seems unnecessary to calculate the physical intake, since the physiological prediction is almost as accurate as choosing the lesser of the two. However, the NAAT model itself generated some of the input variables used in the current study for calculation of energy supply and hence physiological limitation of intake. This could render some auto-correlation which, in turn, leads to overestimation of the results. If most of the studies included had a high forage to concentrate ratio and higher NDF content, the importance of the physical calculations would probably be more obvious. In most countries, however, this is quite unlikely for lactating dairy cows since their energy requirements are too high to be met by rations based on feedstuffs with low energy concentration. However, in the later part of the lactation and the dry period, the physical limitation calculations might be more appropriate to use. Another application is if a feed ration with a maximum amount of forage is desired.

The regressions between observed and predicted DMI showed that the complexity of the model is less important for its accuracy. The best accuracy was obtained using the complete NAAT model. This model was more complicated than necessary, as the physiological part of the model explained almost all of the observations when the lesser of the physiological and physical limitations' results was chosen. One problem in this model that was also found in other models studied is that it is based on observed ECM yield and not predicted yield. This can make the models appear to be reliable when they actually are misleading. There are also other parameters used in the model that are not known prior to feeding and milking the animal, for example amount of NDF from concentrate per day. This means that

the physical limitation part must be solved numerically and with a prediction of the milk yield which probably would reduce the accuracy of the physical model. The usage of predicted milk yield would, of course, also impair the accuracy of the physiological part of the model.

The most complex model, the DFFS, showed the lowest accuracy in terms of R^2 (0.71 and 0.83, when adjusted for study effect) but had the lowest bias (0.59 kg or 3.2%) of the models evaluated. Among the evaluated models, it has greatest potential to adapt to new scientific ideas and new feedstuffs, as it is an additive model. If a new feedstuff is added to the ration, for example a by-product from the food industry, it would be possible to include it into the system without a complete recalculation. One crucial point with a feed management system is that new feedstuffs easily can be incorporated. This is especially important with the opening up of the global market which leads to an increased economic pressure on the farmers who intensify the search for new cheaper feedstuffs and management methods.

Both NAAT and DFFS, unlike the three regression models, consider the dietary properties of the feed. The greater the differences between the farms where the system will be applied, the more important will the feed properties become for accurate prediction of feed intake.

All five models show higher accuracy for diets with higher NDF content. A normal diet consists of 32 to 50% NDF. The NDF content of the rations in this meta-analysis ranged from 18 to 66%. According to praxis in Sweden, a diet with at least 32% NDF is recommended to maintain the cow's digestive function. (Personal communication, R. Spörndly, 2002). Diets with very low NDF content in this survey were found to be potentially unhealthy for the cows and could impair the digestive system if given over a longer period of time. NDF is important for the passage rate of the rumen digesta and therefore the digestibility of the feedstuff (McDonald *et al.*, 2002).

Observations 108 to 115 that were overestimated in all five equations and especially by NAAT were from a trial where the cows were in lactation week 10 and fed grass, clover and corn silage (harvested as whole crop) together with a concentrate containing different levels of post-ruminal lysine and methionine. The feed ration of these cows consisted of 51 to 71% concentrate. The high level of concentrate in these rations seems to have had an impact on the calculations. Observations 116 to 124 were also overestimated, but to a lesser extent than 108 to 115. Possibly, the different outcomes can be explained by examining the feed rations for the two studies. What differs between these two studies? This experiment's feed rations consist of 37-85% concentrate and the measurements were done in the 10th week of lactation. A possible explanation is that the higher content of NDF (275 g/kg DM and 333 g/kg DM respectively) in the latter study balanced the equations and therefore obtained greater accuracy.

The adjustment for the study effect that is presented in Table 5, shows that the R^2 values for all models were increased when the study effect was considered.

Stepwise regressions

The stepwise regression carried out in SAS (SAS/STAT, 1999) indicated that the ECM yield alone explained 82% of the curve. This means that all the other factors in total did not explain more than 18% of the variation to the curve (including residuals). Metabolic weight increased the R^2 of the regression models by approximately 5 to 10% and other factors contributed with very little to the total model. Hence, the improvement in R^2 by adding more factors to the stepwise regression was quite low. It is, however, important to remember that the milk yield figures used were observed values from production measurements.

The attempt to create a linear regression model where only parameters known prior to feeding were used resulted in a poor model with low accuracy (Table 11). The model consisted of week of lactation and ME content of the diet, with total R^2 estimated to 0.52. It is probable that a higher accuracy for a diverse population will be easier to reach with a method other than linear regression.

It could be more constructive to develop a model that predicts milk yield with high accuracy based on knowledge of the farm, genetic potential of the cow and earlier lactation results. An accurate prediction of the milk yield would probably be beneficial for all DMI models. Accuracy would then be improved in all DMI models.

Sources of errors

The material collected was not homogenous. As in all meta-analyses there were probably inconsistencies between studies regarding methods of measurement, laboratory routines *etc.* However these inconsistencies were partially eliminated by adjusting for the study effect according to St-Pierre (2001).

All calculations depend on the milk yield of the cows; this parameter is however not known when the ration is planned. Therefore the data calculated in this thesis should have a better accuracy than in real life where the milk yield would be a predicted value.

The studies were conducted using different feed management methods. There were total mixed rations as well as partly mixed rations and separate feeding experiments in the data. Information about the type of feeding management has not been regarded in the calculations and therefore there could be differences in how the intake was measured. The experiments using separate feeding did not feed the cows concentrate *ad lib*. Hence, the measure is of the amount of roughage the cows will consume when fed a certain amount of concentrate. This is a common experimental design because it would be impossible to feed concentrate *ad lib*.

It is possible that there were restrictions to the amount of feed in some of the studies. In the studies where intake and milk yields are notably lower, a constraint in time of access to feed or amount of feed offered might have reduced the voluntary intake.

What's next?

It would be of interest to evaluate the correlation with principal components analysis (PCA). Roseler *et al.* (1997) used PCA when determining the relevant factors for DMI. This method is a bit more reliable than the methods used in this study and could be one way to continue the work.

A more in-depth evaluation using data from cows in early and late lactation would be meaningful. As shown in Figure 5, the DMI according to LFU, NRC and CNCPS presented along with the observed DMI during the lactation period of cows in the MEMO project (Ingvarlsen and Jensen, 2001), vary in accuracy during the different lactation weeks. The LFU model seems to be less accurate in late lactation than the others.

A suggestion could be to further evaluate and use the data set more efficiently if table values for energy concentrations in the different feedstuffs could be used for the DFFS calculations.

Conclusion

From the results of this study a model based on fill factors is recommended for further development into a common DMI model for the Nordic countries. An argument for this is that the feed management and “normal” feedstuffs are not similar in the different countries. One important characteristic of a new DMI model is adaptability since the advisory organisations believe that there will be a demand for new and cheap feedstuffs for dairy cows. For example, new by-products from the food industry can be expected that should be smoothly integrated in the system without a remodelling. This is possible if an additive model such as the DFFS is used. The future of the regression-based models is more restricted, since these are based on successively narrowing populations.

If a regression model is to be further developed there must be some way of choosing between grass-based diets and maize diets as well as the amount of concentrate. Some feeds are used exclusively in one country (fish in Iceland as an example). Corrections for different feedstuffs are most likely necessary in some cases.

The change in the diet composition from early lactation to the dry period is considerable. At the onset of lactation there is almost always at least 50% concentrate in the diet and at the end almost always no concentrate offered.

A management plan containing all of the pertinent factors, including the increases and decreases of concentrates prior to, during and after lactation would be appropriate to be included in equations for a new model. When all of the new elements, adaptations to specific farm situations, diets and other factors are included in a model, it will be important to examine and document the corrections and alterations when evaluating the results.

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APPENDIX I. Reference, country where the study was conducted, trial number refers to the numbers used in the NKJ 111 and NorFor project, trial ID internal codes for the studies, observation number, number of observations in the study, what models have been possible to calculate, experiment design and complete references to the studies included in the meta-analysis.

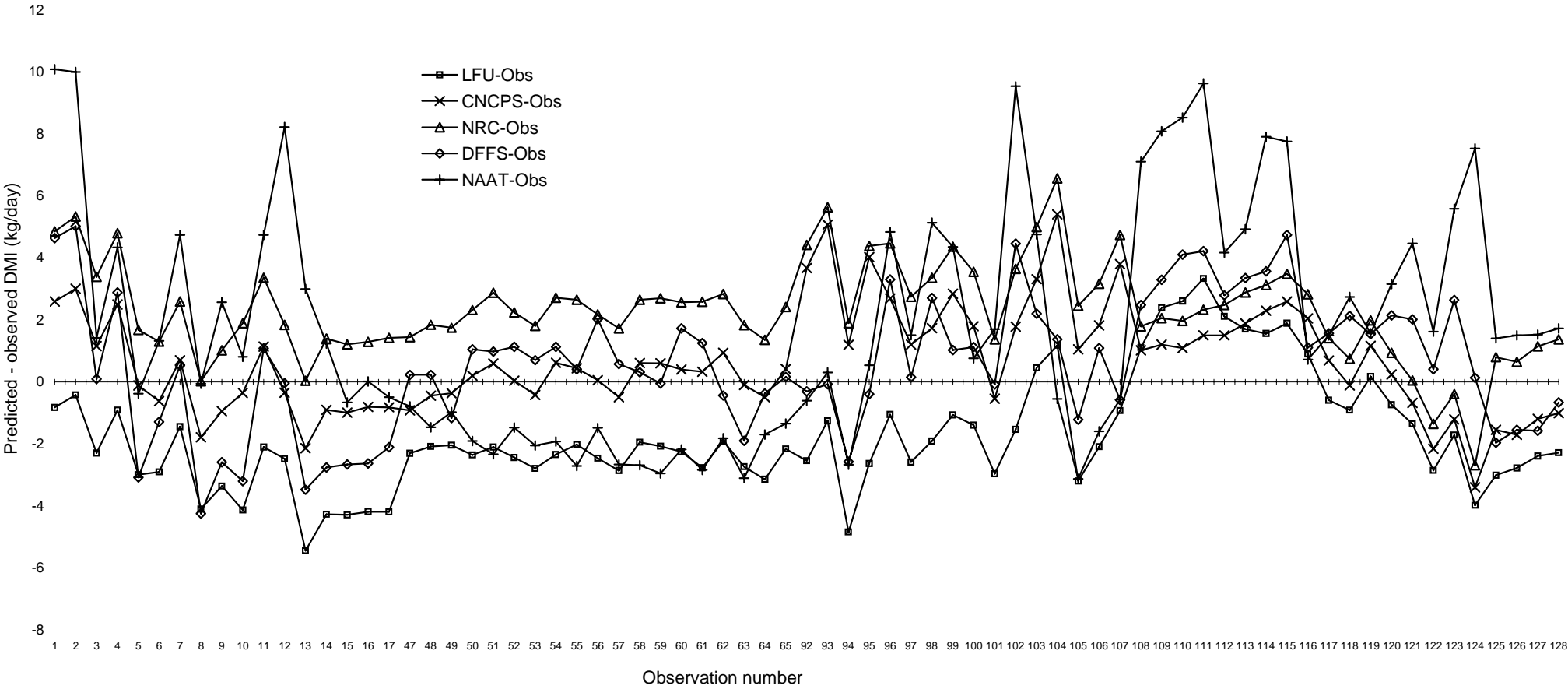
Reference	Country	Trial no	Trial ID	Obs. no	No. of obs.	LFU	NRC	CNCPS	NAAT	DFFS	Design	Complete reference
Murphy <i>et al.</i> (2000)	SE	1	1	1-4	4	X	X	X	X	X	Changeover	Murphy, M., Åkerlind, M. & Holtenius, K. 2000. Rumen fermentation in lactating cows selected for milk fat content fed two forage to concentrate ratios with hay or silage. <i>Journal of Dairy Science</i> 83: 756-764.
Bertilsson & Murphy (2003)	SE	2	2a	5-9	10	X	X	X	X	X	Changeover	Bertilsson, J. & Murphy, M. 2003. Effects of feeding clover silages on feed intake, milk production and digestion in dairy cows. <i>Grass and Forage Science</i> . 58: 309-322.
Bertilsson & Murphy (2003)	SE	3	2b	10-14	10	X	X	X	X	X	Changeover	Bertilsson, J. & Murphy, M. 2003. Effects of feeding clover silages on feed intake, milk production and digestion in dairy cows. <i>Grass and Forage Science</i> . 58: 309-322.
Eriksson <i>et al.</i> (2004)	SE	4	4	15-17	3	X	X	X	X	X	Changeover	Eriksson, T., Murphy, M., Cizuk, P. & Burstedt, E. 2004. Nitrogen balance, microbial protein production and milk production in dairy cows fed fodder beets and potatoes, or barley. <i>J. Dairy Sci.</i> 87: 1057-1070.
Volden (1990)	NO	5	M166	18-20	15	X	X	X			Continuous	
Volden (1990)	NO	6	M158	21-23	15	X	X	X			Continuous	
Volden (1990)	NO	7	M150	24-32	15	X	X	X			Continuous	

Reference	Country	Trial no	Trial ID	Obs. no	No. of obs.	LFU	NRC	CNCPS	NAAT	DFFS	Design	Complete reference
Schei & Bævre (2000)	NO	8	M-TINE	33-35	3	X	X	X		X	Continuous	Schei & Bævre, 2000. Sterk og moderat proteinføring til kyr i tidleg laktasjon og sammenhengen med aceton i mjølk. Husdyr forskningsmøtet 2000, s. 417-420.
Volden (?)	NO	9	M174	36-37	2	X	X	X			Continuous	
Volden (1999)	NO	10	D87	38-43	6	X	X	X			Changeover	Volden, H. 1999. Effects of Level of Feeding and Ruminally Undegraded Protein on Ruminal Bacterial Protein Synthesis, Escape of Dietary Protein, Intestinal Amino Acid Profile, and Performance of Dairy Cows. <i>J. Anim. Sci.</i> 77: 1905-1918.
Randby & Volden (2000, unpublished)	NO	11	M219	44-46	3	X	X	X	X		Continuous	
Randby (2003)	NO	12	M221	47-49	3	X	X	X	X	X	Continuous	Randby, Å. 2003. Høstetid og fôr kvalitet. <i>Grønn kunnskap</i> 7(3): 27-43
Rinne (1999)	FI	13	11/12LP 64	50-65	16	X	X	X	X	X	Changeover	Rinne, M., Jaakkola, S., Kaustell, K., Heikkilä, T. & Huhtanen, P. 1999. Silages harvested at different stages of grass growth v. Concentrate foods as energy and protein sources in milk production. <i>Animal Science</i> . v 69 (1). p 251-263.
Auvo (unpublished)	FI	14	13PSA	66-75	9	X	X	X	X		Changeover	

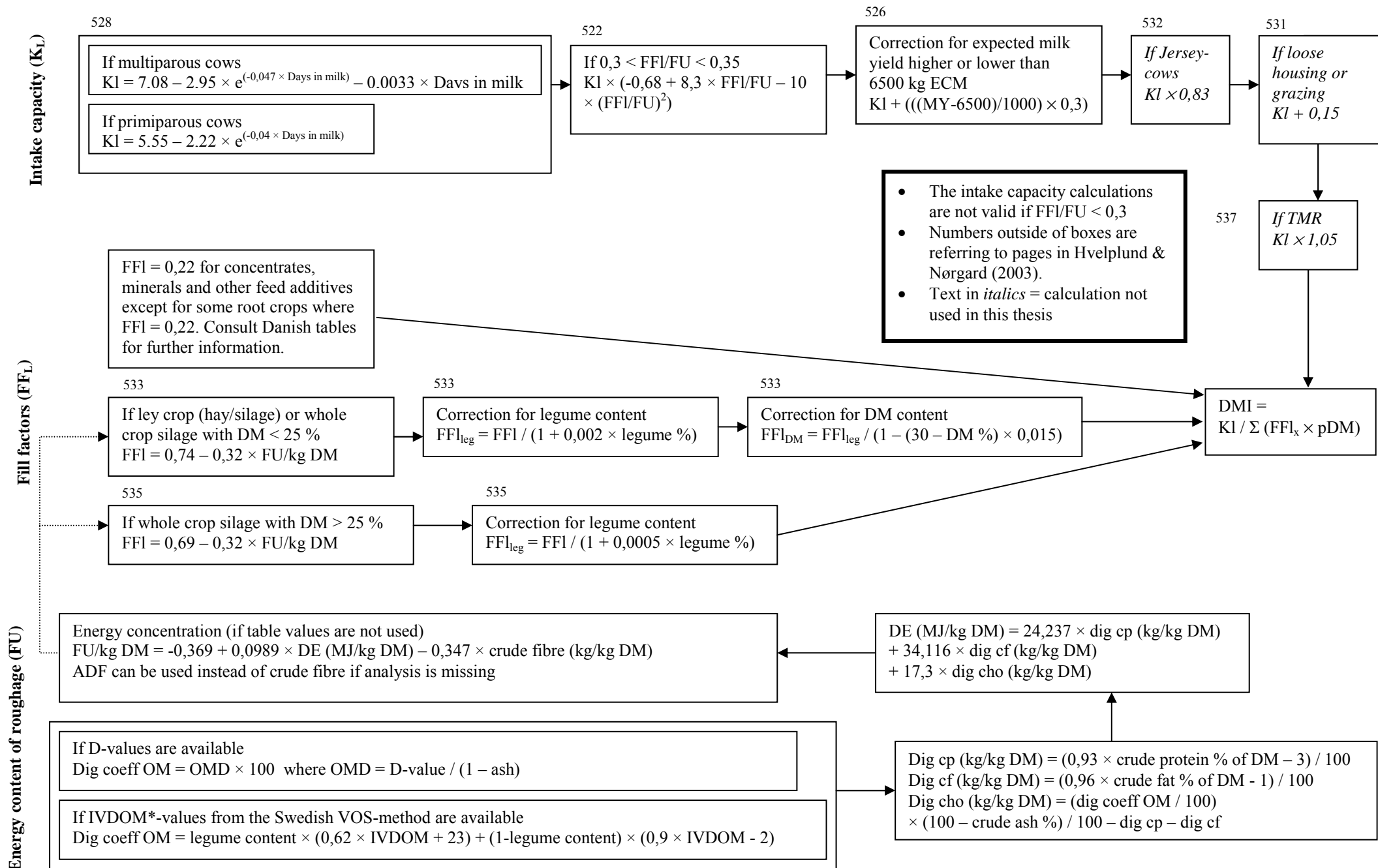
Reference	Country	Trial no	Trial ID	Obs. no	No. of obs.	LFU	NRC	CNCPS	NAAT	DFFS	Design	Complete reference
Shingfield <i>et al.</i> (2003)	FI	15	RSM/S BM	76-91	16	X	X	X	X		Changeover	Shingfield, K.J., Ahvenjärvi, S., Toivonen, V., Ärölä, A., Nurmela, K.V.V., Huhtanen, P. and Griinari, J.M. 2003. Effect of dietary fish oil on biohydrogenation of fatty acids and milk fatty acid content in cows. <i>Animal Science, Vol 77 (1). p. 165-180.</i>
Lund (2002)	DK	16	474(A)	92-95	3	X	X	X	X	X	Changeover	Lund, P. 2002. The effect of forage type on passage kinetics and digestibility of fibre in dairy cows. Ph.D thesis. Danish Institute of Agricultural Sciences, P.O. Box 50, DK-8830 Tjele & The Royal Veterinary and Agricultural University, Copenhagen. 171 p.
Lund (2002)	DK	17	476 (B)	96-99	4	X	X	X	X	X	Changeover	“
Lund (2002)	DK	18	431 (D)	100-103	4	X	X	X	X	X	Changeover	“
Lund (2002)	DK	19	450 (C)	104-107	4	X	X	X	X	X	Changeover	“
Misciattelli <i>et al.</i> (2003)	DK	20	F368	108-115	8	X	X	X	X	X	Continuous	Misciattelli, L., V. F. Kristensen, M. Vestergaard, M. R. Weisbjerg, K. Sejrsen, & T. Hvelplund. 2003. Milk Production, Nutrient Utilization, and Endocrine Responses to Increased Postruminal Lysine and Methionine Supply in Dairy Cows. <i>J. Dairy Sci. 86:275-268</i>
Kristensen, (1999) Weisbjerg <i>et al.</i> (2001)	DK	21	F367	116-124	9	X	X	X	X	X	Continuous	Kristensen, V.F. 1999. Grovfoderkildens betydning for malkekoens produktion og fodereffektivitet. Intern rapport nr. 118: 18-33. Danmarks JordbrugsForskning. ; Weisbjerg, M.R., P. Lund, K.F. Jørgensen & C.F. Børsting. 2001. Brug af cellevægskulhydraternes nedbrydningsprofiler i fodermiddelvurderingen. Intern rapport nr. 142: 80-93. Danmarks JordbrugsForskning.

Reference	Country	Trial no	Trial ID	Obs. no	No. of obs.	LFU	NRC	CNCPS	NAAT	DFFS	Design	Complete reference
Weisbjerg <i>et al.</i> (2002)	DK	22	F501	125-128	4	X	X	X	X	X	Changeover	Weisbjerg, M.R., Børsting, C.F. & Jensen, C. 2002. Majsfodring i relation til udviklingstrin, snitlængde og tyggetid. Bilag til Dansk Kvæg's fodringsdag 27. august 2002. p. 39-48.
Åkerlind <i>et al.</i> (1999)	SE	23		129-130	2	X	X	X	X		Continuous	Åkerlind, M., Holtenius, K., Bertilsson, J. & Emanuelson, M. 1999. <i>Milk composition and feed intake in dairy cows selected for high or low milk fat percentage</i> , in: Milk composition and Metabolism of Cows Selected for High or Low Milk-Fat Concentration. Doctorial thesis. <i>Acta Universitatis Agriculturae Scandinavica</i> . No 171. Swedish University of Agricultural Sciences. Uppsala. Sweden.
Österman (2003)	SE	24		131-133	3	X	X	X			Continuous	Österman, S. 2003. Extended Calving Interval and Increased Milking Frequency in Dairy Cows – Effects on Productivity and Welfare. <i>Acta Universitatis Agriculturae Sueciae</i> . Agraria 383. Swedish University of Agricultural Sciences. Uppsala. Sweden.
Aaes (1991)	DK	25		134-139	6	X	X	X	X		Continuous	Aaes, O. 1991. Grøncobs som erstatning for kraftfoder til malkekøer. I: Rapport til KISAM over resultater af undersøgelser udført i projektperioden 1987-1990. 44 p.
Aaes (1993)	DK	26		140-145	6	X	X	X	X		Continuous	Aaes, O. 1993: Fuldfoder kontra separat tildeling af energirige foderrationer udfodret efter ædelyst eller restriktivt til malkekøer. Forskningsrapport nr. 16, Statens Husdyrbrugsforsøg. 23 p.
No of observations					143	143	143	143	114	76		

APPENDIX II. Difference between predicted and observed (= 0) DMI for each observation used in the meta-analysis.



APPENDIX III. Flowchart illustrating the calculation steps of DFFS on the data from Denmark, Norway, Sweden and Finland discussed and used in the thesis



* IVDOM = in vitro digestible organic matter = VOS

Nr	Titel och författare	År
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201	Mjölkkors välbefinnande i AMS och konventionell lösdrift – skillnader i beteende och hormonstatus för oxytosin och kortisol mellan kor av hög och låg social rang Welfare of dairy cows in AMS and conventional loose housing - differences in behaviour and the hormones oxytocin and cortisol between cows high or low in social rank Karin Alm & Jenny Möller	2004
202	Automatisk Mjölknig och Betesdrift – Betydelsen av tillgång till dricks- vatten på betet samt kornas synkronisering vid passagen ut till betes- området Automatic Milking and Grazing – Effect of offering drinking water in the field and synchronization of passages to the pasture Maria Bergman	2004
203	Organic acidification of grass and clover silage Application of additives in the mower/conditioner or in the precision chopper Patrik Ingvarsson	2004
204	Utfodringens inverkan på klassning och tillväxt hos slaktsvin med Norska gener Impact of feeding on carcass quality and growth in slaughter pigs from Norwegian origin Ronnie Samuelsson	2004
205	Träckdiagnostik hos mjölkkor Manure evaluation in dairy cows Katarina Steen	2004
206	En studie av proteinkvalitet i hundfoder A study of protein quality in dog food Elin Wertsberg	2004
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208	Performance and behaviour of growing/finishing pigs in organic production Sofia Folestam	2005
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