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Estimation of roughage intake for dairy cows based on eating time and individual intake rate

Skattning av grovfoderintag för mjölkkor baserat på ättid och individuell äthastighet

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Sammanfattning

Prediktering av foderintag för mjölkkor är en viktig aspekt att ta hänsyn till både ur djurvälfärdssynpunkt men även ekonomiskt då foder är en av de största utgifterna inom svensk mjölkproduktion. Precis prediktering av foderintag är viktigt för att undvika att över- eller underutfodra sina djur vilket i sin tur kan leda till sjukdomar hos djuren och/eller högre omkostnader.

På grund av det stora behovet utvecklas det ständigt modeller för prediktering av foderintag för mjölkkor, dessa foderintagsmodeller brukar ofta vara en del av nutritionsmodeller för att säkerställa att foderintaget även täcker näringsbehovet.

I detta examensarbete har djurfaktorn äthastighet (foderintag i g/s) utvärderats och huruvida denna faktor kan användas framgångsrikt i en foderintagsmodell för mjölkkor. För att ta reda på om äthastighet går att använda har variation i äthastighet mellan och inom individer undersökts samt hur förändring av äthastigheten ser ut över tid. I litteraturgenomgången listas de vanligast förekommande faktorerna som används i foderintagsmodeller samt vilken effekt de har på foderintaget. Utöver det har två foderintagsmodeller (Norfor och National Research Council, NRC, modellerna) granskats.

Modellen för foderintag framtagen i detta arbete skattar grovfoderintaget för varje enskild mjölkko baserat på individuell historisk äthastighet (g grovfoder/s) samt förväntat energibehov. Formlerna som används i foderintagsmodellen är baserade på Norfor-modellens formler som använder sig av nettoenergi (NE) medan dataseten som används registrerar energi i omsättbar energi (ME), för att omvandla ME till NE antas NE vara 60 % av ME. Data från fyra dataset från olika studier har använts som underlag för utformningen och utvärderingen av foderintagsmodellen. Totalt ingick 112 kor i försöken varav tre försök (88 kor) följde korna en hel laktation. Dagliga registreringar av foderintag, mjölkmängd, äthastighet etc. har använts när tillgängligt.

Resultaten visar att äthastighet skiljer sig mellan individer men även inom individen, dock verkar förändringen i äthastighet över tid vara relativt låg. Resultaten visar även att äthastighet går att använda framgångsrikt för att skatta grovfoderintag. Utvärderingen av foderintagsmodellen visade att modellen överskattade mängden predikterat foderintag jämfört med det observerade foderintaget. Modellen fungerade bäst på ett av dataseten som följde korna genom en hel laktation, på det försöket var skattningsfelet på 17 % och Root Mean Square Prediction Error (RMSPE) på 7,9 kg färskvikt ensilage, samt ett R^2 värde på 0,54. Modellen presterade sämre på de övriga tre dataseten. Slutsatserna som kunnat dras utifrån detta arbete är att äthastigheter skiljer sig mellan individer och förändras långsamt över tid. Det går att skatta foderintag på individnivå baserat på individens historiska äthastighet. Den framtagna modellen behöver genomarbetas mer för att kunna fungera kommersiellt.

Nyckelord: foderintagsmodell, äthastighet, mjölkkor, foderskattning

Abstract

Prediction of feed intake for dairy cows is a crucial aspect to consider both from an animal welfare point of view and an economic point of view since one of the largest expenses for Swedish dairy farms are the costs for feed. Precise feed intake prediction is incredibly important to avoid over or under feeding the dairy cows which in turn might result in sick animals and/or larger expenses for feed. Due to the high demand of reliable feed intake prediction models' new models are being created continuously as well as improvements of already existing models. The feed intake prediction models are often combined with nutrition prediction as well to guarantee that feed intake covers the nutritional requirements as well.

The purpose of this master thesis was to investigate the animal factor eating rate (feed intake in g/s) and if said factor could be used successfully in predicting roughage intake for dairy cows. To investigate eating rate variation between and within individuals were analysed together with change of eating rate over time. The literature review lists the most common factors included in feed intake prediction models and how said factors affect feed intake. The review also examines two commonly used feed intake prediction models (the Norfor and National Research Council, NRC, models).

The model created in this thesis predicts individual silage intake for dairy cows based on historical individual eating rate together with estimated energy requirement. The calculations used in the model is based on Norfors calculations which uses net-energy (NE). The datasets used for this thesis register energy in metabolizable energy (ME). NE is assumed to be 60 % of ME. Data from four datasets were used to create and evaluate the feed intake prediction model. 112 cows were included in the four studies in total, whereas three studies (88 cows) followed all cows a full lactation. Daily registrations of feed intake, milk yield, eating rate etc. have been used when available.

The results show that eating rate differs between and within individuals and changes slowly over time. It also shows that eating rate can be used to predict silage intake for dairy cows. The evaluation of the feed intake prediction model showed overestimation of silage intake for all datasets compared to observed intake. The model worked best with one of the continuous datasets where the prediction error was 17 % and Root Mean Square Prediction Error (RMSPE) was 7.9 kg fresh weight silage with a R^2 value of 0.54. The model performed worse on the other three datasets

It could be concluded that eating rate varies between and within individuals and changes slowly over time. It is possible to predict silage intake for dairy cows based on historical individual eating rate. Lastly, the feed intake prediction model needs more work before it can be used commercially.

Keywords: Roughage intake prediction, dairy cows, eating rate, feed intake

Table of contents

List of tables

List of figures

1 Introduction

Feed prediction for dairy cows have generated a lot of interest through many decades. Dry matter intake (DMI) is one of the most important variables when it comes to dairy production since intake capacity and milk production are interdependent (Forbes 2013). The consumed feed does not only need to supply enough energy for maintenance but milk production as well, which can be as much as five times the energy requirement for maintenance (Forbes 2013). If the energy consumed does not cover the energy requirements for both maintenance and production, it might result in loss of milk production or a loss in body condition score or both. It is also known that cows will mobilize energy from fat reserves within the body to cover the energy requirements of milk production, this puts the cow in a negative energy balance which will cause the cow to lose weight (Forbes 2013). This is normal and unavoidable for high producing dairy breeds at the start of lactation since cows can't consume enough feed to cover the energy requirements for both maintenance and lactation (Forbes 2013). It is of importance to minimize weight loss due to negative energy balance since a thin cow, with a low body condition score (BCS), will have a lower chance of resuming a normal oestrus cycle and therefore getting pregnant again (Haresign & Lewis 1979).

Good quality feed for dairy cows is a key to a profitable production and one of the largest production costs for dairy farmers. Methods to maximize production based on feed intake predictions are continuously being improved and evaluated to help create the most optimal feeding strategy. For advisory services in the Nordic countries (Sweden, Denmark, Norway and Iceland) the NorFor system is commonly used (Volden 2011b). In other parts of the world the National Research Council (NRC, National Research Council 2001) model is more commonly used for nutrient supply and feed intake prediction.

However, these systems are not perfect, and studies have shown that both systems have a rather high intake prediction error which results in systemic overprediction at high DMI and underprediction at low DMI (National Research Council

2001; Jensen *et al.* 2016). To improve the systems, the intake prediction models need to be refined.

Both models use factors strongly correlated to feed consumption when estimating DMI. These factors are commonly separated into three categories; animal, dietary and environmental factors. The different factors help estimating the animal's nutrient requirement and feed intake. The nutrient requirements differ between different parts of the animal's life and prediction models are often divided between growth, maintenance, pregnancy and lactation to better predict what each individual requires to sustain production and remain healthy. By understanding and adding new factors to intake models the predictions can become more precise.

Both feed prediction systems use body weight (BW), milk production (either predicted or planned) and stage of lactation as animal factors in their models for estimating dry matter (DM) intake for lactating cows (National Research Council 2001; Volden 2011b). NRC uses less factors in their intake prediction model compared to NorFor however, which makes the NRC model easier to use on farms and by non-advisory personnel. Systems that are easy to manage might get a wider spread but can also lack in precision. Therefore, models with better adjustment are still needed.

The purpose of this study is to investigate individual dairy cows eating rate (mass of fresh or dry feed per time unit) and evaluate if variation within and between individuals exist and what may cause this variation. Secondly, eating rate will be incorporated in a new silage intake prediction model. This model will use individual cows eating rate to predict silage intake for dairy cows.

The content of this paper will investigate the animal factor *eating rate* to better understand how this factor can be used in predicting silage intake for dairy cows. Eating rate is as of yet, an unused factor in feed intake prediction, however, similar factors, such as chewing time is incorporated in feed intake predictions in NorFor (Nørgaard *et al.* 2011). Only a feed intake prediction model, and not a nutrient requirement model, will be created. The silage intake prediction model will use historic data of individual eating rate recordings to predict individual silage intake but will not use individual predictions of energy requirement. The hypothesis for this paper is that there will be a variation in eating rate between individuals and that individual eating rate can be used as a factor in an intake prediction model to help lower prediction error on an individual and group level.

2 Literature study

2.1 Factors that affect roughage intake

There are different kind of factors that can be linked to dairy cows' roughage intake where animal factors, dietary factors and environmental factors are the most commonly used in intake prediction studies (Kertz *et al.* 1991; Ingvartsen 1994; Roseler *et al.* 1997; Fox *et al.* 2004; Halachmi *et al.* 2004, 2016; Huhtanen *et al.* 2011; Volden 2011b). Not all factors can be easily measured which makes it imperative to understand how different factors interact and affect each other. By understanding the different factors, a selection of the most vital ones can be made without compromising the prediction. Table 1 lists different factors that may affect the roughage intake for dairy cows and which category they belong to. Feeding behaviour and individual differences affect feed intake as well and some of the listed categories fall under the feeding behaviour category, such as eating rate and palatability of feed. Individual differences may affect many dietary factors as well such as digestibility and rate of passage. Feeding behaviour and individual differences are therefor important to consider as well when creating feed intake prediction models, however, it might be more difficult to implement behaviour studies in a model as well as take individual differences into account.

Table 1. *A selection of factors affecting voluntary feed intake of dairy cows (modified after Ingvartsen 1994; Van Soest 1994; Arnerdal 2005)*

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	Photoperiod

Animal factors	Dietary factors	Environmental factors
Stage of lactation	Conservation	Temperature
Gestation	DM content	Humidity
Body condition	Fermentation quality	
Eating rate	Palatability	
Rumen activity	Mineral salts, alkaline agents	
Health status	Food additives	
Previous feeding	Feed refusal	

2.1.1 Animal factors

Animal factors are widely used for the prediction of voluntary feed intake in cattle. In a study by Ingvartsen (1994) more than 20 different models for prediction of voluntary feed intake was investigated and compared for advantages and disadvantages and all models compared used animal factors in varying degrees. Only half of the reviewed models in the study by Ingvartsen (1994) used dietary factors and only one included environmental factors. Since animal factors are so widely used in prediction models for food intake it can be argued that animal factors are of great importance for the quality of prediction.

The animal factors that most affect feed intake include BW, stage of lactation, milk production, gestation, live weight gain and BCS (Volden *et al.* 2011a). The size of the animal can thus be considered important for feed prediction models since three (live weight gain, BW and BCS) of the five factors stated by Volden *et al.* (2011) all measures different aspects of size of the animal. Ingvartsen (1994) states that parameter estimates indicate that DM intake increases 0.66 to 2.5 kg per 100 kg raise in live weight in dairy cows. Except the previously mentioned factors breed, genetic potential, age and parity all relate to animal size and weight as well but are not included in the list of factors that affect feed intake the most.

Table 2 lists a selection of animal factors and briefly describes how said factor affect voluntary feed intake of dairy cows. Some of the listed factors mentioned in Table 2 are easy to understand why and how they affect voluntary feed intake while some are not.

Table 2. *Animal factors, and how said factor might affect voluntary feed intake of dairy cows*

Factor	Effect on DMI	Reference
Breed	Variations in intake capacity between breeds	Muller & Botha (1998)
Genetic potential	Intake capacity has a hereditable factor	Gravert (1985); Manzanilla Pech *et al.* (2014)
Body weight	DMI increases with rising live weight	Ingvartsen (1994)
Age	DMI increases with age in dairy cows	Grandl *et al.* (2016)

Factor	Effect on DMI	Reference
Parity	Primiparous cows has a lower DMI than multiparous cows	Azizi *et al.* (2009)
Milk yield	Higher milk yield is positively correlated with higher DMI	Ingvartsen (1994)
Stage of lactation	DMI changes during the lactation	Azizi *et al.* (2009)
Gestation	DMI decrease during the last weeks of pregnancy	Grummer *et al.* (2004)
Body condition	Cows with low BCS have a higher DM intake than cows with high BCS	Bines & Morant (1983)
Eating rate	Eating rate affect time spent eating	Greter & Devries (2011)
Rumen activity	Rumen disorders affect intake	Van Soest (1994)
Health status	Most diseases result in decreased DMI	Baile & Forbes (1974)
Previous feeding	DMI pre- and postpartum have a positive relationship	Grummer *et al.* (2004)

Breed and genetic potential

Breed and genetic potential are both factors that affect voluntary feed intake and can be compared since genetic potential correlates with breed. Studies have shown that intake capacity (DMI/kg of BW) is partly heritable and intake capacity is also positively correlated with live weight. In a study by Gravert (1985) DMI had a heritability of h^2 = 0.38 and feed intake and weight were positively correlated with each other (r = 0.71). In a study by Manzanilla Pech *et al.* (2014) heritabilities for DMI of the entire lactation were estimated to be h^2 = 0.46 and daily heritabilities for DMI during a full lactation (DMI was recorded until 324 DIM) were estimated to be between h^2 = 0.21 to 0.40 which indicates that heritability of DMI changes depending on stage of lactation. Manzanilla Pech *et al.* (2014) also observed a positive correlation between DMI and weight which ranged between r = 0.29 to 0.56 depending on DIM. Differences between breeds are mostly discussed in literature when big differences in live weight exists. Cows of larger breeds (such as Holstein and Red and White breeds) are commonly assumed to have equal intake capacities (Oldenbroek 1986; Volden *et al.* 2011a). This assumption often leads to studies investigating differences in variation on intake capacity between small and large breeds. However, studies show varying results on how much variation there actually is between breeds. Jersey cows are often presumed to consume more feed per 100 kg live weight compared to larger breeds (Ingvartsen 1994; Aikman *et al.* 2008). The hypothesis of Aikman *et al.* (2008) was that Jersey cows would consume more per 100 kg live weight than Holstein cows, however, no differences in intake capacity between the breeds were found. In contrast to the results from Aikman *et al.* (2008), a study from Muller & Botha (1998) found that Jersey cows consumed more feed per 100 kg live weight compared to Holsteins. Since variation in intake capacity between breeds are debatable it can be argued that breed differences might not be affecting intake capacity to the extent that it needs to be included in DMI predictions if BW is taken into consideration.

BW, age, parity, gestation and previous feeding

BW is one of the five most important factors used in voluntary feed predictions as stated by Volden *et al.* (2011). Age, parity and gestation affect BW of dairy cows since mature live weight isn't reached until after first parity. In a study by Hayirli *et al.* (2002) the weight and DMI of cows (having had at least one calf) and heifers (pregnant and approaching first lactation) were compared, the cows weighed 127 kg more and consumed more feed compared to heifers while still having similar BCS. Another study that investigated differences in intake between cows of different parities as well, also noticed that multiparous cows ate significantly more than primiparous cows (Azizi *et al.* 2009). Intake capacity for dairy cows is dependent on two factors, structure of the feed (NDF) and energy demand of the animal (Mertens 1987; Volden 2011b). With a higher BW energy demand for maintenance and lactation increase, which in turn means a higher capacity for feed intake (Brown *et al.* 1977). Even though high BW indicates a larger intake capacity it is also dependant on BCS. Cows with higher than average BCS will eat less than cows with low to moderate BCS in relation to their weight (Grummer *et al.* 2004). Just as BW influence feed intake so does parity and previous feeding (Marquardt *et al.* 1977; Hayirli *et al.* 2002; Grummer *et al.* 2004). Positive relationships between prepartum DMI and postpartum DMI have been found in several studies (Grummer *et al.* 2004) and it has been shown that restricted feeding before parturition might increase DMI postpartum (Grummer *et al.* 2004).

Gestation affect DMI as well, it is common for both young (first and second parity) and aged (third parity or greater) cows to drop in DMI a short period before parturition (two to three weeks prepartum) (Marquardt *et al.* 1977; Hayirli *et al.* 2002). Young cows might have a lower depression in DMI than multiparous cows, however, younger cows have a lower DMI in relation to their bodyweight (Marquardt *et al.* 1977; Grummer *et al.* 2004).

Stage of lactation and milk yield

In early lactation energy output for milk production is higher than what's possible for the cow to consume. It has been observed that both primi- and multiparous cows increase their daily DMI about 20 % after parturition until lactation week 15 (Azizi *et al.* 2009). Variations in DMI between different milk yields was investigated in the same study and the results showed that high yielding cows ate significantly more than low yielding cows. It is commonly known that milk yield and DMI are interdependent of each other (Forbes 2013).

Health status, rumen activity and eating rate

Health status is one of the most obvious factors that affect DMI. Rumen activity however is not as straight forward as health status on how it affects DMI. The structure of feed affect how much time the cow spends eating and eating rate (Van Soest 1994). Concentrates is already in a finer state compared to forage and will pass more quickly through the rumen and is not in need of as much rumination as forage (Van Soest 1994). Because of this concentrates can be consumed in greater amounts than forage which results in a higher DMI (Van Soest 1994). There is also a big difference in passage rates through the rumen for different silages, a cut silage will have a quicker passage rate than an uncut silage for example. Type of feed will affect the rumen function as well. Ruminants are adapted to eat a fibrous diet and thus need fibres to maintain a healthy status of the rumen (Van Soest 1994). Rumen dysfunctions are therefore often related to diets containing a high amount of concentrate compared to the amount of forage (Van Soest 1994). Which is one reason why forage is necessary in the diet of dairy cows even though it would be easier to feed mainly concentrates to meet the energy requirements of the animal, albeit, this solution would be more expensive. High amounts of concentrates may lead to ruminal acidosis, which can be categorized either as acute or sub-acute ruminal acidocis (Krause & Oetzel 2006). Sub-acute acidosis (SARA) is the most common of the two in dairy cattle (Krause & Oetzel 2006) and SARA is defined as a drop in ruminal pH caused by an increased production of volatile fatty acids (VFA) as a result of a concentrate rich diet (Krause & Oetzel 2006; Abdela 2016). One of the most common effects of SARA is a decline in DMI, a decrease of 25 % have been observed in several studies (Krajcarski-Hunt *et al.* 2002; Kleen *et al.* 2003).

2.1.2 Dietary factors

Dietary factors have a great effect on feed intake for cattle which makes it essential to include in DMI models to gain a general interest for real life use (Ingvartsen 1994). Dietary factors such as diet composition and physical form of feed stuff affect the rumen fill value of and, hence, feed intake (Kristensen 1983). Fibre content and length of feed particles affect the passage and degradation rate through the rumen which then leads to a lower intake capacity (Kristensen 1983). This section will bring to light the most commonly used dietary factors in DMI models and table 3 contains a brief description of said factors and how they affect feed intake.

Table 3. *A list of dietary factors and the effect they have on DMI for dairy cows*

Factor	Effect on DMI	Reference
Diet composition	Concentrate ratio affect DMI	Nousiainen *et al.* (2009)
Chemical composition	High fibrous mass decrease DMI	Van Soest (1965)

Factor	Effect on DMI	Reference
Digestibility	High NDF digestibility increase DMI	Oba & Allen (1999)
Degradation profiles	Faster degradation rate increases DMI	Mertens & Ely (1979)
Rate of passage	High DMI results in faster passage rate	Kristensen (1983)
Physical form	Bigger particle sizes decrease DMI	Kristensen (1983)
Conservation	Conservation method might affect DMI	Van Os *et al.* (1995)
DM concentration	DMI increase with increased DM	Krizsan & Randby (2007)
Fermentation quality	High concentrations of organic acids decrease DMI	Dulphy & Van Os (1996)
Palatability	Palatable feed increases DMI	Kristensen (1983)

Digestibility, degradation profiles, chemical composition and diet composition

When digestibility is discussed it often refers to NDF digestibility. NDF content of the diet affect rumen fill which in turn affect DMI (Mertens & Ely 1979; Oba & Allen 1999). Not only does NDF content of the diet affect DMI but the digestibility of NDF affect as well, Oba & Allen (1999) investigated the effect of NDF digestibility on DMI and concluded that an enhanced NDF digestibility increased DMI significantly. Mertens & Ely (1979) created a model that simulated fibre digestibility, when digestion rates increased, DMI increased as well.

Type of roughage affect digestibility as well, legumes have a higher percentage of lignin compared to grasses but still has a higher percentage of soluble dry matter (Smith *et al.* 1972). Grasses generally have a higher percentage of cell wall constituents compared to legumes but the cell walls in legumes are more lignified which makes them less digestible, legumes cell walls are however, still digested faster than grass cell walls (Smith *et al.* 1972). A high amount of cell wall constituents in the feed affect DMI negatively (Van Soest 1965). Most grasses contain more cell wall constituents compared to legumes which leads to a decreased intake of grasses compared to legumes, the fibrous mass ingested from legumes is not large enough to affect intake (Van Soest 1965).

In terms of chemical composition, Van Soest (1965) found that the only consistent effect on DMI, for both legumes and grasses, is the fraction of cell wall constituents (fibrous mass) which is in accordance with Oba & Allen (1999). The amount of concentrate inclusion in the diet does affect DMI as well. Nousiainen *et al.* (2009) found that more inclusion of concentrate in the diet increased DMI.

Passage rate and physical form

Physical form and passage rate are closely linked together, finer feed particles results in a shorter retention time in the rumen and thus have a faster passage rate (Mertens & Ely 1979; Kristensen 1983; Van Soest 1994; Nousiainen *et al.* 2009). Due to a faster passage rate for smaller particles the feedstuffs fill value will decrease which increases the possible DMI. Concentrates and chopped silage are in a finer state compared to uncut roughages and will have an increased passage rate through the rumen which in turn results in higher DMI, however, Mertens & Ely (1979) found that pelleted grasses, compared to longer particles, increased DMI but decreased digestibility. The same result occurs with the inclusion of a larger concentrate proportion, DMI increases but it will however, decrease digestibility of the total diet (Nousiainen *et al.* 2009).

Fermentation quality, DM content, conservation and palatability
Higher DMI for roughages with higher DM content have been observed in several studies and the reason why is widely discussed in those studies. Dulphy & Van Os (1996) reviewed literature on voluntary intake for silages compared to hay and found that DMI for hays was higher than silages. Krizsan & Randby (2007) compared silages of different fermentation qualities and found a positive relationship between DM content and intake, their conclusion was that the fermentation quality affected intake rather than the DM content in itself which is corroborated by Dulphy & Van Os (1996), however Dulphy & Van Os (1996) states that even though fermentation quality effect DMI, DM content can be used as a predictor of roughage intake. Both Dulphy & Van Os (1996) and Krizsan & Randby (2007) found that high concentrations of fermentation products (lactic acid, acetic acid, propionic acid and butyric acid) affect DMI negatively. Lactic acid is often associated with good fermentation quality, which is true, up to about 100 g/kg DM, as stated in the review by Dulphy & Van Os (1996), the same review also stated that clear evidence existed on high lactic acid concentrations affecting intake negatively which means that lactic acid, up to a certain point, indicates good fermentation quality. Krizsan & Randby (2007) found that the best indicator of these acids for fermentation quality was butyric acid, where high concentrations indicates bad fermentation quality. A study by Huhtanen *et al.* (2007) found that it was best to measure total acid concentration of silages instead of all fermentation products separately.

Both Dulphy & Van Os (1996) and Krizsan & Randby (2007) mention that effective additives might increase DMI in low DM silages which means that conservation method of silages has an effect on DMI. Shingfield *et al.* (2005) investigated how conservation method and concentrates levels affected milk composition and observed higher intake for silages than for hay. Slight differences in DMI between conservation methods could be seen as well in the same study. Van Os *et al.* (1995) found that silage preserved with formic acid, compared to silage without additives, resulted in a significantly higher DMI due to lower concentrations of fermentation products.

Van Os *et al.* (1995) also explained that a lower palatability for the untreated silage might explain the decreased DMI. Palatability of feed is however, more difficult to measure and is often described as the willingness of the animal to eat a certain feedstuff. Palatability is often measured in experiments by intake observations and what feedstuff the animal chooses to eat when different options are available. Fermentation products are often discussed as being a reason for lowered palatability of silage but a specific fermentation product that affect palatability most is still undecided (Van Os *et al.* 1995; Dulphy & Van Os 1996; Krizsan & Randby 2007).

Other dietary factors affecting DMI

In Table 1, four dietary factors affecting DMI were mentioned that has yet to be described here; mineral salts, alkaline agents, food additives and feed refusals. Food additives, such as ionophores, may affect voluntary intake, such products are however, not commonly or commercially used in Europe and only included in one DMI prediction for growing cattle in the review by Ingvartsen (1994). Mineral salts and alkaline agents are described as having inconsistent effects on DMI according to Ingvartsen (1994) which makes them difficult to incorporate in DMI prediction models.

2.1.3 Environmental factors

Environmental factors are thus far the most complicated factors to include in DMI models since many environmental factors are difficult to translate into numerical measurements. For example, management factors where the individual farmer has different styles of management that might affect DMI, these kinds of factors are difficult to take into consideration when intake models are designed. However, the factors listed in Table 4 are more easily incorporated and translated into values that can be included into DMI models.

Table 4. *Environmental factor and how they affect DMI for dairy cows*

Factor	Effect on DMI	Reference
Duration of access to feed	Restricted access to feed might lower DMI	Friend *et al.* (1977)
Frequency of feeding	Increased frequency increase DMI	Campbell & Merilan (1961)
Separate vs. Complete feed	TMR feeding might increase DMI	Nocek *et al.* (1986)
Tie stalls vs. Loose housing	Loose housing increase DMI	Ingvartsen & Andersen (1993)
Area per animal	Small feed bunk area/animal decrease DMI	Friend *et al.* (1977)
Photoperiod	Longer photoperiods increase DMI	Dahl *et al.* (2000)
Temperature	High temperatures lower DMI	Holter *et al.* (1996)
Humidity	High relative humidity lower DMI	West (2003)

Duration of access to feed, frequency of feeding and area per animal

Access to feed impacts feeding behaviour of cows, when stocking density increases competition over access to feed increases as well (DeVries & von Keyserlingk 2006; DeVries 2019). When stocking density increase and space at feed bunk decrease eating rate and displacements of cows increase as well (DeVries & von Keyserlingk 2006; DeVries 2019). DMI does however, not decrease due to the increased eating rate that compensates for the lowered access to the feed bunk (DeVries & von Keyserlingk 2006; DeVries 2019). Friend *et al.* (1977) investigated different spaces at feed bunks and only the smallest allowed space of 0.1 m resulted in a lowered DMI. When duration of access to feed is restricted, either by competition or by frequency of feeding the microbial flora in the rumen is affected negatively and result in a lower fibre digestibility which in turn affect feed efficiency (Campbell & Merilan 1961; Robinson 1989). Campbell & Merilan (1961) investigated how frequency of feeding affect production parameters for dairy cows and observed increased total feed intake with increased feeding frequency.

Tie stalls vs. loose housing and separate vs. complete feed

In early research on differences in DMI between separate feed and Total Mixed Ration (TMR) an increase of DMI was observed for TMR feeding (Owen 1984; Nocek *et al.* 1986). In later research it has been found that small to no differences in DMI can be found between separate and TMR feeding if concentrate rations are given as small frequent meals (Yan *et al.* 1998; Yrjänen *et al.* 2003). Therefore, management of feed distribution effect DMI more than feeding method.

Ingvartsen & Andersen (1993) found that growing cattle increased DMI by 4 % in loose housing systems compared to tied-up stalls. DMI is related to animal activity which is why loose housing increase DMI.

Temperature, humidity and photoperiod

A temperature-humidity index (THI), which incorporates the combined effect of temperature and relative humidity, can be used to measure heat stress in dairy cows. In a study by Holter *et al.* (1996) depression in DMI from heat stress could be observed when THI rose above 56. Peters *et al.* (1981) found that cows increased intake when exposed to longer photoperiods than the natural, it was theorized that the larger feed intake was due to an increased energy demand due to increased milk yield. A review article by Dahl *et al.* (2000) corroborated the same conclusion as Peters *et al.* (1981), that increased photoperiods leads to increased intake due to an increased milk yield.

2.2 Methods used to estimate roughage intake

Prediction of feed intake is one of the most important elements of production and is mainly influenced by animal and dietary factors (Ingvartsen 1994; Volden *et al.* 2011a). Several methods are used throughout the world to estimate feed intake for dairy cows since it is of outmost importance for a profitable production. A farmer needs to be able to accurately predict feed consumption to be able to plan for the cost of feed and which crops to grow. Both models described in this review predict nutrient requirement as well, which will not be described in this review. Since there are numerous methods that can be used for feed prediction this thesis will only describe two of the most widely used models which many other prediction models are based upon.

2.2.1 Norfor

NorFor is the semi-mechanistic nutrient and feed prediction system used by advisory services in the Nordic countries (Volden & Gustafsson 2011). It is a science-based model that predicts nutrient supply and requirements for cattle in four different stages of life; maintenance, milk production, growth and pregnancy (Volden 2011c). The model is divided into five parts:

1. An input section for animal and dietary factors
2. A module for processes in the digestive tract and metabolism, also called the feed ration calculator (FRC)
3. A module for feed intake predictions
4. A module predicting the structure of the diet
5. The output of nutrient supply, nutrient balances and production responses

NorFor uses animal and dietary factors as input variables for the model. For dairy cows, body weight, stage of lactation, pregnancy day and planned or potential milk production are the main animal input variables (Volden 2011c). The dietary input variables separates the feed dry matter (DM) into eight categories: ash, crude protein (CP), crude fat (CF), neutral detergent fibre (NDF), starch, sugar, fermentation products (FPF) and a residual fraction. Furthermore CP, NDF and starch are divided into sub-groups depending on degradability. FPF are divided into lactic acid, volatile fatty acids (VFA) and alcohols. The model also require fractional degradation rates of the soluble and non-soluble but potentially degradable feed fractions to be able to work properly (Volden 2011c). Since this thesis focuses on feed intake predictions for dairy cows only the third part of Norfors model regarding lactating and dry dairy cows and pregnant heifers will be reviewed more closely. The intake model for growing cattle and bulls will not be described.

Prediction of voluntary feed intake in NorFor

Volden *et al.* (2011) introduces the chapter for prediction of voluntary feed intake with stating that feed intake prediction is the most important determinant of production for dairy cows even though ration formulation and nutrient absorption is important as well. The intake prediction model in NorFor is mainly built around two aspects, structure of the feed (fill value) and intake capacity (IC) of the cow. The base calculation and assumption in the NorFor feed intake model is that the IC equals the total feed intake expressed in fill units. In the NorFor system all feeds are assigned a basic FV expressed in fill units, where concentrates have a fixed FV of 0.22 FV/kg while the FV for roughages uses a variable which is calculated from OMD and NDF content in the roughage (Volden 2011a). The NorFor system also corrects FV of roughages based on fermentation quality, where total content of fermentation acids and ammonia N in the ensiled feed is used in the equation which makes it possible to use fermentation quality of silage as a factor in the feed intake prediction model. Volden *et al.* (2011) describes the importance of not assuming feed FV to be static. Concentrate substitution rate (defined in Norfor as how the ration of concentrate affect availability of ruminal space for roughages) affect roughage intake as does energy concentration (relative of the animals' energy requirement) of the ration. Thus, a factor for metabolic rate should be included in the aforementioned equation to meet specific animal production levels. Metabolic rate is defined as a factor that causes the cow to stop eating before even before reaching full ruminal FV capacity. This factor is included in the Norfor model to compensate that a cow will stop eating before reaching full FV capacity.

Intake capacity in NorFor

To create the NorFor feed intake prediction model and evaluate it, data from 183 dietary treatments from Nordic production experiments was used. The following animal and dietary parameters were used to develop and evaluate the equation for predicting IC of dairy cows in the Nordic countries:

- DIM
- BW, kg
- ECM, kg/day
- DMI, kg/day
- Concentrate proportion, kg/kg DM
- Roughage intake, kg DM/day
- Roughage basis fill value, FV/kg DM
- Starch + sugars, kg/day

By using these parameters, a multiple regression approach was used to derive the equation used for predicting IC. The multiple regression equation uses DIM, ECM and BW together with regression coefficients that represent the different Nordic breeds and parity to predict IC for the animal.

The equation for IC is complemented with corrections for exercise and feeding level. Level of exercise is dependant on housing system (loose or tied-up) and pasture and feeding level is taken into consideration when or if cows are fed below *ad. Libitum.* IC for dry cows is a bit different and uses BW, a regression coefficient and a breed correction factor.

Fill value

Since the base equation for DMI in the NorFor model is that intake capacity is equal to the fill value intake, factors that affect fill value intake is needed to be considered when creating an equation. Concentrate substitution rate and metabolic rate are both factors that affect the fill value intake, which the NorFor model takes into consideration when calculating FV intake. FV intake is expressed in fill units and needs the FV of concentrates and roughages, substitution rate factor and metabolic rate factor to calculate.

Substitution rate has traditionally only been related to concentrates effect on digestion of roughages, however, the NorFor model does not use definition of feedstuffs to explain variation of substitution rate, instead changes in NDF digestion in the rumen and the effect of rapidly degradable carbohydrates on ruminal digestion is used. To be able to do this the equation for FV substitution rate includes the proportion of sugar and starch in the diets as well as total sugar and starch intake since both proportion of sugar and starch and intake of sugar and starch have been shown to have a negative effect on roughage FV. The FV substitution rate results in a value between 0 to 1.

The NorFor model uses a factor for metabolic rate that is defined as a regulatory factor that causes the cow to stop eating before reaching full ruminal FV capacity. This factor is physiologically an animal factor and affect IC however, Norfor uses it on the feed side for computational reasons. The equation for the metabolic rate factor uses the mean of roughage FV, IC and IC divided with 8, this is a ratio that function as an adjustment factor for animal IC so that it can be applicable across dairy breeds.

Prediction of voluntary feed intake for heifers and during gestation in NorFor

A few other parameters than the ones for cows were used in the dataset when creating the NorFor intake equations for heifers. Age in days, average BW in kg, average live weight gain in g/day and concentrate intake in kg DM/day were included. When IC for heifers are predicted BW, average daily weight gain and correction for IC during gestation is needed. IC during gestation incorporates gestation day in the equation. Just as IC for cows' exercise level is incorporated as well.

The FV substitution rate for heifers is calculated differently than for cows due to limitations on concentrate characteristics in the available datasets. Instead of using starch and sugars, concentrate proportion of diet is used to calculate substitution rate for heifers.

By including metabolic rate correction factor for growing cattle (used for heifers as well), prediction of DMI was significantly improved, just by including this equation, Mean Square Prediction Error (MSPE) was reduced by 14 %. Just as for cows, a mean for roughage FV, BW and intake capacity ratio (IC/3) was used to describe the metabolic rate correction factor.

Model evaluation of total DMI and roughage DMI in NorFor

The NorFor intake model was evaluated with data from Nordic countries by Volden *et al.* (2011b). The datasets used for evaluation were divided into two sub sets where the cows either were fed roughages *ad libitum* separate from concentrates (n = 226) or TMR *ad libitum* (n = 62). The dataset where roughages were fed separately from concentrates was used to evaluate predictions for only roughage intake while the dataset with TMR feeding was used to evaluate predictions for total DMI. Both datasets had wide variations in DMI and diet composition and published nutrient composition data was used. When data on nutrient composition didn't exist values from the NorFor feedstuff table was used.

Results of accuracy and precision when using the NorFor model can be seen in Table 5 and 6. For roughage predictions, observed mean DMI was 11 kg/day and predicted DMI was 10.1 kg/day, the regression slope was 0.88 and not significantly different from 1 which shows a high correlation between observed and predicted values. The r^2 value was 0.87 which shows that 87 % of the variability has been accounted for in the model. Prediction error for roughage intake was 11.6 % however, predicted roughage intake was within ±10 % of observed intake for 58 % of the observations. The Root Mean Square Prediction Error (RMSPE) of roughage intake was 1.3 kg DM/day and 53 % of the prediction error can be explained by disturbance. Overall bias explains 48 % of total Mean Square Prediction Error (MSPE) and showed that the NorFor model underpredicts roughage intake.

Predicted values for TMR intake worked slightly better in most categories. Mean observed TMR intake was 21.2 kg DM/day and predicted TMR intake was 21.1 kg DM/day and the regression slope (0.97) was just as for roughage intake not significantly different from 1. R^2 value of the TMR model was 0.59 which shows that 59 % of the variability within the model has been accounted for. Disturbance explain 62 % of the MSPE and the regression explain almost all the rest (37 %) of the MSPE which means that overall bias of the model almost doesn't influence the MSPE at all. The RMSPE of 1.6 kg DM/day corresponds to a prediction error of 7.7 % and predicted intake was within 10 % of observed intake for 79 % of observations.

Table 5. *Observed and predicted DMI using NorFor's model, as seen in Volden et al. (2011b)*

Item	N	Intake, kg DM/day		Regression	
		Observed	Predicted	Intercept	Slope
Roughage[1]	229	11.0	10.1	0.49	0.876
TMR	62	21.2	21.1	0.48	0.972

1 Roughage intake from datasets where roughage and concentrates were fed separately

Table 6. *Accuracy and precision of NorFors' ability to predict DMI, as seen in Volden et al. (2011b)*

Item	n	r^2	Prediction error, %	RMSPE[1]	Proportion of MSPE[2]		
					Overall bias	Regression	Disturbance
Roughage	229	0.866	11.6	1.3	0.468	0.001	0.531
TMR	62	0.593	7.7	1.6	0.006	0.371	0.623

1 RMSPE = Root Mean Square Prediction Error

2 MSPE = Means Square Prediction Error

2.2.2 NRC

Since 1944 has the National Research Council published editions of *Nutrient Requirements of Dairy Cattle* and just as NorFor the NRC model includes prediction of nutrient and energy requirement and a DMI model for dairy cattle (National Research Council 2001). The 2001 edition is the seventh revised edition of the Nutrient requirements of dairy cattle published by NRC, this edition consists of 13 chapters about the nutrition of cattle and one of these chapters handles DMI for lactating dairy cows and growing heifers, the other chapters include energy calculations for all stages of life for cattle, information on nutrition of cattle and nutrient requirements. Only the DMI chapter and the model evaluation will be mentioned in this part and not the energy calculations or nutrient requirement estimations that's included in the NRC model as well.

The 2001 edition expresses the need for computer models, National Research Council (2001) writes that computer models is the only effective way to take animal variation into account when estimating nutrient requirements and thus predicting DMI. The seventh edition includes a computer model that can describe animals in various stages of life and the differing need these stages represent for the animal. National Research Council (2001) describe their model as a user-friendly tool to provide practical and situation-specific information for the user.

DMI model in NRC

The chapter that includes the DMI model discusses many aspects on factors affecting DMI. Environmental, diet and physiologic aspects were considered and discussed when developing the equations included in the DMI model. National

Research Council (2001) states at the start of the chapter that prediction of DMI is fundamentally important for health and production of the animal and stresses the importance of accurate predictions to avoid under and/or over prediction of DMI.

When developing the DMI model for the seventh edition data from continuous lactation trials running at least six weeks published in the *Journal of dairy science* from 1988 to 1998 were used as well as data from Ohio State University and the University of Minnesota. The datasets included in total over 17,000 cow weeks from both primi- and multiparous cows where the majority of data were between lactation week 1-40. Only animal factors are included in the DMI prediction model with the motivation that animal factors are both easily measured and known. The motivation NRC declared to not use dietary factors when predicting DMI for lactating dairy cows was that the most commonly used approach when formulating diets for dairy cows is to estimate DMI before diet compositions are known.

The equation for DMI in kg/day for lactating dairy cows includes Fat Corrected Milk (FCM) of 4 % in kg/day, metabolic BW ($BW^{0,75}$) and week of lactation. The week of lactation is used as a correction for depressed DMI during the first weeks of lactation. The equation for growing, nonlactating heifers is the same as for growing beef cattle but with a correction for gestation in the NRC model. The heifer DMI prediction model includes metabolic BW, net energy of the diet in Mcal/day, the gestation correction is based on gestation day, this correction is used as to not create a large disconnect in the DMI prediction during the last trimester of the gestation.

An equation for DMI for dry cows in the last 21 days of pregnancy were developed as well, which uses days pregnant – 280 and BW to predict DMI.

Model evaluation in NRC

The NRC DM intake model was evaluated by the National Research Council (2001) and the data used when creating the equation for lactating dairy cows are entirely based on observations on Holstein cows which means that no variations are considered for breed differences that might exist, therefore NRC recommends another model when predicting DMI for jersey cows. For lactating dairy cows an adjustment for early lactation is made to compensate for a depressed DMI. When predicted DMI is plotted against actual DMI for the first 14 weeks of lactation a trend of underestimating DMI is shown. However, the first ten weeks of prediction is very close to actual intake but still lower, after ten weeks the underprediction of DMI increases. NRC found that no adjustment for parity was needed in the equation since the bias and RMSPE for primiparous (- 0.16 kg/day and 1.75 kg/day respectively) and multiparous (- 0.12 kg/day and 1.79 kg/day respectively) cows were deemed similar enough. NRC stressed however, the importance of using appropriate data of BW and milk production for primi- and multiparous cows in the model for accurate predictions. NRC considered implementing an adjustment factor for temperature and humidity, however, there were insufficient amount of data available to create such a factor. Even though an adjustment factor for temperature and humidity is lacking NRC argues that the drop in milk production observed during heat stress will reflect a drop in DMI in the model predictions as well and therefore an indirect environmental effect is taken into consideration.

Validation data for the heifer DMI model is sparser than for dairy cows. The base model without the gestation adjustment is originally created for growing beef cattle. As with the dairy cow model, only animal factors are used in the DMI prediction model for heifers. Validation of the model is based off of 2727 observations of growing Holstein heifers with a BW ranging between 58 to 588 kg and a dietary net energy-maintanance concentration of 1.24 to 1.55 Mcal/kg. No adjustments in the equation for breed, empty body fat, feed additives, anabolic implant and temperature/humidity was made. NRC didn’t find any need of implementing an adjustment factor for breed and didn’t have sufficient data on temperature and humidity to be able to create an adjustment factor regarding that. The adjustment factor regarding gestation days were not validated during the seventh edition but used anyway.

When comparing predicted DMI with observed DMI, predicted intake was within ± 5 % in 41 % of observations and ± 10 % in 73 % of observations.

Table 7. *Validation statistics on NRC DMI model for lactating dairy cows and heifers (National Research Council 2001)*

	Average DMI kg/day			
Prediction model	Observed	Predicted	RMSPE kg/day	Bias kg/day
Lactating dairy cows	22.3	22.1	1.82	- 0.27
Heifers	-[1]	-	1.2	- 0.51

1 Data not given due to large variations in intake between growing heifers ranging 58-588 kg BW

2.3 Eating rate as a factor in roughage intake predictions

It is essential to understand feeding behaviour to be able to create accurate feed prediction models. One of the less often studied factors in DMI predictions is eating rate. Eating rate is a factor that contributes to net energy intake but may also indicate palatability and choice of feed (Van Soest 1994). Since both palatability and feed refusal are two measurable factors (Table 1) eating rate might be used as an indicator for both. Technically eating rate is the consumed mass of fresh or dry feed per time unit which means that different studies uses different time units when investigating eating rate, Van Soest (1994), for example, measures eating rate in grams/minute. To calculate eating rate the quantity of feed consumed, and the duration of eating must be known.

2.3.1 Factors that affect eating rate

Eating rate might be affected by many factors, for example; hierarchy, stocking density, type of feed and age have been proven to affect eating rates (Harb *et al.* 1985; Nielsen *et al.* 1995; Nielsen 1999). Nielsen *et al.* (1995) and Harb *et al.* (1985) studied pigs and cows and found that both species increase eating rate when more competition for food was present. In the study by Harb *et al.* (1985) ten cows, in late lactation, were used to investigate the association of voluntary silage intake, social behaviours and duration of eating. All cows went through three treatments with the respect to the competition between cows for access to feed, a non-competitive (A), a competitive (B) and a semi-competitive (C) feeding strategy. Harb *et al.* (1985) observed that the cows spent longer time eating in a non-competitive environment compared to a competitive environment (on average 204 minutes daily (A) compared to 124 (B) and 150 (C) minutes daily respectively). There was however, no significant difference in silage intake between treatments. Since time spent eating decreased with more competition over food, but daily feed intake didn't decrease, the conclusion drawn in the study by Harb *et al.* (1985) was that competition between individuals affect eating rate. The mean rate of eating silage increased 65 % and 27 % from treatment A to treatment B and C and the maximum recorded eating rate recorded without any observed decrease in intake was 71 g silage DM/min.

Harb *et al.* (1985) also studied how eating rate was affected by dominance and the results indicated that dominant cows eat for longer periods of time compared to submissive cows. However, the results showed that dominance did not correlate with the amount of silage consumed (Harb *et al.* 1985). Thus submissive cows might change their rate of eating to consume their daily desired food intake, this theory is also supported by a study by Nielsen (1999). Nielsen (1999) writes that an animal, regardless of stage in life (lactating, growing etc.) has a desired level of daily feed intake which it will consume given free access. This level of food consumption will be defended by the individual by, for example, increasing eating rate if needed (Nielsen 1999). Proudfoot *et al.* (2009) corroborates the theory that competition at feeding increases eating rate but DMI is not affected.

In a study on pigs, eating rate was investigated, and the different treatments was feeding pigs in groups of varying sizes (Nielsen *et al.* 1995). The results in this study showed similar results as the study by Harb *et al.* (1985) that pigs increased eating rate when introduced to higher competition. Nielsen *et al.* (1995) and Nielsen (1999) argues that pigs and other species has a preferred eating rate just as they have a preferred amount of food intake. However, both Harb *et al.* (1985) and Nielsen *et al.* (1995) observed that the eating rate of individuals will change even though they might prefer eating at a slower pace. Nielsen (1999) argues that this compromise in eating rate might be due to the desire to eat together with conspecifics, since both pigs and cows are social animals. The desire to eat together with the group is, therefore, higher than their desire to eat at a certain rate.

Preferred eating rate may also change over time with changes of the physiological state of the animal when going from growing to mature (Nielsen 1999). Differences in eating behaviour between primiparous and multiparous cows have been observed in several studies (Azizi *et al.* 2009; DeVries *et al.* 2011; Nasrollahi *et al.* 2017; Neave *et al.* 2017). In one study the eating rate of primiparous and multiparous dairy cows differed with approximately 29 g DM/min where the multiparous cows average eating rate were approximately 95 g DM/min and the primiparous average eating rate was approximately 66 g DM/min (Azizi *et al.* 2009).

3 Material and methods

3.1 Data set

Four different experiments have been included in the data set for evaluation of eating rate for dairy cows in this paper. In Table 8 a summary of tested effects, number of cows, diets, experimental designs, recordings, sampling and breeds are listed. All trials have been conducted at the Swedish Livestock Research Centre, Uppsala, Sweden. Data from one unpublished work have been used (Karlsson *et al.* unpublished). The different trials have consisted of 23-37 dairy cows and have been of either continuous or change-over design (Table 8). The breeds used is of Swedish red (SRB) and Swedish Holstein (SH) and both primiparous and multiparous cows have been included in the trials. Between mid-May to mid-August all cows in Sweden needs to have access to pasture according to Swedish animal welfare regulation (SJVFS 2019:18); this includes cows in trials if exceptions haven't been approved by an Ethics Committee for Animal Research. Two of the trials had the cows on pasture for a shorter or longer time-period than May-August (Table 8). Since the trials of both Spörndly *et al.* (2017) and Karlsson *et al.* (unpublished) were continuous, the cows included in their studies had access to pasture during these months, however, in the trial by Karlsson *et al.* (unpublished) the cows were allowed access to paddocks with minimal amount of pasture to ensure a low pasture intake. All continuous trials followed all cows during a full lactation, approximately 305-days.

The changeover study by Karlsson *et al.* (2018) was conducted in November 2015 to February 2016 and included 12 primiparous and 12 multiparous cows in mid lactation. The purpose of the study was to investigate if concentrate based on different by-products had any effect on milk production and feed consumption compared to commercial concentrates. The study contained four dietary treatment groups and four periods. Three different by-product concentrates were used and one control concentrate containing cereal and soybean meal. The cows were blocked by parity and breed, and then randomly assigned to treatment groups, there were six cows per treatment. The treatment periods lasted three weeks each. The first two weeks were used as an adaptation period for the new diets and the third week of each period was used for sampling and data collection. After each period all groups changed treatment, the new concentrate was gradually changed during the first four days of each new period.

The second study by Karlsson et al. (unpublished), included in this dataset, was conducted in February 2017 to May 2018 and was a continuous trial. The purpose of the study was to investigate the effect of added synthetic amino acids to high or low concentrate rations. The cows were randomly divided into one of four treatments where they were given a high or low concentrate ration with or without synthetic amino acids. In total 37 cows were studied for a full lactation (305 DIM or until nine weeks before expected calving) and all cows were multiparous.

The study by Spörndly *et al.* (2017) published data from two experiments conducted during two consecutive years in 2014 and 2015, which is why it is referred to here, as two experiments. Both experiments were of continuous design and warranted one data set each to be used in this paper. This study investigated performance in dairy cows with only cereals as concentrate compared to dairy cows with both cereals and protein concentrate. The first cow entered the study in the beginning of October 2014 and the last cow exited in mid-October 2015. In the second year the first cow entered the study at the end of September 2015 and the study ended in mid-October 2016. In total 51 cows were included in the study, 16 of these were primiparous and 35 were multiparous. The first year included 23 cows and the second year included 28. The trial had two groups which cows were randomly assigned to. All 51 cows entered the study at calving and ended at drying-off.

Table 8. *List of trials included in the data set used for evaluating eating times.*

References	N	Tested effects	Diet	Experimental design	Recordings and sampling	Breeds
Karlsson *et al.*, 2018	24	Effect on feed intake and milk production from by-product-based concentrate combined with high quality grass silage	Timothy, ryegrass and tall fescue silage and four concentrates; Control[1], Conc1[1], Conc2[1] & Conc3[1]	Change over, 4x4	Daily feed intake, BW, BCS, milk yield, milk sampling, silage samples, concentrate samples and feces for digestibility,	SH, SRB
Karlsson *et al.* unpublished	37	Effect of added synthetic amino acids in high or low concentrate rations	Grass/clover silage and by-product-based concentrate	Continuous, 2x2 factorial design	Daily feed intake, BCS, BW, progesterone, activity, milk yield, milk samples, blood samples, silage samples, concentrate samples and feces for digestibility[2]	SH, SRB
Spörndly *et al.* 2017, year 1	23	Effect on cows' performance when excluding protein concentrate from diet	Timothy grass silage[3] and one of two concentrates; cereal concentrate or cereal and protein concentrate	Continuous, 2 treatments	Daily feed intake, pasture intake, milk yield, BW, BCS, urine samples, blood samples, milk samples, silage and concentrate samples for digestibility	SH, SRB
Spörndly *et al.* 2017, year 2	28	Effect on cows' performance when excluding protein concentrate from diet	Timothy grass silage[4] and one of two concentrates; cereal concentrate or cereal and protein concentrate	Continuous, 2 treatments	Daily feed intake, pasture intake, milk yield, BW, BCS, urine samples, blood samples, milk samples, silage and concentrate samples for digestibility	SH, SRB

1 Control = Cereal grain, soybean meal; Conc1 = Sugar beet pulp, distillers grain; Conc2 = Sugar beet pulp, rape seed meal; Conc3 = Sugar beet pulp, rape seed meal, distillers grain

2 A parallel trial using the same animals measured methane production in the VMS and passage rate of digestion with rumen samples

3 The cows had access to pasture from 5th of May until the 1st of September, this time period was excluded from the data set due to unsure roughage intake recording

4 The cows had access to pasture from 12th of May until the 3rd of October, this time period was excluded from the data set due to unsure roughage intake recording

3.1.1 Animals and housing

Average DIM for all cows in the four data sets used was 128 days in milk with an average BW of 663 kg. On average total DMI was 23.6 kg/day and average silage DMI was 16.7 kg/day with an average eating rate of 4.1 g FW/s. All descriptive statistics of the data sets used can be seen in Table 9.

Table 9. *Descriptive statistics of the data sets used to investigate eating rate and developing equations for predicting DMI*

Item	Average	SD	Maximum	Minimum
DIM	128	77.2	318	2
BW kg	663	80.7	944	223
ECM kg	35	7	63	5.9
Silage DMI kg/d	16.7	4.8	36.9	0.1
Concentrate DMI kg/d	6.8	3	15.7	0
FW silage intake kg/d	43.9	13.1	114.5	0.1
Total DMI kg/d	23.6	4.5	43.8	0.6
Total FW intake kg/d	51.8	12.5	121.7	0.8
Eating rate g FW/s	4.1	1.2	12.6	0.6

All cows in the included studies were held in an insulated barn with a loose housing system with a total of 60 cows per group which means that all experiments had cows not included in the study in the same area. The lying area had cubicles with rubber mats and sawdust bedding. The cows in the study by Spörndly *et al.* (2017) had free traffic between feed stations and the laying area since they were milked in an Automatic Milking Rotary (AMR, DeLaval International AB). All cows in both studies by Karlsson *et al.* (2018) and Karlsson *et al.* (unpublished), where all milked in a Voluntary Milking System (VMS, DeLaval International AB), which used the Feed-First cow traffic system. Concentrate dispensers (FSC400, DeLaval International AB, Tumba, Sweden) and silage throughs (CRFI, BioControl Norway As, Rakkestad, Norway) for individual feeding was used in all trials (Spörndly *et al.* 2017; Karlsson *et al.* 2018; Karlsson *et al.* unpublished) and both systems recorded daily feed intake automatically. Daily concentrate intake was recorded with the farm management system, DelPro (DeLaval International AB). The forage feed throughs were placed on weight cells that recorded feed intake and the throughs were shared by 2.7 cows/through (Spörndly *et al.* 2017) or 3 cows/through (Karlsson *et al.* 2018; Karlsson *et al.* unpublished). The cows gained access to the silage dispensers by access-controlled gates operated by cow transponder. However, the cows milked in the VMS used the feed first system which means that the cows had free access from the laying to the feeding area, but selection gates ushered the cows to either the waiting area for milking or the laying area if no milking permission were established when the cow wanted to leave the feeding area. Both the AMR- and VMS-barn had four concentrate dispensers installed but the cows milked in the VMS also had access to concentrate from the concentrate dispensers within the VMS. Since all groups averaged in 60 cows the concentrate dispensers approximately fed 15 cows/dispenser. The concentrate dispenser was operated by cow transponder as well to ensure individual concentrate amount and type of concentrate.

All cows in the study by Spörndly *et al.* (2017) were milked twice daily whereas all cows from Karlsson *et al.* (2018) averaged in 2.5 milkings per day and all cows from Karlsson *et al.* (unpublished) were milked averagely 2.6 times per day. Milk yield, expressed as kg milk, was automatically recorded in both systems.

During the grazing period, between early May until September year 1, and mid-May until October year 2, the cows in Spörndly *et al.* (2017) had access to pastures. In the beginning of the grazing period the cows still had access to silage inside the barn, however the pasture completely replaced the need for feeding silage after approximately 20 days on pasture. At the beginning of July, the cows started to have access to silage inside again however, much of the daily roughage intake were still from pasture. Concentrate were still fed inside the barn in dispensers. The continuous trial by Karlsson *et al.* (unpublished) used three grass-covered paddocks during the grazing period between mid-May to mid-August instead where the grass was mowed in order to control feed intake from pasture. The individual pasture intake was estimated to 0.5 kg DM/day and was not included in the total DMI. The paddocks were approximately 0.2 hectare in size and the cows used one of the three paddocks and rotated paddock daily to ensure clean paddocks. The cows were allowed access to the paddock during the night only.

3.1.2 Feeding

Silage

All cows were fed silage *ad libitum* in all studies (Spörndly *et al.* 2017; Karlsson *et al.* 2018; Karlsson *et al.* unpublished). Both years in the study by Spörndly *et al.* (2017) and Karlsson *et al.* (unpublished) used silage preserved in bunker silos and Karlsson *et al.* (2018) used silage preserved in round bales. Silage from four different bunkers were used in Karlsson *et al.* (unpublished) study and from three different bunkers both years in the study by Spörndly *et al.* (2017). Chemical composition of the silages included in all studies are listed in Table 10. Karlsson *et al.* (unpublished) used first cut grass/clover silage for feeding. The silage was from perennial swards sown predominantly with timothy (*Phelum pratense* L.) but with inclusion of perennial ryegrass (*Lolium perenne* L.), tall fescue (*Festuca arundinacea* Schreb.) and red clover (*Trifolium pratense* L.). The second study by Karlsson *et al.* (2018) used a mixture of two-thirds first cut and one-third second cut grass silage. This silage was also cut from perennial swards dominated by timothy but with the inclusion of perennial ryegrass, tall fescue hybrid (*Festulolium pabulare*) and tall fescue. The silage fed both years in the study by Spörndly *et al.* (2017) mainly contained timothy.

The raw data from Karlsson *et al.* (unpublished) showed unusual high silage intake for some cows and days. Silage intake from those occasions, were intake rate were >8.28 g/s, was replaced by intake estimates derived from daily average intake rate <8.28 g/s (95 % of population had an eating rate <8.25 g/s).

Table 10. *Chemical composition (means) of silage used in diets fed to dairy cows in Karlsson et al. unpublished; Karlsson et al. 2018 and Spörndly et al. 2017. Displayed as g/kg DM unless otherwise stated*

Study	Karlsson *et al.* *unpublished*	Karlsson *et al.* *2018*	Spörndly *et al.* 2017, year 1	Spörndly *et al.* 2017, year 2
DM, g/kg	396	437	320	359
ME MJ/kg of DM	11.5	11.3	11.4	11.2
CP	170	132	148	126
EE[1]	-	23	-	-
NDF	415	460	459	464
Ash	86	90	86	82
Am-N[2]	1	1	0,55	0.44
VFA	-	44	-	-

1 Ether extract

2 Ammonia Nitrogen

Concentrate

In the study by Spörndly *et al.* (2017) one treatment group was fed forage and a cereal mixture consisting mainly of barley, wheat and oats (Table 11). The second treatment group was fed a cereal mix, only complemented with a protein concentrate consisting of soy and rapeseed expeller, rape seed and oats (Table 11). Chemical composition of the different feeds is shown in Table 12. Appropriate concentrate rations were given according to milk yield for each individual cow in accordance to advisory consultation and by KRAV regulations (Spörndly *et al.* 2017).

Karlsson *et al.* (2018) tested four different concentrates, one control and three other concentrate mixes. The control concentrate consisted mainly of cereals and soybean meal, concentrate 1 consisted mainly of sugar beet pulp and distillers grain, concentrate 2 consisted mainly of sugar beet pulp and rapeseed meal and concentrate

3 consisted mainly of sugar beet pulp, rapeseed meal and distillers grain (Table 11). The daily ration was limited to 7.8 kg DM per day and cow not including the 1.7 kg of DM/d that was offered in the VMS concentrate dispensers. In total each cow was offered 9.6 kg of DM/d of concentrate.

The continuous trial by Karlsson *et al.* (unpublished) also had four treatment groups with different concentrates. The different treatments contained low concentrate ration with added synthetic amino acids (AA), low concentrate ration without synthetic AA, high concentrate ration with added synthetic AA and high concentrate ration without added synthetic AA. Ingredients can be found in Table 11 and chemical composition in Table 12. The low concentrate ration consisted of 20 % concentrate on a DM basis and the high concentrate ration consisted of 40 % concentrate on a DM basis over the whole lactation. All concentrates consisted of by-products and were pelleted.

Table 11. *Ingredients of concentrates in all studies included in the datasets. Displayed as g/kg DM if not otherwise stated*

Study	Karlsson *et al.* (unpublished)		Karlsson *et al.* (2018)				Spörndly *et al.* (2017)	
Concentrates	Conc w AA	Conc w/o AA	Control	Conc 1	Conc 2	Conc 3	Cereal	Prot
Barley	-	-	230	-	-	-	360	-
Wheat/Wheat flour[1]	100[1]	100[1]	230	-	-	-	340	30
Oats	-	-	230	-	-	-	250	150
Soybean meal/chrushed[2]	-	-	202	-	-	-	-	40[2]
Rapeseed meal/chrushed[2]	70[3]	70[3]	-	-	302[3]	168[3]	-	120[2]
Sugar beet pulp[4]	566	566	-	506	530	501	-	-
Distillers grain[5]	70	70	-	360	-	150	-	-
Wheat bran	120	120	-	36.8	72.4	80	-	-
Rapeseed expeller	-	-	-	-	-	-	-	160
Soya expeller	-	-	-	-	-	-	-	470
Limestone, ground	7.4	7.4	30.3	3	-	-	-	-
Feed fat[6]	25	25.8	21	36.8	42.2	39.8	-	-
Feed fat[7]	-	-	-	2.2	-	-	-	-
Molasses	22.1	28.3	20	20	20	20	20	10
Salt	10.7	10.6	10	-	-	-	-	-
Palm kernel expeller	-	-	9.7	30	-	40	-	-
Green meal pellet	-	-	8.1	-	20	-	-	-
Magnesium oxide	-	-	3.6	2.1	0.9	-	-	-
Mineral and vitamin mix	2	2	5.8	3.9	2	2	30	20
Rumen protected methionine[8]	1.9	-						
Rumen protected lysine[9]	4.99	-	-	-	-	-	-	-

1 Wheat flour was not of food quality
2 Crushed rape seeds and soybeans were used in Spörndly *et al.* (2017) due to use of organic feedstuffs
3 Solvent-extracted and heat-moisture treated rape seed meal. Low levels of erucic acid and glucosinolates (ExPro, AAK Sweden AB, Karlshamn, Sweden)
4 Dried and unmolassed (Nordic Sugar AB, Eslöv, Sewden)
5 Fiber and yeast cells from ethanol manufacturing (Agrow Drank 90, Lantmännen Agroetanol, Norrköping, Sweden
6 Fatty acids (99 % fat; 45 % C16:0, 37 % C18:1 according to manufacturer; Ako Feed Cattle, AAK Sweden AB, Karlshamn Sweden)
7 Fatty acids (99 % fat; 40-55 % C16:0, 40-55 % C18:0, mac 8 % C18:1).
8 MetaSmart Dry (Adisseo, Antony, France)
9 LysiPearl (Kemin, Herentals, Belgium)

Table 12. *Chemical composition (means) for concentrates used in all studies included in the datasets. Displayed as g/kg DM if not otherwise stated*

Study	Karlsson *et al.* (unpublished)		Karlsson *et al.* (2018)				Spörndly *et al.* (2017) year 1		Spörndly *et al.* (2017) year 2	
Concentrates	Conc w AA	Conc w/o AA	Control	Conc 1	Conc 2	Conc 3	Cereal	Prot	Cereal	Prot
DM g/kg	880	879	882	872	877	877	896	920	867	898
ME MJ/kg[1]	12.5	12.5	13.3	13.3	13.2	13.2	12.7	16.1	13.3	15.9
CP	151	148	187	192	187	187	125	333	121	332
EE[2]/CF	59	57	54[2]	79[2]	71[2]	71[2]	25	119	34	124
NDF	39	39	144	320	339	338	159	168	183	149
Ash	65	65	75	61	58	56	-[3]	-	-	-
Starch	49	49	415	40	38	34	530	106	514	115
Calcium	9.7	9.7	12.7	5.7	6.7	5.9	-	-	-	-
Potassium	8.1	8.3	8.8	8.9	8.8	8.9	-	-	-	-
Magnesium	3.7	3.7	4	4.3	3.7	3.7	-	-	-	-
Phosphorus	4.3	4.3	4.3	4.7	5	5	-	-	-	-
Sodium	5.7	5.7	3.8	1.9	0.8	1.5	-	-	-	-

1 of DM
2 Ether extract
3 Numbers not available or published

3.1.3 Sampling

Relevant samplings

Milk samples were taken each month (Spörndly *et al.* 2017), once every trial period (Karlsson *et al.* 2018) or every other week (Karlsson *et al.*, unpublished). The milk samples in the study by Spörndly *et al.* (2017) was performed routinely each month according to the Swedish Official Milk Recording Scheme (SOMRS) schedule and sent for analysis for fat, protein, somatic cell count (SCC) and urea content. Milk samples from one morning and evening milking each month was taken as well separately from the SOMRS schedule and analysed separately as well. In the trial by Karlsson *et al.* (2018) milk samples were taken from all milkings during a 24-hour period in the middle of each sampling week for each test period. The milk samples were analysed, within three days of sampling, for fat, protein and lactose content. In the study by Karlsson *et al.* (unpublished) milk samples for milk composition (fat, protein, lactose and SCC) were taken every second week from two consecutive milkings. The milk samples for composition were then used for energy corrected milk (ECM) calculations in all studies and were analysed by infrared Fourier transform spectroscopy (CombiScope FTIR 300 HP, Delta Intruments B.V., Drachten, the Netherlands) in the study by Karlsson et al. (unpublished). All studies except for Spörndly *et al.* (2017) analysed all milk samples at the laboratory at the Department of Animal Nutrition and Managment for fat, protein and lactose content.

Silage samples were collected five times a week in all included studies (Spörndly *et al.* 2017; Karlsson *et al.* 2018; Karlsson *et al.* unpublished) and concentrate samples were collected either each delivery (Spörndly *et al.* 2017) or once a week (Karlsson *et al.* 2018; Karlsson *et al.* unpublished). All concentrate samples were pooled together, for each test period (Karlsson *et al.* 2018) or into four week periods (Karlsson *et al.* unpublished), and analysed for chemical components. Spörndly *et al.* (2017) analysed samples for each batch. The equipment that recorded silage intake was calibrated weekly and the equipment that recorded concentrate intake was calibrated monthly (Karlsson *et al.* 2018; Karlsson *et al.* unpublished).

Body weight was automatically recorded for each cow by scale (AWS100, DeLaval International AB) after leaving the feeding area in the VMS trials (Karlsson *et al.* 2018; Karlsson *et al* unpublished) or after leaving the AMR in the study by Spörndly *et al.* (2017). Body condition score (BCS) was recorded automatically with a 3D-camera (DeLaval International AB) for each individual cow after leaving the VMS in the trials by Karlsson *et al.* (2018) and Karlsson *et al.* (unpublished). In the trial by Spörndly *et al.* (2017) a manual observation of BCS was made during lactation week 2-3 and then once per lactation month.

Tests performed but not of interest for this paper

Except for the aforementioned samplings, some samplings that's of no interest to this paper was performed, such as blood samples, urine samples, progesterone samples, pasture samples, pasture intake and samples of faeces. Samples of pasture intake and pasture content and digestibility were analysed in the study by Spörndly *et al.* (2017) but the time were all cows were on pasture were excluded from this dataset since the estimations of forage intake from pasture wasn't accurate enough to represent variations in daily forage intake. An in-depth description of how these samplings were made will not be included in this paper.

3.2 Data processing and Statistical analyses

All the data from the four trials were collected and processed in Excel (ver. 1908; Microsoft Corporation). Raw data from the automated barn recording system together with the working datasets created by the researchers performing each trial were used to compile an individual dataset with information needed for this investigation, see Table 13 for category, units and explanations. Daily measurements were collected from raw data available from SLUs servers while periodical data measurements where collected from datasets processed by the original researcher. When only periodic data was available, as for example regarding energy content in feed and in some cases of BW and BCS, the latest registration of each post was expanded to represent the entire time period until next registration. Registrations of feed intake, milk yield and eating rate were always available from daily registrations. Estimations of daily ECM yield were calculated based on daily milk yield and routine fat, protein and lactose samples taken monthly (Spörndly *et al.* 2017), biweekly (Karlsson *et al.* unpublished) or during the measurement period of each treatment (Karlsson *et al.* 2018).

Recordings from the time of pasture in summer time have been excluded from Spörndly *et al.* (2017) dataset since feed intake during those time periods were unavailable or estimated during longer time periods which meant that daily feed intake was highly unreliable during that time. To guarantee that as many cows as possible were included in the datasets for the model evaluation only results from lactation week 5-38 is shown from the dataset made from the Karlsson *et al.* (unpublished) trial, and only results from lactation week 5-21 (year 1) and 5-22 (year 2) are shown from the dataset made from the Spörndly *et al.* (2017) trial.

Table 13. *Description of all the variables included in the dataset for this paper*

Category	Unit of measurement	Explanation
Study	-	Name of original study
Treatment	-	Number of the treatment for individual cow
Year	yyyy	The year each study took place
Date	yyyy-mm-dd	Exact date of observation
ID	xxxx	ID of each cow
Breed	SH/SRB	The breed of each cow
Parity	≥1	What parity each cow was in
Calving date	yyyy-mm-dd	The date of calving
Confirmed pregnancy	yyyy-mm-dd	Insemination date for confirmed pregnancy
DIM	-	Day of lactation
Lactation week	-	Week of lactation, day 1-7 = week 1 etc.
Lactation month	-	Month of lactation, week 1-4 = month 1 etc.
End of study	yyyy-mm-dd	The date where each cow exited the study
DM silage	%	DM concentration of silage
DMI silage	kg	Daily DMI of silage
Silage FW[1]	kg	Daily intake of silage in fresh weight
Eating rate	sec	Time spent eating each day, displayed in seconds
Consumption rate	g/s	Mass of eating per time unit, displayed in gram/second
ME[2] silage	MJ/kg DM	Metabolizable energy content in silage
OMD[3] silage	%	Organic matter digestibility of silage
Ammonia N silage	g/kg DM or %	Ammonia N content in silage
NDF silage	g/kg DM	Neutral detergent fibre content of silage
CP[4] silage	g/kg DM	Crude protein content of silage
FW[1] concentrate	kg	Daily intake of concentrate in fresh weight
DMI concentrate	kg	Daily DMI of concentrate
ME[2] concentrate	MJ/kg DM	Metabolizable energy content in concentrate
Total DMI	kg	Daily DMI of both concentrate and silage
Milk yield	kg	Daily milk yield
Number of milkings	-	Daily number of milkings
ECM[5] yield daily	kg	Daily estimations of energy corrected milk yields
ECM[5] yield mean	kg	Energy corrected milk yields based on milk samples
Fat percent	%	Fat content in milk from milk samples
Protein percent	%	Protein content in milk from milk samples
Lactose percent	%	Lactose content in milk from milk samples
BW	kg	Body weight measured daily or periodiclly
BCS	1-5	BCS measured on a scale to 1-5 manually or by 3D camera

1 Fresh weight
2 Metabolizable energy

3 Organic matter digestibility
4 Crude protein
5 Energy corrected milk

Data of daily eating rate from the three datasets were converted into weekly means and analysed by PROC GLM in SAS (ver. 9.4, SAS Institute Inc, Cary, NC). Three different GLM procedures were used to analyse eating rate from the trials with continuous design. The first GLM procedure used ID and week of lactation as a class variable to detect whether week of lactation and cow influenced variation of eating rate, this model only test if week of lactation and ID has a significance in variation and doesn't take the order of lactation weeks into account. The second GLM procedure used week of lactation as a covariate which assumes a linear effect in regard to week of lactation. The third model assumed an individual linear effect which means that the slope of week of lactation differs between individuals. For the trial with change-over design a GLM procedure using silage DM eating rate as a dependant variable the effect of treatment, period and ID was investigated.

When evaluating the results of the DMI model in Excel intake estimations below 10 kg FW/d and above 90 kg FW/d were arbitrarily assumed to be implausible and thus, excluded from the results. Fluctuations in recordings of observed DMI were taken into consideration when evaluating the model which led to excluding predictions of DMI before lactation week five for three of the four data sets (Spörndly *et al.* 2017; Karlsson *et al.* unpublished). Both these limits were set arbitrarily.

The following equation was used to calculate eating rate for all data sets

$$\frac{Silage\ intake\ (g)}{Time\ spent\ eating\ (s)}$$

Time spent eating and silage intake were recorded automatically by the silage throughs, the recording of time spent eating starts when a cows' head enters the through and stops when the cow exit the through. Daily eating rate was calculated by dividing daily silage intake with daily time spent eating.

Calculations of absolute means were made in Excel using the ABS function which returns the absolute value of a number.

3.3 Modelling actual DMI from eating time registrations and historical records of energy requirements

The silage intake prediction model developed for this thesis only focus on energy requirement as an aid for predicting DM intake and not for satisfying nutrient requirements per se. To be suitable for practical use when eating time registrations but no records on total intake are available, it relies on estimating historical eating rates from energy requirements, dietary energy concentration and recorded eating time.

The model for DMI was developed in Matlab (ver. 9.6.0 R2019a) by Bohao Liao at DeLaval International. To aid in the silage intake prediction, estimations of energy requirements for maintenance and milk production were made by creating an energy requirements model based on the NorFor energy requirements calculations, output from this model were then used as an input variable in the silage intake prediction model. The silage prediction model used eating rate to create a constant (K) for individual cows that in turn is used to estimate DMI. This constant is based on historic data on individual eating rate. The DMI prediction model is limited by the energy requirements model since it's dependant on accurate energy requirements estimations to be able to predict DMI accurately.

Table 14. *Indata used for DMI models*

Indata energy requirement model	Indata silage intake prediction model
Cow ID	Energy calculations from the energy requirement model
Date	ME silage
Breed	ME concentrate
Parity	Eating rate
Calving date	DMI
Pregnancy date	
DIM	
Eating rate	
ME MJ/kg silage	
DMI silage	
DMI concentrate	
ME MJ/kg concentrate	
Daily ECM	
BW	
BCS	
Daily milk yield	
Fat%	
Protein%	
Lactose%	
Fresh weight intake silage	
DM silage	

3.3.1 Energy requirements model calculation

The energy requirements model used indata from the four datasets available (Table 14). To calculate the net energy requirement for maintenance the following equation created by Van Es (1978) was used:

$$NE\_\text{maint} = factor\_1 \cdot BW^{0,75} \cdot NE\_\text{excercise} \quad (1.)$$

NE_maint is the daily energy requirement for maintenance in MJ NE/day, factor_1 is a constant for the maintenance requirement per kg metabolic weight and has a value of 0.29256, $BW^{0.75}$ is the metabolic weight of the cow and NE_excercise is the energy requirement for tied up (1 MJ) or loose-housed/grazing animals (1.1 MJ).

Except for maintenance, energy requirement for milk production is needed and to calculate this, daily ECM yield is used from the datasets and then multiplied with the energy needed to produce 1 kg ECM which is 3.14 MJ NE (Van Es 1978) the following equation calculates this value:

$$NE\_\text{milk} = ECM \cdot 3.14 \quad (2.)$$

NE_milk is the daily energy requirement for ECM production in MJ NE/day and ECM is the daily energy corrected milk yield in kg.

The model compensates for gestation as well, which is why insemination day is used from the dataset. In the NorFor model tabulated values from Van Es (1978) is used to describe the energy requirement for gestation which is used in this model as well. The following equation calculates the energy requirement for gestation:

$$\text{NE\_gest} = \frac{BW\_\text{mat}}{600} \cdot e^{0.0144 \cdot gest\_\text{day} - 1.1595} \quad (3.)$$

NE_gest is the daily energy requirement for gestation in NE MJ/day, BW_mat is the assumed mature BW for the breed, which is 640 kg for SH and SRB (Nielsen & Volden 2011) and gest_day is the actual gestation day of the cow.

Primiparous cows are assumed to continue growing during the first lactation which is why an equation to express growth is needed. This model incorporates the same equation as NorFor created by Berg and Matre (2001) which is the following:

$$\text{NE\_gain} = 0.00145 \cdot BW + 12.48 \cdot \frac{ADG}{1000} + 0{,}68 \quad (4.)$$

NE_gain is the daily energy requirement for growth in primiparous cows expressed in NE MJ/day, BW is the weight of the cow and ADG is the average daily gain of the cow expressed as g/day. There is no assumed growth for multiparous cows which means that this equation isn’t used in the dataset by Johanna (unpublished) since no primiparous cows were used in that study.

Mobilization and deposition of fat reserves are important to consider when estimating energy requirement. To account for this NorFors calculations were used (Nielsen & Volden 2011). To calculate the amount of NE deposited when a cow is fed above her daily energy requirement the following equation is used:

$$\text{NE\_dep} = BCS\text{\_change} \cdot BCS\text{\_kg} \cdot 31 \qquad (5.)$$

The following equation is used to calculate mobilization of fat reserves when the feed intake is below her daily energy requirement:

$$\text{NE\_mob} = -1 \cdot (BCS\text{\_change} \cdot BCS\text{\_kg} \cdot 24.8 \qquad (6.)$$

NE_dep is the deposition of energy in NE MJ/day, NE_mob is the mobilization of energy in NE MJ/day. BCS_change is the daily unit change in BCS/day and BCS_kg is the BW per unit BCS depending on breed (60 kg for SH and SRB in accordance to Nielsen & Volden, 2011).

Since this model is based on the same calculations as in NorFor which uses net-energy (NE) instead of ME, as is used in the data available, the model needs to make a conversion. NEL is approximately 60 % of MEL since NE is the total energy intake with energy losses from gas, urine and feces subtracted while ME is the total energy intake but with only energy losses from urine and feces subtracted. The following equation is used by the model to make this conversion:

$$\text{NEL} = 0.6 \cdot \text{MEL} \qquad (7.)$$

NEL is the total energy intake in NE MJ/day and MEL it the total energy intake in ME MJ/day.

3.3.2 Silage intake prediction model

The silage prediction intake model uses NE estimations from the energy requirements model to predict silage DMI. The following calculation is used to estimate DMI for silage:

$$\text{DMI\_sil} = \frac{\left(\frac{NEL}{0.6}\right) - ME\text{\_conc}}{ME\text{\_ens}} \qquad (8.)$$

DMI_sil is the estimated silage DMI in kg DM/day, NEL (described in equation 7) is divided with 0.6 to get the energy requirement in ME MJ/day. ME_conc is the total ME in MJ/kg concentrate per day, ME_sil is the total ME per kg silage.

To improve the DMI estimation eating rate is transformed into a constant (K). When using eating rate as a constant DMI_sil is assumed to be proportional to total eating time of silage using the following equation as an assumption

$$\text{DMI\_sil} = K \cdot eating\_time \qquad (9.)$$

DMI_sil is explained in equation 8, K is the eating rate constant and eating_time is the time spent eating, taken from the datasets.

K may change during the lactation, it does, however, not change rapidly. Assuming this, at a certain point in time, K can be estimated using this equation:

$$\mathrm{K}(\mathrm{t}-1) = \frac{\mathrm{DMI\_sil}(t-1)}{eating\_time(t-1)} \quad (10.)$$

K(t-1) is the eating rate constant for a specific date and t is the date. DMI_sil(t-1) is the silage DMI in kg for the same specific date and eating_time(t-1) is the time spent eating for the same specific date.

Since K is not assumed to change rapidly a filter function in Matlab was used to compute a smoothed value of K(t-1) called K^1(t-1). The filter function calculates a moving average from seven days prior. K^1 is calculated individually and adapts to stage of lactation and feed quality based on energy calculations from the energy requirements model. Using this smoothed value for K(t-1), DMI_sil at date t can be predicted using the following equation:

$$\mathrm{DMI\_sil}(t) = K^1(t-1) \cdot eating\_time(t) \quad (11.)$$

Where DMI_sil(t) is the estimated silage DMI in kg for date t and K^1(t-1) is the smoothed value of K(t-1) calculated from historical data up to date t-1 using equation 10. Eating_time(t) is the time spent eating for date t.

When the datasets been run through the model a moving average of seven days for predicted DM and FW intake is used for analysis. The moving average showcase a mean based on the seven days prior to the observed date, which means that the moving average for the first six days of observation for all cows are non-representative and therefore excluded from comparison.

4 Results

4.1 Evaluation of individual eating rates for dairy cows

4.1.1 Examples of variation between meals in a day and daily variation during a week

Figure 1-4 show examples of variation between meals in a day (Figure 1 and 2) and daily variation during a week (Figure 3 and 4). The days and weeks shown in these Figures were picked to clearly illustrate variation between and within individuals. In Figure 1 and 2 the relationship between time spent eating and FW silage intake for two different days is displayed for the two cows with the fastest and slowest eating rate from the change-over trial (Karlsson *et al.* 2018). Variation in FW silage intake could largely be explained by time spent eating (R^2 = 58-77 %) for these two days but there were variations between days.

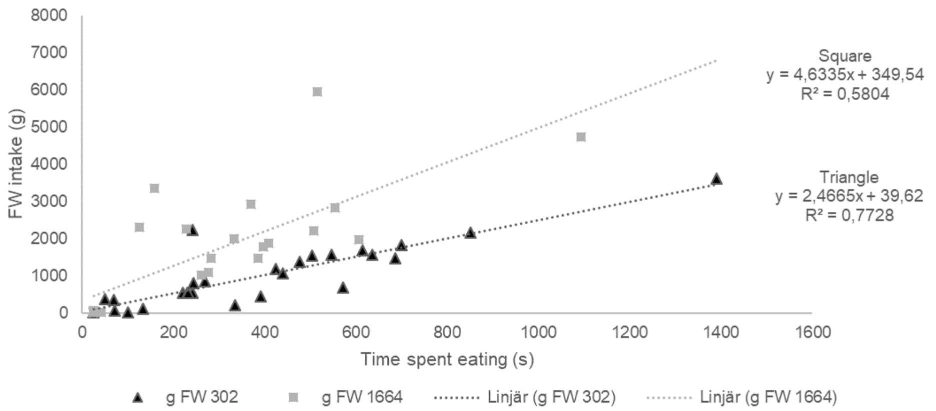

Figure 1. The relationship between time spent eating and fresh weight (FW) silage intake for two cows in one day in January 2016 (16-01-17). Each datapoint represents one meal. Cow 1664 was the cow

with the fastest recorded mean eating rate and Cow 302 was the cow with the slowest recorded mean eating rate during a change-over trial (Karlsson *et al.* 2018).

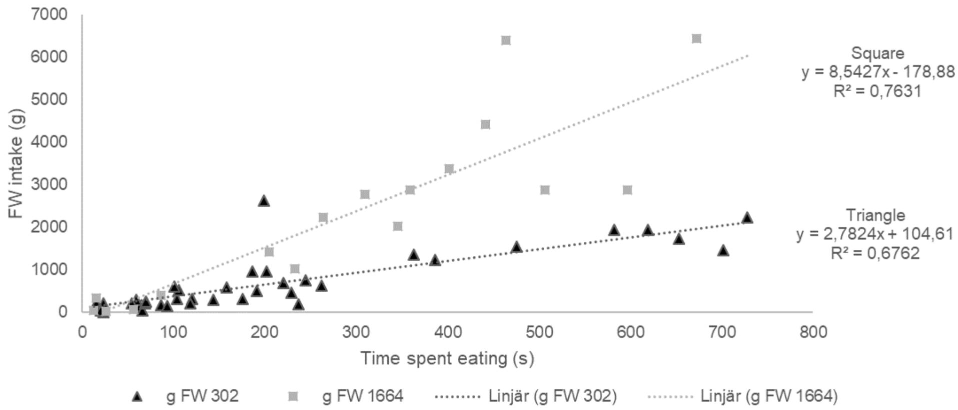

Figure 2. The relationship between time spent eating and fresh weight (FW) silage intake for two cows for one day in January 2016 (16-01-29). Each datapoint represents one meal. Cow 1664 was the cow with fastest recorded mean eating rate and Cow 302 was the cow with the slowest recorded mean eating rate during a change-over trial (Karlsson *et al.* 2018).

Figure 3 and 4 shows relationship between time spent eating and FW silage intake for two different weeks for the same cows as in Figure 1 and 2. As shown in Figure 1-4, the variation in FW silage intake is explained largely by time spent eating. Using daily means, instead of registrations of each meal, increases R^2 as well due to less variation. But just as there are differences between days, there are differences between weeks as well. All four figures (Figure 1-4) shows differences both between and within cows depending on day or week.

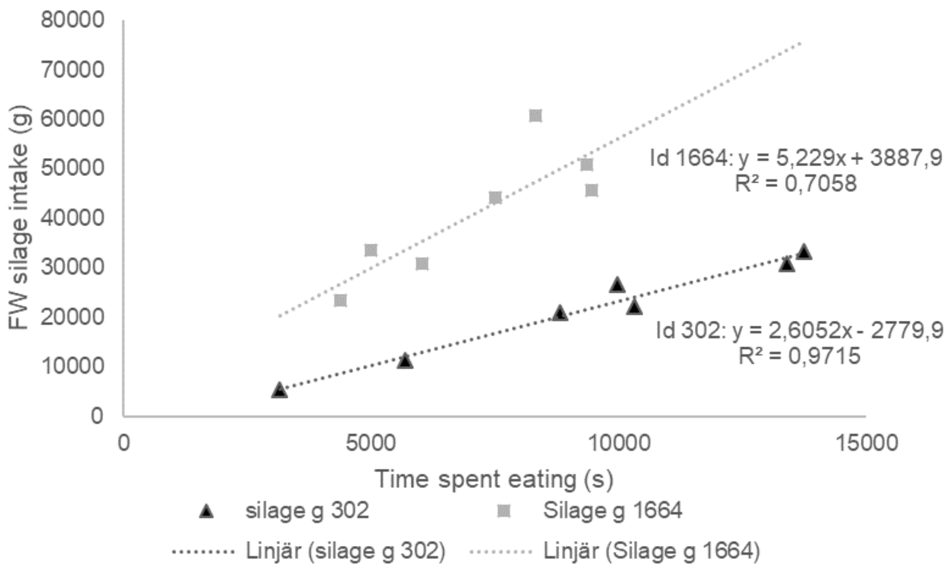

Figure 3. The relationship between time spent eating and fresh weight (FW) silage intake for two cows during one week in December 2015. Each datapoint represents one day. Cow 1664 was the cow with the fastest recorded mean eating rate and Cow 302 was the cow with the slowest recorded mean eating rate during a change-over trial (Karlsson *et al.* 2018)

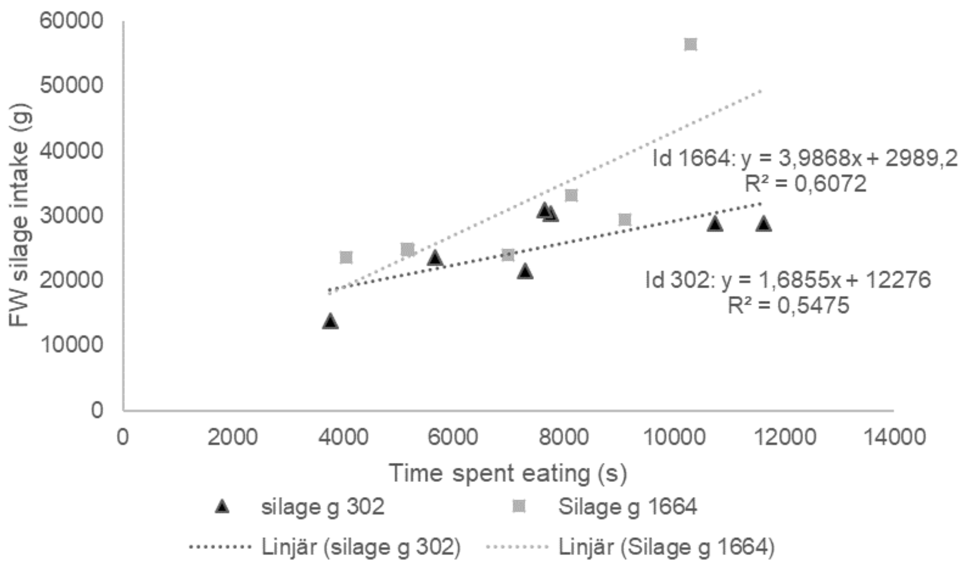

Figure 4. The relationship between time spent eating and silage fresh weight (FW) intake for two cows during one week in November 2015. Each datapoint represents one day. Cow 1664 was the cow with the fastest recorded mean eating rate and Cow 302 was the cow with the slowest recorded mean eating rate during a change-over trial (Karlsson *et al.* 2018).

4.1.2 Variation of eating rate and mean eating rate

In the following tables the data set from Karlsson *et al.* (unpublished) will be called Exp 1, Spörndly *et al.* (2017) year 1 will be called Exp 2, year 2 will be called Exp 3 and Karlsson *et al.* (2018) will be called Exp 4. In Table 15 mean absolute weekly change in eating rate was compared with RMSE of three GLM procedures, model 1 used week of lactation as a class variable, model 2 used week of lactation as a co-variate and model 3 assumed an individual linear effect of week of lactation. The measure of change between two consecutive weeks, mean absolute weekly change, was for all continuous trials lower than RMSE, the measure of variation between randomly chosen weeks, for all three models used.

Table 15. *Mean absolute weekly changes in eating rate (displayed as g FW/s) for all cows in the continuous trials during lactation weeks 5-38 (Exp 1), 5-21 (Exp 2) and 5-22 (Exp 3) compared with RMSE of three models. Units displayed as g/s*

	Exp 1	Exp 2	Exp 3
Mean absolute weekly change	0.352	0.339	0.274
RMSE of model 1[1]	0.615	0.706	0.458
RMSE of model 2[1]	0.616	0.737	0.458
RMSE of model 3[1]	0.555	0.669	0.402

1 RMSE model 1 = GLM model with lactation week as class variable, RMSE model 2 = GLM model with lactation week as a covariate and RMSE model 3 = GLM model with individual slopes for each cow

In Table 16 all continuous trials were run through RMSE model 1. R^2 for Exp 1-3 ranged between 64-71 %. RMSE model 1 used cow and week of lactation as a class variable, cow was significant (<.0001) for all data sets (Exp 1-3) whereas week of lactation was significant for Exp 1 and 2.

Table 16. *Silage FW intake rate for all cows in the continuous trials during lactation weeks 5-38 (Exp 1), 5-21 (Exp 2) and 5-22 (Exp 3). GLM procedure with week of lactation as class variable (RMSE model 1)*

				Effects			
	Intake rate,			F- value		P-value	
Experiment	g FW/s	RMSE	R^2	Cow	WOL[1]	Cow	WOL
Exp 1	4.10	0.62	0.64	68.0	5.2	<.0001	<.0001
Exp 2	4.89	0.71	0.65	40.4	3.7	<.0001	<.0001
Exp 3	3.50	0.46	0.71	64.1	1.2	<.0001	0.21

1 Week of lactation

In Table 17 RMSE model 2 was used on all three continuous trials. R^2 ranged between 59-70 %. RMSE model 2 used week of lactation and cow as a covariate which assumes a steady linear change in eating rate with time. The effect of cow was significant in all three continuous trials and week of lactation had significance levels <.0001 for Exp 1 and 2 and Exp 3 had a P-value of 0.005.

Table 17. *Silage FW intake rate for all cows in the continuous trials during lactation weeks 5-38 (Exp 1), 5-21 (Exp 2) and 5-22 (Exp 3). GLM procedure with lactation week as covariate (RMSE model 2)*

				Effects			
	Intake rate,			F-value		P-value	
Experiment	g FW/s	RMSE	R^2	Cow	WOL	Cow	WOL
Exp 1	4.10	0.62	0.63	67.8	184.6	<.0001	<.0001
Exp 2	4.89	0.74	0.59	37.6	39.2	<.0001	<.0001
Exp 3	3.50	0.46	0.70	65.0	8.0	<.0001	0.005

Table 18 shows RMSE model 3 which assumed individual slope of change over time in eating rate. R^2 ranged between 68-77 %. P-value was significant for all parameters for the continuous trials.

Table 18. *Silage FW intake rate for all cows in the continuous trials during lactation weeks 5-38 (Exp 1), 5-21 (Exp 2) and 5-22 (Exp 3). GLM procedure with individual slopes for each cow (RMSE model 3)*

	Intake			Effects					
	rate, g			F-value			P-value		
Experiment	FW/s	RMSE	R^2	Cow	WOL	WOL*Cow	Cow	WOL	WOL*Cow
Exp 1	4.10	0.56	0.70	25.9	220.3	11.0	<.0001	<.0001	<.0001
Exp 2	4.89	0.67	0.68	17.4	23.2	6.8	<.0001	<.0001	<.0001
Exp 3	3.50	0.40	0.77	14.7	20.0	9.5	<.0001	<.0001	<.0001

The change-over trial was tested in a GLM procedure that tested effect of treatment, period and cow on eating rate. R^2 was 88 % and both period and cow had significance on eating rate. Treatment did not show any significance (Table 19).

Table 19. *Silage FW intake for 24 cows during lactation weeks 9-28. GLM procedure with FW intake rate as a dependable variable*

	Intake			Effects					
	rate,			F-value			P-value		
Experiment	g FW/s	RMSE	R^2	Treatment	Period	Cow	Treatment	Period	Cow
Exp 4	3.61	0.33	0.88	0.7	15.1	18.5	0.542	<.0001	<.0001

4.1.3 Predicting DMI from previously recorded eating rate

Cow was significant for all trials (Exp 1-4) through all RMSE models. Week of lactation was more significant when considering a linear effect over time.

In Figure 5-7 silage DMI for one week was predicted using time spent eating and recorded eating rate from another week. Figure 5-7 shows the relationship between observed and predicted DMI when using eating rate for another week. R^2 ranged between 55-84 % when looking at three different lactation weeks for 37 cows (Exp 1). The prediction worked best when using a lactation week in close proximity to the week of lactation in late lactation (Figure 7), the lowest R^2 was observed when using an early lactation week to predict intake for another early lactation week (Figure 6).

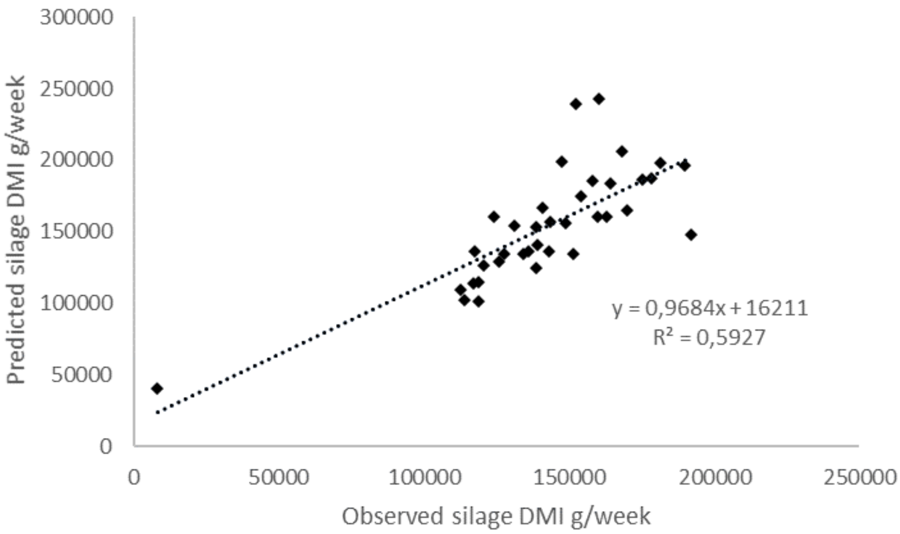

*Figure 5. Observed silage DMI plotted against predicted silage DMI. Predicted silage DMI was calculated by using mean eating rate in lactation week 5 (mean eating rate in lactation week 5*mean time spent eating in lactation week 38) to predict silage intake for lactation week 38 for all cows in the data set from Karlsson et al. (unpublished).*

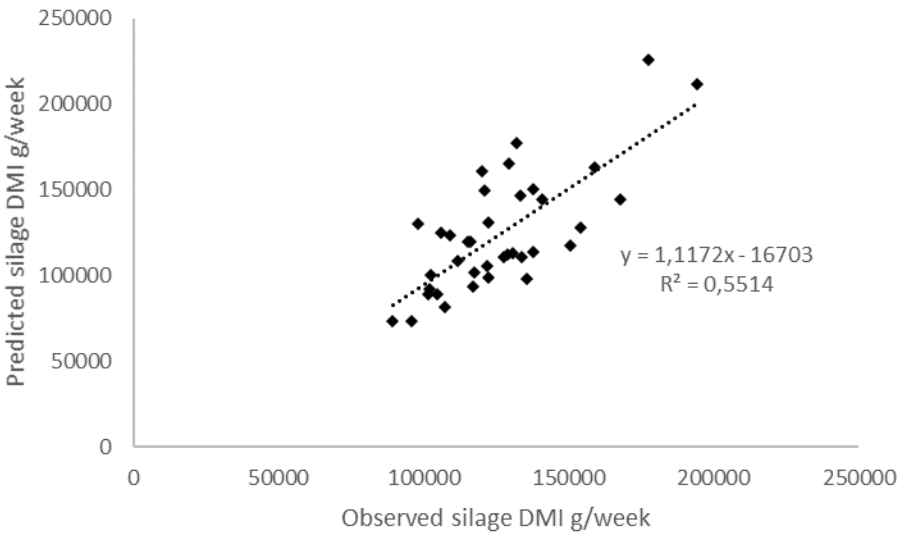

*Figure 6. Observed silage DMI plotted against predicted silage DMI. Predicted silage DMI was calculated by using mean eating rate in lactation week 7 (mean eating rate in lactation week 7*mean time spent eating from lactation week 10) to predict silage intake for lactation week 10 for all cows in the data set from Karlsson et al. (unpublished)*

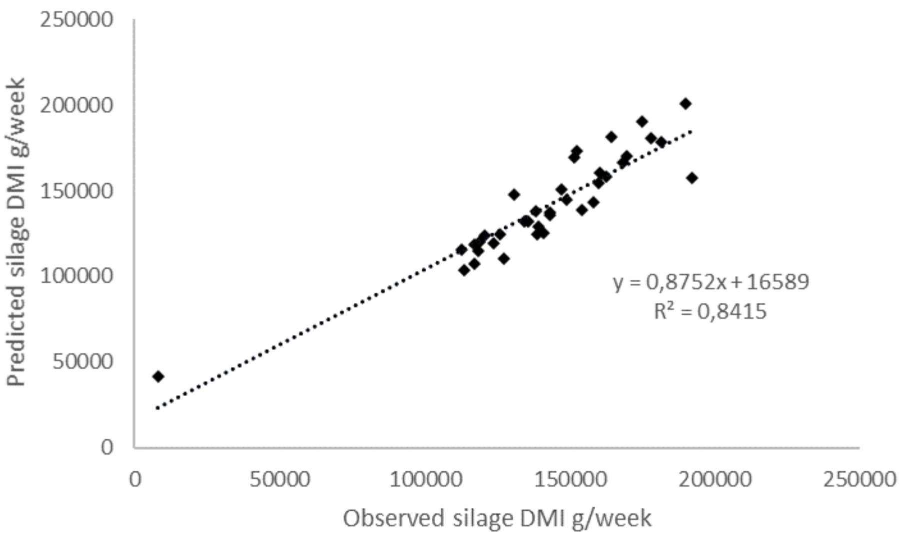

*Figure 7. Observed silage DMI plotted against predicted silage DMI. Predicted silage DMI was calculated by using mean eating rate for lactation week 34 (mean eating rate for lactation week 34*mean time spent eating from lactation week 38) to predict silage intake for lactation week 38 for all cows in the data set from Karlsson et al. (unpublished).*

4.2 Model for actual DMI from eating time registrations and historical records of energy requirements

Model evaluation is shown in table 20 and 21. As seen in Table 20 the model systematically over-estimate DMI for all data sets. The prediction error varies between 17-40 % and the RMSPE is between 7.9-16 kg (Table 21). Proportion of MSPE varies a bit between data sets, however, generally line variations seems to explain most of variations.

Table 20. *Observed and predicted silage FW intake for the model using eating rate and historical energy requirement to predict silage intake for four data sets (Spörndly* et al. *2017; Karlsson* et al. *2018; Karlsson et al. unpublished).*

Experiment	N	Intake kg DM/day		Regression	
		Observed	Predicted	Intercept	Slope
Exp 1	37	46.0	47.3	8.19	0.85
Exp 2	23	48.4	54.0	16.85	0.77
Exp 3	28	39.5	41.0	18.08	0.58
Exp 4	24	30.1	36.1	22.05	0.47

Table 21. *Accuracy and precision of the model using eating rate to predict silage intake for four data sets (Spörndly* et al. *2017; Karlsson* et al. *2018; Karlsson et al. unpublished).*

					Proportion of MSPE		
Experiment	N	R^2	Prediction error	RMSPE	General	Line	Random
Exp 1	37	0.54	17 %	7.9	0.026	0.277	0.697
Exp 2	23	0.21	33 %	16.0	0.121	0.571	0.309
Exp 3	28	0.08	40 %	15.9	0.009	0.775	0.216
Exp 4	24	0.11	40 %	12.2	0.244	0.427	0.329

R^2 for Exp 1 was the highest with 54 % and lowest for Exp 3 with 8 %. Lowest RMSPE was 7.9 kg and highest at 16 kg depending on data set.

Figure 8-10 shows how the model works on a few cows separately. The highest R^2 for the showcased cows reaching 88 %.

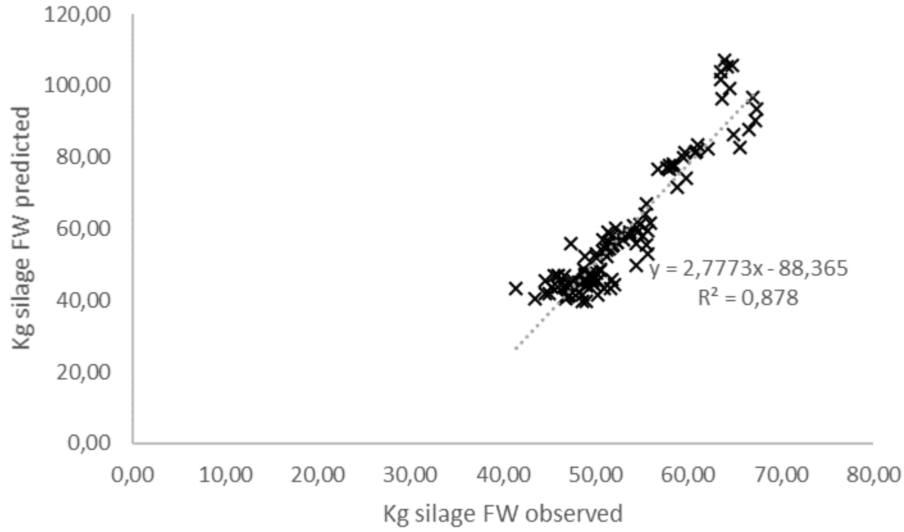

Figure 8. Relationship between observed and model predicted fresh weight (FW) silage intake for cow 1453 during lactation weeks 5-21 during a continuous trial (Spörndly *et al.* 2017). *A moving average over the previous seven days was used as predicted daily silage intake.*

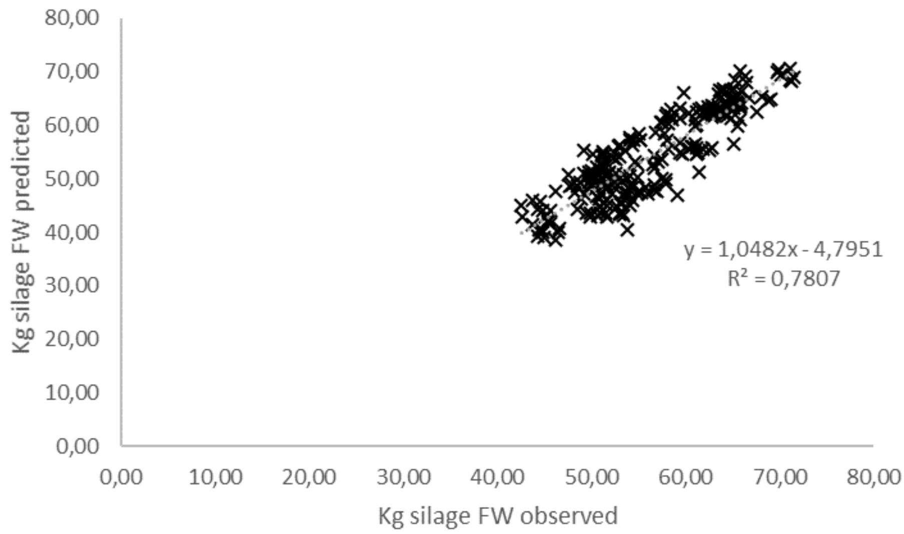

Figure 9. Relationship between observed and model predicted fresh weight (FW) silage intake for cow 404 during lactation weeks 5-38 during a continuous trial (Karlsson et al. Unpublished). A moving average over the previous seven days was used as predicted daily silage intake.

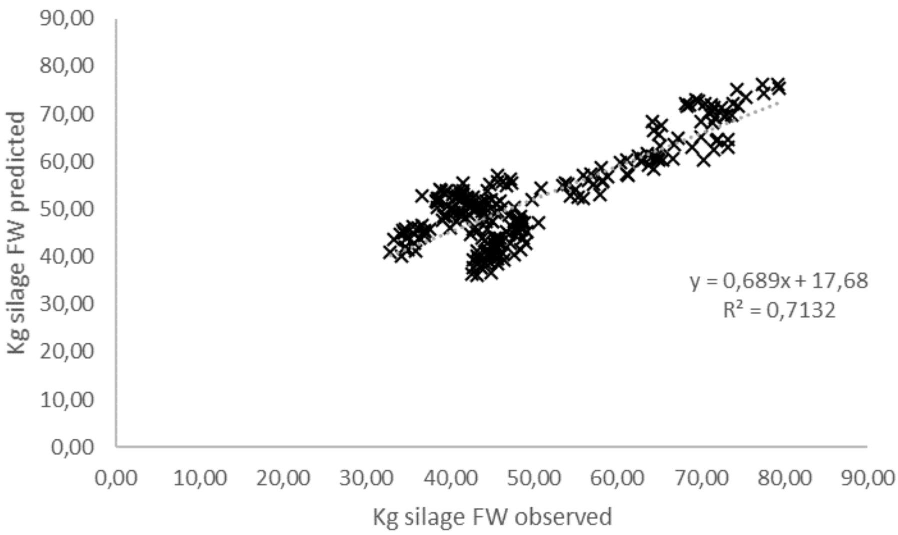

Figure 10. Relationship between observed and model predicted fresh weight (FW) silage intake for cow 391 during lactation weeks 5-38 during a continuous trial (Karlsson et al. Unpublished). A moving average over the previous seven days was used as predicted daily silage intake.

Big variations in BW were observed in the data sets (Table 22) and BW could vary greatly from day to day, especially in Exp 3. A slight improvement of R^2 could be observed by applying a filter in Excel that only included body weights in a 150 kg spectrum (mean BW was included in that spectrum). The improvement was 0.02-0.04 for Exp 1, 3 and for and 0.11 for Exp 2 (Figure 11-13).

Table 22. *Mean, minimum and maximum BW expressed in kg in the data sets used*

Data set	Mean BW	Min BW	Max BW
Karlsson *et al.* (unpublished), Exp 1	734	550	944
Karlsson *et al.* 2018), Exp 4	651	514	783
Spörndly *et al.* (2017) year 1, Exp 2	674	491	838
Spörndly *et al.* (2017) year 2, Exp 3	610	256	920

The R^2 for Exp 1 improved from 0.54 to 0.56, R^2 for Exp 2 improved from 0.21 to 0.32, R^2 for Exp 3 improved from 0.08 to 0.12 and R^2 for Exp 4 improved from 0.11 to 0.14 when excluding cows with a BW far off the mean BW (Figure 11-13).

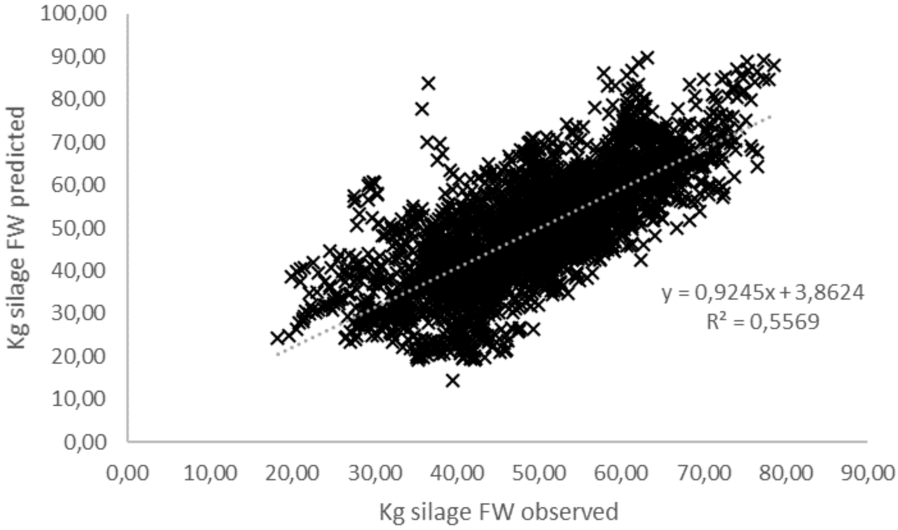

Figure 11. Relationship between observed and model predicted fresh weight (FW) silage intake for all cows in lactation weeks 5-38 in a continuous trial (Karlsson *et al.* unpublished). *A moving average over the previous seven days was used as predicted daily silage intake. A filter function excludes cows with BW far exceeding or falling short of mean BW*

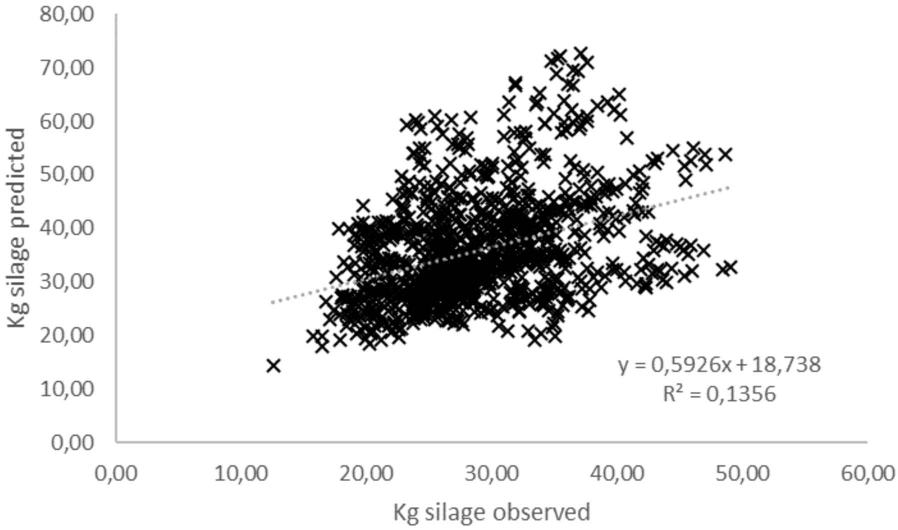

Figure 12. Relationship between observed and model predicted fresh weight (FW) silage intake for all cows in a change-over trial (Karlsson *et al.* 2018). *A moving average over the previous seven days was used as predicted daily silage intake. A filter function excludes cows with BW far exceeding or falling short of mean BW*

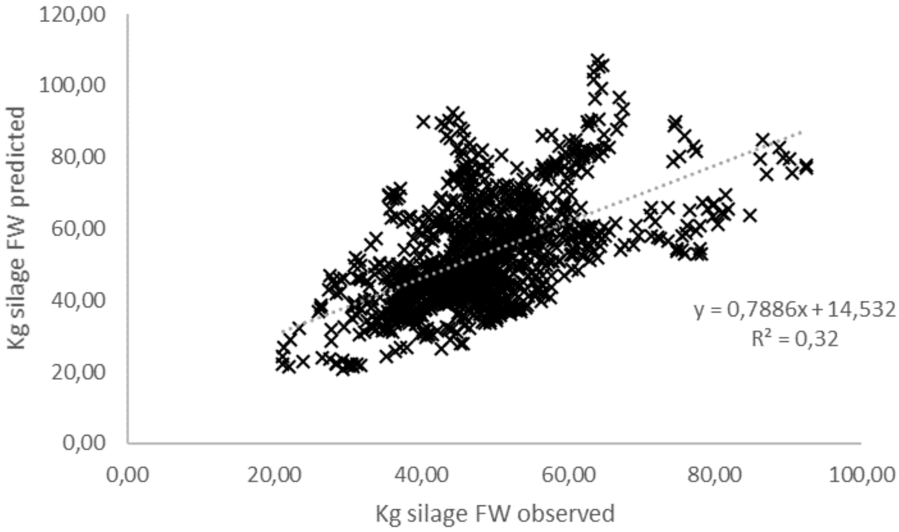

Figure 13. Relationship between observed and model predicted fresh weight (FW) silage intake for all cows in lactation weeks 5-21 in a continuous trial (Spörndly *et al.* 2017). *A moving average over the previous seven days was used as predicted daily silage intake. A filter function excludes cows with BW far exceeding or falling short of mean BW. Two cows with abnormally BW recordings were excluded*

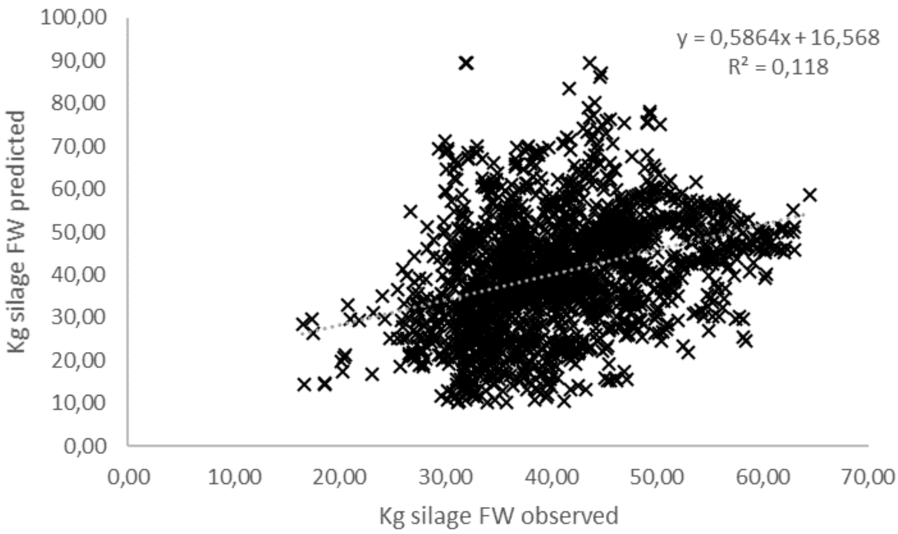

Figure 14. Relationship between observed and model predicted fresh weight (FW) silage intake for all cows in lactation weeks 5-22 in a continuous trial (Spörndly *et al.* 2017). *A moving average over the previous seven days was used as predicted daily silage intake. A filter function excludes cows with BW far exceeding or falling short of mean BW. Three cows with abnormally BW recordings were excluded*

5 Discussion

5.1 Eating rate

The mean eating rates for the data sets used in this study were similar to several studies found in literature (Table 23).

Table 23. *Mean eating rate of silage/TMR displayed as g DM per second*

Reference	Eating rate total	Eating rate primiparous	Eating rate multiparous
Karlsson *et al.* (unpublished)	1.68	-[1]	1.68
Spörndly *et al.* (2017) year 1	1.57	-	-
Spörndly *et al.* (2017) year 2	1.26	-	-
Karlsson *et al.* (2018)	1.56	-	-
Aikman *et al.* (2008)	1.05[2]	-	-
Azizi *et al.* (2009)	-	1.13[2]	1.7[2]
Henriksen *et al.* (2019)	1.85[2]	-	-
Johnston & DeVries (2018)	2.17[2]	-	-

1 No data available
2 Converted from g DM/min to g DM/s by dividing by 60

Table 24 shows mean eating rate for cows before and after calving from several studies in literature. All studies saw an increased eating rate postpartum for both primi- and multiparous cows. Neave *et al.* (2017) found that when correcting for BW and milk production no significant difference between parity in feeding rate could be found.

Table 24. *Mean eating rates of TMR before and after calving*

	Primiparous		Multiparous	
Reference	Before calving	After calving	Before calving	After calving
Aikman *et al.* (2008)	-[1]	-	0.84[2]	1.05[2]
Neave *et al.* (2017)	1.3[3]	1.8[3]	1.27[3]	1.74[3]
Proudfoot *et al.* (2009)	1.2[4]	1.56[4]	1.97[4]	2.33[4]

1 No data available

2 Mean eating rate from week 5 and 2 prepartum and lactation week 2, 6, 10 and 14 after calving

3 Mean eating rate from week 2 and 1 prepartum and lactation week 1, 2 and 3 after calving

4 Mean eating rate from 1 week prepartum and lactation week 1 and 2

As seen in mean eating rates from different studies there are a bit of variation even though the variation isn't that large. This variation might be because of parity since data suggests that first parity cows have a lower eating rate than cows in later parities. As investigated by Nielsen (1999) preferred eating rate may change over time and age which may be an explanation to why eating rate seem to change. The dataset from the continuous trial by Karlsson *et al.*(unpublished) only included cows in later parities and had the highest recorded mean eating rates of the four datasets used in this study.

Palatability and choice of feed might affect eating rate as well as explained by (Van Soest 1994). DM and NDF-content of feed might as well be a factor affecting eating rate. However, it is difficult to see a correlation between DM content of silage and eating rate in this study. In all but one dataset used in this project, silage was stored in bunker silos, Karlsson *et al.* (2018) used silage stored in bales which can be seen in DM content of silage. The other three datasets has a mean DM of 358 g/kg while the silage fed in Karlsson *et al.* (2018) has a mean DM of 437 g/kg. Even though mean DM content for silages for the change-over trial by Karlsson *et al.* (2018) is different than mean DM content in silages for the continuous trial by Spörndly *et al.* (2017) there is not a big difference between mean eating rates between the studies. This might be because of other factors such as parities and feeding strategy (Spörndly *et al.* (2017) fed the cows according to KRAV redulations) which makes the potential affect on eating rate due to DM-content difficult to spot.

5.2 Data set problems

Three different experiments conducted at the Swedish Livestock Research Centre, Uppsala, Sweden were used to create four data sets for this study to investigate eating rate as an animal factor in feed intake predictions, and to create a feed intake prediction model. These data sets presented much information and details usable to thoroughly investigate these questions. However, some problems arose while compiling the data. The dataset from the study by Karlsson *et al.* (Unpublished) was, in retrospect, the data set most appropriate to use in this study which is also shown in the results.

The data set (also referred to as Exp 1) presented the longest running continuous data sampling since no time period needed to be excluded, as in the case of Exp 2 and Exp 3 (Spörndly *et al.* 2017) where pasture constituted a large part of the intake during grazing season. At first, intake predictions for the grazing period in Exp 2 and Exp 3 were to be made, even though roughage intake for these periods were predictions to begin with. It was soon concluded however that this would give unreliable prediction results, which lead to the exclusion of grazing periods in the data sets were the cows only roughage consumption was from grazing. Eating rate from these grazing periods was impossible to use as well since no day to day recordings of observed intake or time spent eating was available. This is very important to take into account when continuing investigations of both eating rate and the developed model. The data sets most appropriate for this will probably be long running experiments with trustworthy roughage intake recordings. It would be very interesting to study eating rate of cows for a couple of consecutive years, this might give a better understanding of how eating rate change for individual cows through the years.

Another factor that seemed to affect the results of the intake prediction model was large variations in BW recordings. Volden *et al.* (2011a) mentions BW as one of five important animal characteristics to consider when creating a feed prediction model. Body weight is an animal factor commonly used in feed predictions and energy requirement estimations, all models of voluntary feed intake (more than 20) included in the review article by Ingvartsen (1994) included BW. Maximum, minimum and mean BW in Table 22, clearly shows big variations in BW recordings, and the largest variation can be found for Exp 3 (Spörndly *et al.* 2017, year 2) with a difference of 664 kg between minimum and maximum recorded BW. Exp 3 is also the data set with the lowest R^2 value in the model evaluation (Table 21). R^2 of all the data sets were slightly improved when filtering out body weights far above and below mean recorded BW (Figure 11-14). In two data sets (Exp 2 and 3) a few cows with abnormal BW recordings were excluded as well. The abnormalities that lead to exclusion included body weight recordings of 0-1 kg BW. The results from Figure 11-14 indicates that the BW recordings affected the quality of prediction.

The choice of using day to day data might have been a reason to why the feed prediction model didn’t work better than it did. By using weekly or even monthly means, irregularities in recordings might’ve been evened out. With, for example, BW, daily recordings caused the energy requirement model to estimate energy requirement incorrectly if the BW was incorrectly registered, which must be the case those times a BW of 1 kg was recorded. In some cases, recorded BW jumped a lot between recordings. It wasn’t unusual to have jumps of 20-60 kg BW from one day to another. The energy requirement model for this project took into account mobilisation and deposition of fat which in turn affected predicted energy requirement for that day. Since the feed prediction model is based on the energy requirement estimation a lot of daily jumps will occur in the prediction of DMI. By using moving averages, the effect of this decreased, it might however, have been better to create weekly or monthly means in the data set instead of using rolling averages on the DMI prediction results.

Figure 1-4 shows examples of variation between meals in a day and daily variation during a week in FW silage intake. DM concentration of the silage did not vary much between the compared days and weeks in this data set (January = 43.6 % DM concentration, December = 43.5 % DM concentration and November = 42.8 % DM concentration). These DM concentrations are however, means, and daily registrations of DM concentrations are not available. Since daily registrations are not available it can't be excluded that a variation in DM concentrations affected the results as well.

5.3 Individual feed intake prediction in the future

As of yet, feed intake prediction models are predicting feed intake on herd level and not individual level. The model created for this thesis is therefore treading new territory when trying to use individual data to predict individual feed intake. Optimizing feed intake after individual cows might become more important with more technological solutions. If individual feeding of both roughage and concentrates become norm then individual feed prediction intake might be more important. Measuring individual feed intake with 3D cameras has shown more and more promise (Lassen *et al.* 2018). This kind of technology will leave room for the need of individual feed intake prediction models since precise feed intake recordings might become reality even in commercial dairy production.

6 Conclusions

Variations in eating rate between individual cows could be strengthened in this study. A change in eating rate throughout the lactation could be found, however the change in eating rate was not that great. Historical data of eating rate can be used to predict DMI successfully.

Improvements of the feed intake model needs to be made before the model can be used competitively with other intake models. For example, adding a nutrition prediction model might improve intake prediction by the model created in this thesis. Improvements on the energy requirement model might improve DMI prediction considerably. The first improvement should be to not use a constant to convert NE to ME. Using individual eating rates for DMI predictions works better than using a mean for all cows in a herd.

Data sets with weekly or monthly means might give better results for DMI prediction than daily recordings. Data sets with long and uninterrupted registrations works best for predicting DMI with this feed intake prediction model.

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Popular science summary

Is individual silage intake prediction possible for dairy cows? By using cow specific information and feed contents, it is! Technology today makes it possible to collect necessary cow specific information such as individual milk yields, weight changes, body condition score and much more. The model created for individual feed intake prediction using animal and feed data in this master thesis shows promise of future use. With further development the model might make it possible for the farmer to better adjust the diet and feeding of individual cows.

The purpose of this master thesis was to investigate variation in individual eating rates of dairy cows, which means silage consumed per second, minute or other time unit. Eating rate was then implemented in a silage intake prediction model and evaluated on whether it could be used to predict silage intake for dairy cows successfully. Data from four different studies, in total 112 different dairy cows, were used as basis for this investigation.

The results showed that individual eating rates for dairy cows can be used to predict silage intake, with some limitations, for individual cows and that eating rates for dairy cows are highly individual and changes over time. The feed intake prediction model created for this project can predict silage intake for dairy cows using individual eating rate and this model is a good start for further development of the method. However, it is not ready to be competitively used for feed intake predictions yet.

In conclusion, three main messages to consider for future investigations into this area are; eating rate is a good factor to use for individual feed prediction since it's highly individual. Technology that allows recordings of individual eating rate on commercial dairy farms might soon be available on the market. And lastly, there is no feed intake prediction model today that is used to predict feed intake on an individual level commercially. Creating this kind of model might prove a good business opportunity.