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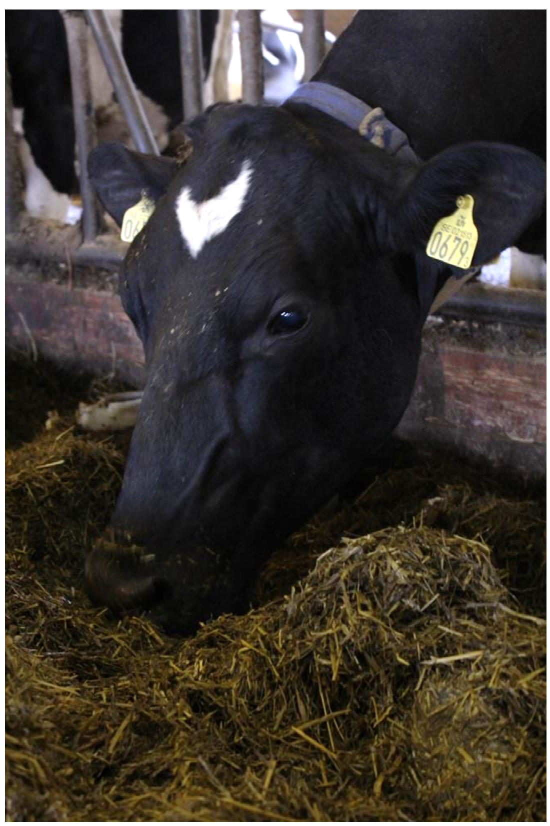

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Abstract

The relatively poor economy in European dairy farming might be improved from efficient feeding systems and dietary management. Increasing herd sizes and transition to loose housing systems in Sweden, increases the possibilities for other feeding systems than separate feeding that is the traditional feeding system in Sweden. Other possible feeding systems are partial mixed ration (PMR) and total mixed ration (TMR), where the TMR system sometimes is associated with overfeeding and thereby increased environmental impact and high feed cost. Diets providing nutrients above or below animal requirements are considered as unbalanced, which in turn are associated with reductions in health, fertility and milk production. On the other hand, a balanced feed ration improves feed efficiency, nitrogen utilization and profitability. Feed efficiency is defined as kg energy corrected milk per kg dry matter intake in the present study, while nitrogen efficiency represents the nitrogen used for salable product in relation to total nitrogen intake. Separate feeding is well-known in Sweden, therefore the present study focused on TMR and PMR feeding systems, aiming for determining the feed efficiency, nitrogen efficiency and milk income over feed cost on commercial farms.

The study was conducted during 24 April to 23 May 2013 and included visits to 20 selected dairy farms in the north of Sweden with PMR and TMR feeding systems. Feed sampling, body condition scoring, feed ration formulation, feed intake, milk production parameters and feed cost were retrieved from the on farm visits. Feed samples were sent for analysis and used for calculations of average diet composition of the herd, forage dry matter and total dry matter intake. Statistical analyses were performed using the software Minitab 17, where Pearson correlation, multiple regression and one-way ANOVA analyses were used for evaluation. Milk income was calculated from the official milk price first of May 2013 with adjustments for fat and protein concentration. Prices were received from farmers or the feed factories; however the price of forage and straw was estimated to 1.4 SEK/kg dry matter and 1 SEK/kg respectively.

The results show a mean value of 1.35 and 1.43 kg energy corrected milk per kg dry matter intake for feed efficiency on farms practicing TMR and PMR feeding respectively, while the average for N efficiency was 28% and 29% for farms feeding TMR and PMR respectively. Milk income over feed cost averaged 45 SEK and 44 SEK for farms feeding TMR and PMR respectively. A positive correlation between feed and nitrogen efficiency was determined, and feed efficiency was positively correlated to profitability and negatively correlated to feed intake. Nitrogen efficiency was negatively correlated to dietary crude protein concentration. Milk income over feed cost was further positively influenced by milk yield. The use of TMR or PMR feeding systems did not affect the feed efficiency, nitrogen efficiency or milk income over feed cost. Improved feed efficiency seems to be associated with good health, productivity, profitability and reduced environmental impact. Further studies involving the relationship between feed and nitrogen efficiency would be interesting in order to identify the important factors for improved nitrogen efficiency at farm level.

Keywords: feed efficiency, nitrogen efficiency, milk income over feed cost, total mixed ration, partial mixed ration, dairy cow

Sammanfattning

En högre effektivitet i utfodringen av mjölkkor skulle kunna bidra till en bättre ekonomi bland Sveriges mjölkföretagare. System med individuell utfodring har traditionellt sett varit den vanligaste formen av utfodring i Sverige, men den ökande besättningsstorleken och övergången till lösdriftssystem, ökar lantbrukarnas möjligheter att välja alternativa utfodringssystem. Exempel på alternativa utfodringssystem är fullfoder och blandfoder, där fullfoder innebär att hela foderstaten utfodras som en fodermix i fri tillgång, medan blandfoder består av en fodermix och en separat fodergiva.

Utfodring med fullfoder är ofta förknippat med överutfodring, vilket medför ökade påfrestningar på miljön och höga foderkostnader. Över- och underutfodring är förknippat med sämre djurhälsa, fertilitet och mjölkproduktion, varför en balanserad foderstat anpassad efter djurets behov av näringsämnen är att föredra. Balanserade foderstater har också visat positiva effekter på fodereffektivitet, kväveutnyttjande och lönsamhet. Bland utfodringssystemen anses fullfoder ofta vara det minst effektiva med avseende på foder- och kväveeffektivitet. I den här studien är fodereffektivitet definierat som kg energikorrigerad mjölk (ECM) per kg konsumerat foder på torrsubstansbasis, medan kväveeffektivitet definieras som det kväve som kroppen utnyttjar och omvandlar till produkter i förhållande till djurets totala kväveintag.

Eftersom individuell utfodring är väl studerat i Sverige, fokuserade den här studien på gårdar som utfodrar med fullfoder och blandfoder i syfte att bestämma fodereffektivitet, kväveeffektivitet och mjölkintäkt minus foderkostnad.

Studien genomfördes mellan den 24 april och 23 maj 2013 i norra Sverige och omfattade totalt 20 gårdsbesök där djuren utfodrades med fullfoder eller blandfoder. På alla gårdar genomfördes hullbedömning och foderprover togs tillsammans med information om foderstatens sammansättning, foderintag och parametrar rörande mjölproduktionen. Foderproverna analyserades av BLGG AgroXpertus och med hjälp av data från lantbrukaren och foderanalyserna beräknades foderstaternas sammansättning, samt vallfodrets torrsubstanshalt och kornas foderintag på torrsubstansbasis. Eftersom foderstaternas energivärden saknades i analysen då hela foderblandningar analyserades, skattades energivärdena med hjälp av tabellvärden och lantbrukarnas egna foderanalyser.

Mjölkintäkten beräknades utifrån Norrmejeriers officiella mjölkpris den första maj 2013 och justerades för mjölkens innehåll av fett och protein. Foderkostnaderna erhölls från lantbrukarna i möjligaste mån, men kompletterades av foderföretaget som levererat fodret där något var oklart. Däremot skattades priset på vallfoder till 1.4 SEK/ kg torrsubstans och priset för halm skattades till 1 SEK/kg halm för alla gårdar.

Resultatet utvärderades genom statistiska beräkningar med hjälp av datorprogrammet Minitab 17, där medelvärden, minimum- och maximumvärden samt standardavvikelser beräknades. Korrelationerna beräknades med hjälp av ”Pearson correlations” och multipla samband beräknades med hjälp av multipel regressionsanalys. Statistisk analys med hjälp av envägs ANOVA genomfördes för att skatta skillnader mellan utfodring av fullfoder och blandfoder.

I genomsnitt hade fullfodergårdarna och blandfodergårdarna en fodereffektivitet på 1.35 respektive 1.43 kg ECM/ kg torrsubstans. Kväveeffektiviteten var i genomsnitt 28 % på fullfodergårdarna och 29 % på blandfodergårdarna, medan mjölkintäkten minus foderkostnaden var 45 SEK på fullfodergårdarna och 44 SEK på blandfodergårdarna.

Resultaten visade också att foder- och kväveeffektivitet var nyckeltal som var positivt korrelerade, där fodereffektiviteten också var positivt korrelerad till mjölkintäkt minus foderkostnad, medan den var negativt korrelerad till foderintag på torrsubstansbasis. Kväveeffektiviteten var negativt korrelerad till foderstatens koncentration av råprotein, medan mjölkintäkt minus foderkostnad var positivt korrelerat till mjölkmängd i kg ECM per ko. Vidare visade resultaten inte på några skillnader mellan fullfoder och blandfoder vad gäller foder- och kväveeffektivitet eller mjölkintäkt minus foderkostnad.

Sammanfattningsvis verkar en förbättrad fodereffektivitet vara associerad med god hälsa, produktivitet och lönsamhet tillsammans med minskade belastningar på miljön. Däremot verkar kväveeffektiviteten i huvudsak ha inflytande på miljön, varför det skulle vara intressant med ytterligare studier som länkar samman foder- och kväveeffektivitet för att lantbrukaren ska få ytterligare kunskap om kväveeffektivitetens betydelse för lönsamheten.

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Abbreviations

BCS	Body condition score
CNS	Central nervous system
CP	Crude protein
DIM	Days in milk
DM	Dry matter
DMI	Dry matter intake
ECM	Energy corrected milk
ME	Metabolizable energy
MUN	Milk urea nitrogen
NDF	Neutral detergent fiber
NIRS	Near-infrared reflectance spectroscopy
PMR	Partial mixed ration
RDP	Rumen degradable protein
RUP	Rumen undegradable protein
SCC	Somatic cell count
TMR	Total mixed ration
VFA	Volatile fatty acids

1 Introduction

Efficient feeding systems and diet management are crucial components to obtain a competitive dairy production. Separate feeding and total mixed ration (TMR) are the two main feeding systems within the dairy industry (NRC, 2001). Separate feeding is characterized by feeding forages *ad libitum* and concentrates separate with individual restricted rations, while all feed components are mixed and fed *ad libitum* in TMR (Martinsson, 1994; NRC, 2001). However, feeding systems combining separate feeding and TMR occurs, commonly referred to as partial mixed ration (PMR) (Spörndly, 2003b) or partial TMR (Bargo *et al.,* 2002).

In general, the farmer's choice of feeding system depends on housing system, required equipment, herd size, labor and cost (NRC, 2001). However, dairy farms in Sweden have traditionally had small herds (Jordbruksverket, 2012) resulting in separate feeding as the traditional feeding system (Martinsson, 1994). According to the Swedish legislation, all new built barns should be built for loose housing of dairy cows (SJVFS 2010:15). Furthermore, the average herd size of dairy farms has increased (Jordbruksverket, 2012) resulting in increased possibilities to choose among different feeding systems.

When choosing feeding system, the farmer has to consider the different principles between the systems and the technology needed to distribute feed. Contrary to TMR, the size of concentrate meals and the allowance and distribution between concentrate and forage has to be considered in separate feeding systems in order to maintain good animal health (Maekawa, Beauchemin & Christensen, 2002). However, in separate feeding where concentrate is individually fed, the risk of overfeeding could be reduced, since Keane *et al.* (2006) showed that cows receiving TMR tends to eat more compared to separate feeding systems. This in turn, increases the risk of overfeeding of cows in TMR compared to separate feeding regimen. Overfed cows' that turns over conditioned are at increased risk of developing lameness and fat cow syndrome; which include metabolic diseases, digestive disorders and reproductive problems (Morrow, 1976; Gearhart *et al.,* 1990). Furthermore, overfeeding is of environmental importance since a larger amount of unutilized nutrients are lost in the manure (Granstedt, 2000). The industrialization of the agricultural sector has resulted in an increased leakage of nutrients, since an overload of nutrients are collected in the manure of animal farms.

Sweden is one of the countries contributing to the eutrophication of the Baltic Sea (HELCOM, 2012) with effects such as growth of phytoplankton, increased toxic algal blooms and sedimentation as well as hypoxia in some areas (Larsson, Elmgren & Wulff, 1985; Bonsdorff *et al.,* 1997; Rönnberg & Bonsdorff, 2004). In 2008, Sweden contributed with 15% N and 12% P to the total load to the Baltic Sea (HELCOM, 2012). However, the main sector contributing to the load of the Baltic Sea is agriculture (HELCOM, 2011).

One solution to reduce the risk of overfeeding in TMR is to group the cows (Coppock, Bath & Harris, 1981) depending on requirements. However, grouping requires often large herds and increases the need of labor for providing different feed mixes and for rearrangement of groups. An alternative to reduce overfeeding and to avoid grouping in TMR could be to use a PMR system, since a part of the diet is fed beside the feed mix in PMR systems (Bargo *et al.,* 2002). The risk of overfeeding in TMR systems might also result in an expensive production, since feed is one of the most important costs in dairy production (Vandehaar, 1998; Britt *et al.,* 2003; Beever & Doyle, 2007).

The relatively poor economy in European dairy farming (Karlsson, 2013) does not promote expensive feeding systems. However, TMR feeding might not be more expensive than separate feeding since Ferris *et al.* (2006) found no difference in feed intake between the two feeding systems. Furthermore, Coppock, Bath & Harris (1981) and Owen (1984) mention potential economic benefits from feeding TMR in comparison to separate feeding system. In order to improve the economy in dairy farming, it is interesting to maximize output over input i.e. efficiency. Since feed is the most important running cost (Vandehaar, 1998; Britt *et al.,* 2003; Beever & Doyle, 2007) and milk is the most important return (Kulak *et al.,* 1997) in dairy farming, measuring of nutrient utilization in terms of feed efficiency and nitrogen efficiency is of interest, as well as estimates of milk income over feed cost.

2 Background

Feed efficiency is not commonly used as a bench mark in dairy farming despite its potential, though it measures productivity through milk output in relation to feed dry matter intake (DMI) (Britt *et al.,* 2003; Beever & Doyle, 2007). Furthermore, reducing cost is unimportant if the cow loses in productivity, elucidating the relevance of improved feed efficiency.

While feed efficiency describes how much of the nutrients in feed that is converted to milk (Britt *et al.,* 2003; Beever & Doyle, 2007), N efficiency describes the N used for saleable product in relation to N input (Biagini & Lazzaroni, 2009). The high cost of N rich feedstuffs and the negative environmental effects of excessive N (HELCOM, 2011) highlight the relevance of N efficiency in order to reduce the N loads to the environment. Furthermore, milk income over feed cost in monetary units is of interest to determine the actual economic status in relation to feed efficiency and N efficiency.

2.1 Feed, health and productivity

The concept of TMR is to supply the cow with all nutrients in every bite, thus avoiding shifts in rumen microorganisms in order to keep high producing cows with good health (Coppock, Bath & Harris, 1981). Farmers whom are practicing TMR feeding in Sweden has to put their cows on PMR rations during several months in summertime, due to the Swedish legislation for pasture (SJVFS 2010:15). However, when feeding PMR the farmer has to consider the risk of unbalancing the diet in order to keep healthy cows (Linn, 1995).

Animals fed according to their nutrient requirements are fed balanced diets, meaning that the animals receive diets without lack or excess of nutrients in relation to its needs (McDonald *et al.*, 2002). Thereby, the animals´ metabolism is in balance with presumptions for optimum health (Bertoni, Trevisi & Lombardelli, 2009) and productivity (Garg *et al.,* 2013).

Regarding the risk of overfeeding with TMR and the risk of unbalancing the mixture with PMR, there is a risk of feeding unbalanced feed rations within these feeding systems. Unbalanced feed rations are shown to affect animal health (Garg *et al.,* 2013) and fertility (Randel, 1990). Metabolic diseases may occur due to imbalances of nutrients within the body (Goff, 2006a; Goff, 2006b; Plaizier *et al.,* 2009), where cows that have suffered from a metabolic disease are more prone to develop metabolic problems in the following lactations (Dohoo & Martin, 1984). However, according to Bigras-Poulin, Meek & Martin (1990), milk fever and ketosis normally do not reappear in the following lactation. Other diseases, for example mastitis, might also occur due to imbalances of nutrients, since unbalanced feed rations negatively affect the immune system (Garg *et al.,* 2013).

Nutrition is also well known to influence fertility (Butler, 2000; Fernandez-Fernandez *et al.,* 2006; Scaramuzzi & Martin, 2008). Overfeeding is shown to increase steroid metabolism (Sangsritavong *et al.,* 2002) and overfeeding of protein is shown to reduce fertility (Butler, 1998). Reduced fertility is also seen among cows with prolonged negative energy balance postpartum (Butler, Everett & Coppock, 1981), as well as in cows with high (Heuer, Schukken & Dobbleaar, 1999) and low body condition scores (BCS) (Markusfeld, Galon & Ezra, 1997; Pryce, Coffey & Simm, 2001) i.e. fat and thin cows. Nutrition can also affect fertility due to changes in plasma hormone concentration (Butler, 1998; Garcia-Bojalil *et al.,* 1998; Webb *et al.,* 2004). Several studies have focused on insulin that could affect fertility (Downing & Scaramuzzi, 1997; Szymanski *et al.,* 2007; Garnsworthy *et al.,* 2008) through its inhibiting effect on the luteinizing hormone (Downing & Scaramuzzi, 1997) that in turn affects ovarian function (Webb *et al.,* 2004). However, several other hormones that are influenced by nutrition seem to play a role in fertility (Webb *et al.,* 2004; Fernandez-Fernandez *et al.,* 2006; Garnsworthy, Sinclair & Webb, 2008).

Regardless of the negative association of unbalanced feed rations with health and fertility, the milk production could be positively affected due to overfeeding (Malossini *et al.,* 1996). However, Waltner, McNamara & Hillers (1993) showed that cows with a BCS higher than 4 on a scale of 1-5, produced less milk compared to cows with BCS of 4 and below. Furthermore, Butler, Everett & Coppock (1981) showed that the energy balance postpartum is negatively correlated to milk yield, and Garg *et al.* (2013) found improved milk yield with balanced feed rations compared to unbalanced rations. Feeding a balanced feed ration also improves feed efficiency and reduces N excretion compared to an unbalanced feed ration (Garg *et al.,* 2013).

2.2 Nutrient efficiency in dairy production

A balanced feed ratio improves feed efficiency and profitability due to lowering of feed cost and higher milk yield compared to unbalanced feed rations (Garg *et al.,* 2013). Improved profitability due to improvement in feed efficiency is also shown by Beever & Doyle (2007). Speicher (1968) mentioned that a high milk production and low feed costs are important for a profitable dairy herd, which is almost what feed efficiency is about i.e. high milk yield and low DMI (Beever & Doyle, 2007). Furthermore, Kulak *et al.* (1997) showed that milk income over feed cost is a simple measure that highly correlates to lifetime profit of dairy cows, and therefore, milk income over feed cost could be used when predicting lifetime profit.

To improve profitability within the dairy herd, one tool might be to improve feed efficiency due to the results of feed efficiency and profitability as suggested by Beever & Doyle (2007). Improvement in feed efficiency is also shown to reduce the environmental impact (Kristensen *et al.,* 2011), which is also true for improved N efficiency due to reduction in N losses (Castillo *et al.,* 2001). Both feed and N efficiency is shown to be affected by the type of farming (Kristensen *et al.,* 2011), where conventional farming seems to be more efficient compared to organic farming. However, another study (Kristensen & Kjaergaard, 2004) resulted in organic farming as a more efficient farming system compared to conventional farming in terms of feed efficiency.

When different feeding systems are compared with focus on feed and N efficiency, TMR seems to be the least efficient feeding system, due to higher dry matter (DM) and crude protein (CP) intakes with similar milk yield (Vibart *et al.,* 2008; Fan *et al.,* 2002), meaning that a high DMI not necessarily results in an increased milk yield even though a positive correlation between DMI and milk yield exist (Britt *et al.,* 2003). However, Kristensen & Kjaergaard (2004) found no difference in feed efficiency caused by feeding system, but highlighted the importance of DMI when considering feed efficiency.

2.2.1 Feed intake

Determining DMI on farm level is of importance for balancing the feed ration to the cows' appetite (Allen, 2000), but is also important for milk production (Britt *et al.,* 2003). Furthermore, recordings of DMI is required in determining feed efficiency (Britt *et al.,* 2003; Beever & Doyle, 2007), and is shown to influence N efficiency (Nadeau, Englund & Gustafsson, 2007). Dry matter intake correlates negatively to feed efficiency (Britt *et al.,* 2003; Kristensen & Kjaergaard, 2004) and positively to methane emissions (Ellis *et al.,* 2007; O´Neill *et al.,* 2012), which mean that DMI could be used to predict the cow´s emission of methane (Ramin & Huhtanen, 2013).

Feed intake is regulated through an additive effect of several mechanisms (Forbes, 2007) that could be divided into physical and metabolic regulation as follows.

Physical regulation of feed intake

The physical regulation of feed intake mainly concerns the fill of the digestive tract with the major emphasis on the rumen fill (Forbes, 2007). The feed intake is thus influenced by the digestibility of the feed and the passage rate through the digestive tract. The feed intake could be reduced due to limited space for the rumen in the abdomen during late pregnancy for example. Furthermore, the motility of the rumen could contribute to regulate feed intake, since the ruminal contraction promotes the outflow of rumen content. Reduction in DM concentration of a TMR could result in a decreased DMI (Miller-Cushon & DeVries, 2009) and is explained by Forbes (2007) to be due to that water is trapped within the plants. In the rumen wall, there are receptors sensitive for distension that contributes to regulate feed intake through signals to the central nervous system (CNS) (Allen, 1996; Allen, 2000).

The concentration and content of neutral detergent fiber (NDF) affects the rumen fill (Allen, 1996; Oba & Allen, 1999) and could be used to predict DMI (Waldo, 1986). With increasing concentration, NDF is in general expected to be followed by a decrease in DMI (Allen, 2000). However, NDF that includes cellulose, hemicellulose and lignin have in general variable digestibility depending on the concentrations of the different compounds within the NDF matrix (McDonald *et al*., 2002). Fiber is required by ruminants in order to stimulate saliva production and rumination (Van Soest, Robertson & Lewis, 1991). Fiber is also important for reduction of the passage rate through rumen, which reduces loss of undigested feed particles and other nutrients.

Even though the major emphasis regarding physical regulation concerns the digestive tract, health disorders (Bareille *et al.,* 2003) and the cows´ surroundings (Scott, Johnson & Hahn, 1983; DeVries & von Keyselingk, 2006) are shown to influence feed intake as well. Health disorders are associated with a decrease in DMI and milk production (Bareille *et al.,* 2003). Furthermore, the flooring in front of the feed bunk (Tucker *et al.,* 2006) and the feeding space (DeVries & von Keyserlingk, 2006) is shown to affect feed intake. A softer flooring material in the form of rubber flooring or sawdust in front of the feed bunk increased the feeding behavior in comparison to concrete flooring (Tucker *et al.,* 2006). A larger feeding space per cow increased the feeding time, where especially a larger area in feeding stalls allowed subordinated cows to increase their presence in front of the feed bunk (DeVries & von Keyserlingk, 2006).

The ambient temperature seems also to be important, since feed intake is affected by temperature (Scott, Johnson & Hahn, 1983). Kamiya *et al.* (2006) showed a decreased DMI when the ambient temperature was 28°C in comparison to 18°C, which is consistent with the results by Scott, Johnson & Hahn (1983) and the review by Hahn (1999). Hahn (1999) further explained that the dairy cow perform at optimum level between 5-15°C, and that temperatures above and under result in reduction in performance. In comparison, the optimum level of performance in dairy cows is between 5-20°C according to NRC (2001). Kurihara (1996) showed that the energy requirement increases with increasing ambient temperature, but as the other authors (Scott, Johnson & Hahn, 1983; Hahn, 1999; Kamiya *et al.,* 2006) the feed intake is shown to be reducing with increasing ambient temperature (Kurihara, 1996). Contrary to increasing ambient temperature, a decrease in temperature results in a decrease of digestibility (Westra & Christopherson, 1976), where cold weather is shown to increase feed intake (Milligan & Christison, 1974).

Metabolic regulation of feed intake

Even though the fill of the digestive tract has been regarded as the major factor influencing DMI, the volatile fatty acids (VFA) and the osmolality within the rumen are known to influence DMI as well, in a probable additive manner (Forbes, 2007). Osmolality in rumen increases when water allowance is reduced, and causes reduction in DMI (Burgos, Langhans & Senn, 2000). The response in DMI due to change in osmolality seems to be limited to changes within the rumen, since changes in osmolality further down the digestive tract has not been shown to reduce DMI (Carter & Grovum, 1990). Furthermore, DMI is affected by the palatability of the feed (Baumont, 1996) and the presence of toxins (Helferich *et al.,* 1986; Yannikouris & Jouany, 2002; Mostrom & Jacobsen, 2011), even though it seems like DMI is not affected by fusarium toxins in feed (Charmley *et al.,* 1993; Osweiler *et al.,* 1993; Ingalls, 1996).

Dietary components, such as fat (Tackett *et al.,* 1996) and starch (De Visser *et al.,* 1998; Abramson *et al.,* 2005; Sveinbjörnsson, Murphy & Udén, 2006), are shown to influence the VFA proportions due to increasing the propionate production. Infusion of propionate has been shown to limit DMI (Sheperd & Combs, 1998; Oba & Allen, 2003a; Stocks & Allen, 2012) even though Oba & Allen (2003b) showed no effect on DMI from propionate infusion. However, Stocks & Allen (2012) showed that infusion of propionate affect DMI due to increased concentration of acetyl coenzyme A in the liver. The results by Stocks & Allen (2012) supports the theory that propionate could be oxidized in the liver through acetyl coenzyme A via the tricarboxylic acid cycle, resulting in increased ATP production, which in turn would reduce DMI (Allen, Bradford & Oba, 2009).

The reduction in DMI due to supplementation of fat and starch might not only be due to the increase in propionate production. Fat supplementation might contribute to a decrease in DMI due to increase in the concentration of the satiety hormones cholecystokinin and pancreatic polypeptide in blood plasma (Choi & Palmquist, 1996). Fat might also reduce digestibility in rumen due to growth inhibition of microorganism (Palmquist & Jenkins, 1980) resulting in a possible reduction in DMI (Conrad, Pratt & Hibbs, 1964). On the other hand, starch supplementation is suggested to decrease DMI since it contributes to a decreased digestibility of NDF (Oba & Allen 2003c; Van Vuuren *et al.,* 2010). Starch also results in an increased supplementation of metabolizable energy, which could contribute to reduction in DMI (Reynolds, 2006).

Contrary to fat (Palmquist & Jenkins, 1980) and starch (Oba & Allen, 2003c) that could decrease the digestibility, CP could possibly increase fiber digestion (Huhtanen, Rinne & Nousiainen, 2009) and increase DMI (Kung & Huber, 1983; Mäntysaari *et al.,* 2004; Huhtanen, Rinne & Nousiainen, 2008). Whether the increase in DMI due to increasing concentration of CP is caused by the increase of fiber digestion or by a more favorable ratio of amino acids and energy in the tissues is unknown (Mäntysaari *et al.,* 2004).

To summarize, the complexity to predict DMI on farm level makes it hard to formulate balanced feed rations without determining the actual DMI on the specific farm where feed ration calculations will be made.

Prediction of feed intake

There are several models that are developed to predict feed intake in dairy cows, but only a few will be presented here. Simple prediction of feed intake is possible through the assumption that cows in early lactation has a DMI of 28g/kg body weight and 32g/kg body weight during the middle of lactation when feed intake peaks (McDonald *et al.,* 2002). However, in order to predict feed intake more precisely, more complicated models are required, since several parameters need to be included. Vadiveloo & Holmes (1979) developed a model to predict feed intake in dairy cows as follows:

Total DMI = 0.076 + 0.404 * concentrate DMI + 0.013 * live weight – 0.129 * week of lactation + 4.12log * week of lactation + 0.14 * milk yield

The parameters total DMI, concentrate DMI and milk yield in the model by Vadiveloo & Holmes (1979) are expressed in kg/day, while live weight is expressed in kg. In Nutrient requirements of dairy cattle (NRC, 2001), the model for intake capacity during lactation is based on Holstein cows and is predicted as follows:

DMI (kg/day) = (0,372 * fat corrected milk (kg/day) + 0.0968 * body weight (kg)$^{0.75}$) * (1 – e $^{(-0.192 * (\text{week of lactation} + 3.67)}$)

In Sweden, Norfor - The Nordic feed evaluation system is used by the dairy advisors (Krizsan *et al.,* 2013) for predicting DMI. The NorFor model is based on studies on cows in Nordic countries, where Swedish dairy cows and feeds are included (Volden, 2011). The NorFor model includes several parameters involving both feed and animal factors that contribute to regulate DMI. Furthermore, the NorFor system takes advantage to interactions in the nutrient digestion and metabolism, why feed values for each feed do not exist. The complex model used for prediction of DMI in NorFor result in a requirement for a computer program. The NorFor model used for DMI prediction could be expressed in a simplified manner as follows:

Intake capacity = Fill value of total feed intake

The simplified NorFor model for prediction of DMI for loose housed dairy cows fed *ad libitum* could be presented in a more complicated way as follows:

((a * days in milk^b *e^c * days in milk – days in milk^{-d} + e * ECM + (body weight – f) * g) + 0.15)(0.0214(100/5 – 13) + 0.8502) = ∑DMI$_i$ * fill value$_i$ + ∑DMI$_j$ * fill value$_j$ * (0.97 + 0.562 * (proportion of starch and sugar/1000 – 0.2119) * 0.1 – 0.1932 * (intake of starch and sugar/1000 – 5.122) * 0.05) + ((1.453 – 2.530/(1+e$^{(0.466 -(0.86 - \text{roughage fill value})/0.065}$) * ((a * days in milk^b *e^c * days in milk – days in milk^{-d} + e * ECM + (body weight – f) * g) + 0.15)(0.0214(100/5 – 13) + 0.8502) / 8

In the complicated NorFor equation (Volden, 2011) the letters a to g are regression coefficients, and the lowered letters i and j are representing each concentrate and each roughage respectively. The proportion and intake of starch and sugars are expressed in g/g DM and g/day respectively, whiles the energy corrected milk (ECM) and DMI is expressed in kg/day and bodyweight in kg. The fill value for roughage is expressed as follows:

Fill value for roughage = (0.86 – organic matter digestibility * 0.005) / (0.94 + 0.56 * e $^{-0.000029(\text{NDF content}/10)\ \hat{}2.9}$)

The fill value of roughage is expressed in kg DM, while organic matter digestibility is expressed in % and NDF content is expressed in g/kg DM.

Milk yield is included in the presented models by Vadiveloo & Holmes (1979), NRC (2001) and Volden (2011). Since DMI and milk yield is positively correlated (Britt *et al.,* 2003), inclusion of milk yield in models predicting DMI would therefore probably result in a fairly good prediction of DMI, but is the capacity of intake well predicted? Furthermore, as reviewed in the present study, feed and animal characteristics contribute in the regulation of feed intake, why the accuracy of the model of NRC (2001) could be questioned as well as the model by Vadiveloo & Holmes (1979) that only includes concentrate. In a study by Zom, André & van Vuuren (2012), five models predicting DMI were compared, where the model by NRC (2001) had an intermediate accuracy, while the model by Vadiveloo & Holmes (1979) was the least accurate (Zom, André & van Vuuren, 2012). However, Keady, Mayne & Kilpatrick (2004) evaluated five models for dairy cows and found that the model by Vadiveloo & Holmes (1979) was most accurate. Furthermore, the NorFor model is shown to over predict DMI at high intakes, but under predicts DMI at low intakes (Krizsan *et al.,* 2013).

2.2.2 Nitrogen efficiency

When considering nutrient efficiency and feed intake, the dietary concentration of CP is shown to affect both feed (Nadeau, Englund & Gustafsson, 2007) and N efficiency (Huhtanen & Hristov, 2009; Rius *et al.,* 2010). Improved N efficiency is received when the CP level is reduced (Castillo *et al.,* 2001; Huhtanen & Hristov, 2009), meaning a reduction in N intake (Iphaguerre & Clark, 2005) and in N losses to the environment (Castillo *et al.,* 2001; Monteils *et al.,* 2002). The cow excretes most of the excess N through the urine (Castillo *et al.,* 2001; Iphaguerre & Clark, 2005; Rius *et al.,* 2010) with no effect (Castillo *et al.,* 2001) or a small positive effect on the milk production in relation to the urinary excretion (Monteils *et al.,* 2002).

Milk urea nitrogen (MUN) could be used to predict the urinary excretion of N (Zhai *et al.,* 2007), since MUN is positively correlated to urinary-, fecal- and total N excretion (Zhai, Liu & Ma, 2005). Milk urea nitrogen is also known to be negatively correlated to N efficiency (Nousiainen, Shingfield & Huhtanen, 2004; Huhtanen *et al.,* 2008) and to be influenced by CP intake through its positive correlation (Nousiainen, Shingfield & Huhtanen, 2004; Zhai *et al.,* 2007; Rius *et al.,* 2010), why MUN could act as an indicator when formulating and evaluating diets (Jonker, Kohn & Erdman, 1998). Even though MUN could be used for prediction of N excretion and influences N efficiency, Huhtanen *et al.* (2008) found that dietary CP could be used to predict the actual N efficiency rather accurate.

The effect on N efficiency of the CP source in terms of rumen degradable protein (RDP) and rumen undegradable protein (RUP) are contradicting (Iphaguerre& Clark, 2005; Wang *et al.,* 2008). Wang *et al.* (2008) mentions the ratio between RDP and RUP in order to achieve improvements in N efficiency, since a reduction of the ratio results in improvement of N efficiency. Hristov *et al.* (2004) showed that RDP fed at level of requirement result in higher N efficiency compared to RDP fed above requirement, while Iphaguerre & Clark (2005) claims that it is the dietary level of CP that causes differences in N efficiency. However, the source of protein might affect feed efficiency, where the highest feed efficiency can be received when RDP and RUP are matched to the carbohydrates in the diet (Iphaguerre & Clark, 2005).

Carbohydrates are an important source for supplying the microbes and the animal with energy (Cheeke & Dierenfeld, 2010). Therefore, the statement of matching carbohydrates to the source of protein (Iphaguerre & Clark, 2005) is consistent with the results by Huhtanen *et al.* (2008) that showed a small effect on N efficiency due to supply of carbohydrates and metabolizable energy. It seems to be an interaction between the energy and protein level of the diet since Rius *et al.* (2010) found that the excretion of N is especially high from diets containing high level of CP and low level of energy. An interaction between dietary energy and protein is also confirmed by Brun-LaFleur *et al.* (2010) who found that protein has to be fed to requirements in order to improve milk production when supplying energy. So reducing CP level in order to improve N efficiency will not be advantageous if CP is reduced to below requirement, since negative effects on milk production and economy will occur (Vandehaar & StPierre, 2006).

2.2.3 Conclusion to improved nutrient efficiency

In order to improve feed and N efficiency, DMI and CP intake respectively, seems to be the most contributing factors on farm level, based on the present literature review. However, other factors like type of breed, health (Kristensen & Kjaergaard, 2004), ambient temperature (Britt *et al.,* 2003; Kamiya *et al.,* 2006), milk yield (Britt *et al.,* 2003; Huhtanen & Hristov, 2009) and forage to concentrate ratio (Gonda, Emanuelson & Murphy, 1996; Britt *et al.,* 2003) are also shown to influence nutrient efficiency. Improvement in especially feed efficiency is concluded to result in a herd with good health, high milk production, good economy and less loads to the environment.

2.2.4 Aim of the study

The aim of the present study was to evaluate the nutrient utilization and profitability among Swedish dairy farms through measuring of feed efficiency, nitrogen efficiency and milk income over feed cost. Since there are increased possibilities to choose among different feeding systems in Swedish dairy farming and since separate feeding systems are well described in Sweden, this study was conducted on commercial farms in Northern Sweden, with TMR and PMR feeding systems.

3 Materials and methods

3.1 Selected farms

Twenty dairy farms were selected due to their feeding systems. The selection was based on information in the database of the official Swedish Dairy Milk Recording system. Ten of the farms were practicing TMR feeding; while nine farms practiced PMR and one farm used both TMR and PMR feeding. The selected farms had loose-housed dairy cows in order to represent contemporary production systems, since all new barns for dairy cattle should be built for loose-housing systems according to the Swedish legislation of animal welfare (SJVFS 2010:15). However, two of the studied farms also had tied up stalls where a few lactating cows where kept for intensive care (these cows were not included in this study).

The selected farms differed in milking systems, where farms that practiced TMR feeding in general had milking parlor, while farms practicing PMR feeding in general had milking robot as milking system. However, there was one exception within each type of feeding system.

3.2 Farm visits

The studied farms were visited once each during the period 24 April 2013 until 23 May 2013. The studied farms were located in the north of Sweden, where the farms were situated in the region from Umeå to Haparanda. Information regarding the production and the feeding on the studied farms were recorded (Appendix I), as well as BCS and faeces consistency. The estimated BCS was based on Holdvurderingsskjema for NRF-kyr (GENO avl og semin), where a proportion of the lactating cows in the herds were scored. The faeces consistency was graded from a general impression of the lactating groups according to the faeces consistency chart for advisors at Växa Sverige.

In order to record dietary characteristics, complete samples of each feed mixture were collected at each farm and refrigerated during transport. The feed samples were kept frozen until departure to the feed lab BLGG AgroXpertus, which is a commercial analytical lab for feeds. Feed samples were collected from the feed table in conjunction with feeding on 12 of the farms, while the other feed samples were collected either from the mixer wagon or from the feed table up to 6h after feeding. When samples were collected from the feed table several hours after feeding, the aim was to collect feed beyond the cows' range in order to avoid samples of refusals. However, it was not possible to get completely unsorted feed samples at all farms.

3.3 Feed Analysis

All feed samples were sent for BLGG AgroXpertus for analysis, because it is the only lab in Sweden that conduct feed analyzes on complete diets and not only on individual feed components (Åkerlind, 2013), all other labs only analyze feed components. Analysis of complete diets has the same reliability as analysis of single feed components (Åkerlind, 2013), if properly mixed. The feed samples were completely analyzed through near-infrared reflectance spectroscopy (NIRS) as described by BLGG AgroXpertus, except for the concentrations of DM and Ash which were analyzed with the reference methods.

When analyzing the complete diets, the estimated energy values of the diets were missing, since each feed has its own digestibility coefficient for predicting the energy value and since the diets include several feeds, making it hard to determine a true energy value (Åkerlind, 2014). Therefore, energy contents were estimated through calculations based on the farmers' feed analysis, proportions of feed components in the diet and tabulated energy values according to Spörndly (2003a).

The feed analysis was used for comparison of the diet characteristics between farms, in order to determine factors influencing feed and N efficiency. Tabulated values (Spörndly, 2003a) and analytical values received from farmers were used as a complement when comparing diet characteristics. In order to compare the diets, the feed analysis was used to calculate the average dietary characteristics among the lactating cows on farm level. The DM content of the mixture was used for calculations of the DMI, the DM of the forage and the proportion of roughage and concentrate in the diet. The DMI was based on the farmers information of feed delivered to and feed removed from the feeding table per day. The farmer weighed the feed in the mixer wagon before delivering the feed to the feeding table, while the amount of feed removed from the feeding table was estimated by the farmer. The estimated intake in kg where then multiplied with the concentration of DM in the feed analysis in order to estimate DMI per day. In this study, the expression roughage includes silage and straw while the definition forage only includes silage.

3.4 Calculations of cost and nutrient efficiency

The total feed cost of the diets was calculated based on the individual price of the individual feed components. The individual feed prices were estimated by the farmer, and complemented with prices from the feed company that had delivered the feeds when information from the farmer was missing. However, the price of forage and roughage was set to a fixed value at all farms. For forages, the price was estimated to 1.4 SEK/kg DM forage and was based on the DM proportion of the mixtures, while the price for straw was estimated to 1 SEK/kg.

The milk incomes were calculated with a basal price of 3.4 SEK/kg milk, which was the earning for a farmer connected to Norrmejerier the first of May 2013. The farmer also received additional payment depending on the milk quality. Included in the calculations for milk income were also the adjustment in payment for fat- and protein content. The basal price of 3.4 SEK/kg milk was received if the milk contained 4.4% fat and 3.5% protein. For each deviation with 0.1% in fat concentration and protein concentration, the farmer earned or lost 0.04 SEK/kg milk for fat and 0.05 SEK/kg milk for protein depending on an increase or a decrease in fat and/or protein concentration. However, additional national subsidy payment for milk delivered in northern Sweden was not included in the calculations. Neither were the adjustments in payment for somatic cell count (SCC), hygienic quality (bacteria and spores), abnormal composition, smell and taste of the milk.

When calculating the feed efficiency (kg ECM/kg DMI) on the different farms, the calculated ECM and DMI were used as parameters. The ECM was calculated according to the following formula (Sjaunja *et al.,* 1990 see Volden, 2011):

ECM = milk yield (0.25+0.122(milk fat content/10) + 0.077(milk protein content/10))

In the previous equation for ECM, the ECM and milk yield is expressed in kg/day, while milk fat content and milk protein content is expressed in g/kg. However, the program for feed management, called NorFor, was used to calculate N efficiency through the concept "one day feed control". The weight of the cows was set to an average live weight of 610kg for older cows and 570kg for first calvers. The number of first calvers and older cows was estimated from the number of cows at milk recording and the actual number of cows at the farm visit.

3.5 Statistical analysis

The software Minitab 17 was used for calculations of the statistical analyses. The on farm recordings were used in the calculations with exception of breed, veterinary service, hygiene and handling of the dry cows (Appendix I), due to inconsistent data. One of the farms practicing TMR was excluded from the study since all the required information never was obtained. The farm that practiced both TMR and PMR feeding was split into two sub herds according to feeding system in the calculations.

Average, minimum, maximum and standard deviations were determined for on farm recordings (table 1a; table 1b). One-way ANOVA analyses were made in order to evaluate if differences occur between TMR and PMR feeding systems (table 2). A one-way ANOVA analysis evaluates if the averages of the compared groups differ. Furthermore, correlations were determined using the Pearson linear correlation (table 3). The Pearson correlation evaluates if two continuous variables co-varies, meaning that the correlation evaluates if changes in one variable are associated with changes in another variable. Multiple regression analyses were further used for developing regression equations and to evaluate if the significant Pearson correlations were supported by significance in the multiple regression analyses. The multiple regression analysis develops models with the least square and determines how well the variables in the developed models fit to the model. All results were considered significant when P-value was ≤ 0.05.

4 Results

4.1 On farm recordings; diets, intake and performance

The results of the on farm recordings and the feed analyses are presented in table 1a for farms practicing TMR feeding, and in table 1b for farms practicing PMR feeding. The dietary composition, intake and performance are similar between farms practicing TMR and PMR feeding according to table 1a and table 1b, which is further supported by table 2. The presented milk yield in table 1a and table 1b is the milk delivered to the dairy plant, why the actual daily milk yield is probably a bit higher than presented. All farms that participated in the study had larger number of eating places per cow than required by the Swedish legislation for animal welfare.

4.1.1 Body condition score

Since the BCS was determined on different proportions of lactating cows between herds, the proportions of scored cows are also presented in table 1a and table 1b for lactating cows fed TMR and PMR respectively. The average BCS of the herds practicing TMR and PMR feeding was between three and 3.5 (table 1a; table 1b), meaning optimum BCS. However, the fattest cows were scored to 4.5 and the thinnest cow was scored to 2.0, meaning that both fat and thin cows existed in the studied herds.

4.1.2 Faeces consistency

Faeces consistency was subjectively scored to between two and three in the lactating groups among the herds, meaning that the faeces consistency was between loose and optimal. Three of the farms practicing TMR feeding, and two of the farms practicing PMR feeding were graded the score three, meaning optimal faeces consistency, while the other farms were graded somewhere in between two and three.

4.1.3 Nutrient efficiency and economy among farms practicing TMR feeding

The on farm recordings among farms practicing TMR feeding resulted in a feed efficiency of 1.35 in average that ranged between 1.21-1.45, while the N efficiency ranged from 25 to 32 % with an average of 28 % (table 1a). The on farm recordings further resulted in a milk income over feed cost of 45 SEK in average and a feed cost per kg ECM of 1.7 SEK in average (table 1a). The range of the milk income over feed cost and feed cost per kg ECM was 33-58 SEK and 1.4-2.1 SEK respectively (table 1a).

Table 1a. *Average, maximum, minimum and standard deviation (SD) values for recorded parameters at farms with TMR feeding*

Variable	Unit	Average	Minimum	Maximum	SD
Diet composition					
DM	g/kg	441	359	620	76.2
ME[1]	MJ/kg DM	11.7	11.1	12.1	0.287
CP	g/kg DM	163	146	180	11.4
NDF	g/kg DM	382	288	469	53.1
Starch & Sugar	g/kg DM	174	133	274	46.5
Calcium	g/kg DM	7.4	5.0	9.5	1.5
Phosphorus	g/kg DM	4.1	2.5	4.9	0.66
Roughage	g/kg DM	544	440	710	72.9
Concentrate	g/kg DM	456	290	560	72.9
Intake and animal performance					
DMI	kg/cow/day	22	18	26	2.3
CP intake	kg/cow/day	3.6	2.7	4.3	0.50
ME intake	MJ/cow/day	261	220	300	28.2
Eating places per cow	numbers	0.77	0.45	1.1	0.21
BCS		3.2	2.0	4.5	0.45
BCS (proportion scored)		0.36	0.20	0.55	0.11
Milk parameters					
Milk yield[2]	kg ECM/cow	30	25	34	2.4
Milk fat	g/kg	43	41	46	1.7
Milk protein	g/kg	35	32	37	1.2
MUN	mmol/L	4.6	3.5	5.1	0.49
Milkings/day	numbers	2.0	2.0	2.2	0.06
DIM[3]	days	214	182	235	19.5
Calving interval	months	12.9	11.7	16.3	1.57

Recruitment		0.41	0.32	0.49	0.064
Feed efficiency		1.35	1.21	1.45	0.0964
N efficiency		0.28	0.25	0.32	0.024
Milk – Feed[4]	SEK	45	33	58	7.4
Feed cost/kg ECM	SEK/kg ECM	1.7	1.4	2.1	0.20

[1] Metabolizable energy [2] kg ECM per cow per day delivered to the dairy plant, [3] Days in milk, [4]Milk income over feed cost per cow.

4.1.4 Nutrient efficiency and economy among farms practicing PMR feeding

The recordings on the farms with PMR feeding resulted in an average feed efficiency of 1.43, ranging from 1.26 to 1.69, while the N efficiency in average was 29 %, ranging from 25 to 33 % (table 1b). Milk income over feed cost and feed cost per kg ECM ended up with an average of 44 SEK and 1.4 SEK respectively (table 1b). The range of milk income over feed cost was 32 to 56 SEK, while the range for feed cost per kg ECM was 1.5 to 2.0 SEK (table 1b).

Table 1b. *Average, maximum, minimum and standard deviation (SD) values for recorded parameters at farms with PMR feeding*

Variable	Unit	Average	Minimum	Maximum	SD
Diet composition					
DM	g/kg	427	330	520	6.68
ME[1]	MJ/kg DM	11.7	11.1	12.0	0.280
CP	g/kg DM	162	135	178	13.0
NDF	g/kg DM	383	324	412	25.5
Starch & Sugar	g/kg DM	180	125	316	52.9
Calcium	g/kg DM	7.3	5.0	10	1.6
Phosphorus	g/kg DM	4.1	3.3	4.9	0.53
Roughage	g/kg DM	557	430	670	63.1
Concentrate	g/kg DM	443	330	570	63.1
Intake and animal performance					
DMI	kg/cow/day	21	19	25	1.8
CP intake	kg/cow/day	3.4	3.1	4.0	0.30
ME intake	MJ/cow/day	249	213	275	19.4
Eating places per cow	numbers	0.81	0.51	1.1	0.17
BCS		3.2	2.0	4.5	0.42
BCS (proportion scored)		0.43	0.27	0.58	0.11
Milk parameters					

Milk yield[2]	kg ECM/cow	29	24	32	3.0
Milk fat	g/kg	42	40	48	2.2
Milk protein	g/kg	33	31	36	1.3
MUN	mmol/L	4.2	2.8	5.5	0.71
Milkings/day	numbers	2.6	2.0	3.0	0.34
DIM[3]	days	205	164	250	30.2
Calving interval	months	12.4	11.5	14.9	1.08
Recruitment		0.38	0.30	0.49	0.058
Feed efficiency		1.43	1.26	1.69	0.127
N efficiency		0.29	0.25	0.33	0.029
Milk – Feed[4]	SEK	44	32	56	7.8
Feed cost/kg ECM	SEK/kg ECM	1.8	1.5	2.0	0.15

[1] Metabolizable energy [2] kg ECM per cow per day delivered to the dairy plant, [3] Days in milk, [4] Milk income over feed cost per cow.

4.2 Comparison between TMR and PMR feeding systems

The lack of difference between TMR and PMR feeding systems regarding the parameters feed and nitrogen efficiency, milk income over feed cost and feed cost per kg ECM in table 1a and table 1b is confirmed by one-way ANOVA analysis according to table 2.

Since the present study includes both TMR and PMR feeding systems, where farms practicing TMR feeding in general used a milking parlour for milking while farms practicing PMR feeding in general used milking robot for milking, milk- and feed parameters, as well as parameters related to nutrient efficiency and economy could differ between the systems. However, in this study, only protein in milk was different between farms practicing TMR and PMR feeding systems according to table 2. Farms practicing TMR feeding had in average higher milk protein content compared to farms practicing PMR feeding (table 2).

Table 2. *Results from one-way ANOVA analysis comparing TMR and PMR feeding systems*

		TMR		PMR		
	Unit	Mean	SD	Mean	SD	P-value
Diet characteristics						
ME	MJ/kg DM	11.7	0.287	11.7	0.280	0.756
CP	g/kg DM	163	11.4	161	13.0	0.770
NDF	g/kg DM	382	53.1	383	25.5	0.972
Starch & Sugar	g/kg DM	174	46.5	180	52.9	0.802
Roughage	g/kg DM	554	72.9	557	63.1	0.675

Intake and animal performance						
DMI	Kg/day	22	2.3	21	1.8	0.328
BCS		3.2	0.45	3.2	0.42	0.135
BSC (proportion scored)		0.36	0.11	0.43	0.11	0.193
Milk parameters						
Milk yield	kg ECM/cow	30	2.4	29	3.0	0.754
Milk fat	g/kg	43	1.7	42	2.2	0.477
Milk protein	g/kg	35	1.2	33	1.3	0.003*
MUN	mmol/L	4.6	0.49	4.2	0.71	0.141
DIM	Days	214	19.5	205	30.2	0.428
Calving interval	Months	12.9	1.57	12.4	1.08	0.399
Recruitment		0.41	0.064	0.38	0.058	0.382
Feed efficiency		1.35	0.0964	1.43	0.127	0.129
N efficiency		0.28	0.034	0.29	0.029	0.427
Milk - Feed	SEK	45	7.4	44	7.8	0.719
Feed cost/kg ECM	SEK/kg ECM	1.7	0.20	1.8	0.15	0.397

*Significant (P-value ≤ 0.05) difference

4.3 Correlations

The results from the Pearson correlation are presented in table 3.

4.3.1 Correlations related to nutrient efficiency and economy

When determining correlations related to nutrient efficiency through Pearson correlation, feed efficiency was shown to be positively influenced by N efficiency and milk income over feed cost (table 3). Furthermore, a negative correlation was found between feed efficiency and feed cost per kg ECM and DMI, while N efficiency was negatively correlated to CP content in the diet according to table 3.

Except from being positively correlated to feed efficiency, milk income over feed cost further correlated positively to roughage proportion in the diet and kg ECM per cow, while there was a negative correlation between milk income over feed cost and feed cost per kg ECM and BCS (table 3).

Table 3. *Correlations between variables associated with profitability, diet composition and production*

						Diet characteristics												
	FE[1]	NE	M - F	FC/ kg ECM[2]	DMI	NDF	ME	CP	S&S	R	EP	BCS	DIM	CI	RE	kg ECM/ cow	MUN	Milk protein
N efficiency (NE)	**0.58**																	
Milk – Feed[3] (M-F)	**0.56**	0.09																
FC/kg ECM	**-0.56**	-0.07	**-0.88**															
DMI	**-0.51**	-0.31	0.20	0.14														
NDF	0.14	0.04	0.37	-0.29	0.17													
ME	0.03	0.21	-0.27	0.32	-0.12	**-0.55**												
CP	0.10	**-0.54**	0.32	0.34	-0.05	-0.15	0.21											
Starch & Sugar (S&S)	-0.12	0.23	-0.26	0.29	-0.04	-0.32	0.02	**-0.49**										
Roughage (R)	-0.02	-0.24	**0.45**	-0.40	0.33	0.34	**-0.73**	0.06	0.03									
Eating places (EP)	0.03	-0.07	0.36	-0.35	0.04	-0.09	-0.26	0.19	0.21	0.27								
BCS	-0.29	-0.09	**-0.54**	0.36	-0.32	-0.29	0.10	-0.10	0.23	-0.13	-0.09							
DIM	-0.16	-0.13	-0.02	-0.15	-0.03	0.04	-0.03	0.01	-0.12	-0.13	0.14	0.40						
Calving interval (CI)	-0.03	-0.26	0.32	-0.36	0.13	0.09	-0.06	0.38	-0.10	0.15	0.35	-0.14	**0.60**					
Recruitment (RE)	-0.07	0.21	-0.25	0.07	-0.27	-0.13	0.40	-0.16	0.24	**-0.51**	0.06	0.36	**0.44**	-0.08				
kg ECM/cow	0.42	0.22	**0.77**	**-0.48**	**0.53**	0.32	-0.04	0.07	-0.19	0.23	0.08	**-0.60**	-0.03	0.20	-0.19			
MUN	0.10	-0.37	0.41	-0.40	0.04	0.28	0.08	**0.68**	**-0.66**	0.01	-0.01	-0.12	0.16	0.36	-0.16	0.18		
Milk protein	-0.43	-0.30	-0.14	0.09	0.06	0.02	0.23	0.23	0.01	-0.19	0.01	0.38	0.24	0.17	0.32	-0.28	**0.55**	
Milk fat	-0.11	-0.43	0.20	-0.36	-0.15	0.24	-0.44	0.29	-0.07	0.43	0.23	0.22	0.25	0.25	-0.02	-0.27	**0.52**	**0.47**

Significant correlations (P-value ≤0.05) are bold. [1]Feed efficiency [2]Feed cost/kg ECM [3]Milk income over feed cost.

4.4 Regression equations

The multiple regression analyses resulted in several equations that might be used in order to predict feed and N efficiency, kg ECM per cow and day, and MUN. In the following equations, the including variables are significant (p-value ≤ 0.05).

Feed efficiency could be predicted through the following equations according to the results of the present study;

Feed efficiency = -0.627 + 0.03923*N efficiency + 0.00566*CP

Feed efficiency = 0.676 + 0.02547*N efficiency

The equations explaining feed efficiency requires that N efficiency is known. The multiple regression analyses in the present study resulted in the following equations for N efficiency;

N efficiency = 47.44 – 0.1198*CP

N efficiency = -5.2 – 0.1496*CP + 14.23*feed efficiency + 3.23*ME

In the previous regression equations, feed efficiency is determined as kg ECM per cow per day/ kg DMI, while N efficiency is determined as the N utilized in proportion to its intake. Furthermore CP and metabolizable energy (ME) is expressed as g/kg DM and MJ/kg DM respectively. Further equations developed by the multiple regression analyses are the following equations describing milk yield in terms of kg ECM per cow and day, and MUN;

ECM yield = 14.90 + 0.669*DMI

ECM yield = 72.4 – 13.25*BCS

MUN = 1.34 + 0.02507*CP – 0.00556*starch & sugar

In the regression equations explaining ECM yield and MUN, ECM yield is expressed in kg ECM/cow/day and MUN is expressed in mmol/L. Dry matter intake (DMI) is expressed in kg/day, while CP and starch & sugar is expressed in g/kg DM. Considering the equations of kg ECM per cow and day, it is important to remember that the milk yield included in the present study is the milk delivered to the dairy plant, why the equations describe the same.

The regression equations presented, includes variables that correlates to the explained variable according to table 3. However, some of the significant (p-value ≤ 0.05) variables in the multiple regression analysis were not significant in the Pearson correlation and vice versa.

5 Discussion

The present study resulted in a feed efficiency of 1.35 and 1.43 kg ECM/kg DMI for farms practicing TMR and PMR feeding respectively (table 1a; table 1b). Normally, the range of feed efficiency is between 1.3 kg ECM/kg DMI and 1.7 kg ECM/kg DMI, meaning that the feed efficiency in the present study is within the expected range, but could also be improved. However, the N efficiency was calculated through NorFor and thus describes the proportion of N input that is converted to salable products. Most of the studies found, explain N efficiency as the proportion of N input that is recovered in milk, which makes it hard to compare the results of the present study to other studies and should be remembered when reading the following discussion.

5.1 Nutrient efficiency and profitability

In earlier studies, improved feed efficiency has been expected to improve profitability in the herd (Beever & Doyle, 2007; Garg *et al.,* 2013). This is consistent with the results from the present study where feed efficiency is positively correlated to milk income over feed cost (table 3), since milk income over feed cost could be used as a measure of lifetime profitability in dairy herds (Kulak *et al.,* 1997). Furthermore, in the present study, feed efficiency is negatively correlated to feed cost per kg ECM (table 3), meaning that feed cost per kg ECM is reduced when feed efficiency is improved. However, the negative correlation between feed efficiency and feed cost per kg ECM is not supported by other studies, since there are no previous studies in this area to the knowledge of the author.

In comparison to feed efficiency, N efficiency had no influences on the profitability parameter milk income over feed cost, neither on feed cost per kg ECM (table 3). Since N rich feedstuffs are expensive, and since improved N efficiency is reached through reduced CP intake (Huhtanen & Hristov, 2009), a positive correlation between N efficiency and milk income over feed cost was therefore expected. Consistent with Huhtanen *et al.* (2008), the present study resulted in a significant negative correlation between N efficiency, dietary CP concentration and CP intake. However, the negative correlation between N efficiency and CP intake could be questioned since the regression analysis did not support that correlation. The reason why economy is unaffected by N efficiency in the present study is unknown, but since Vandehaar & StPierre (2006) mentions that CP has to be fed in levels of requirement in order to avoid losses in milk production, there might be similar economic impact from high N efficiency as low N efficiency.

5.2 Nutrient efficiency and milk yield

Feed efficiency was expected to be influenced by milk yield since Vandehaar (1998) claimed that high milk production is important in order to improve feed efficiency, which is supported by the positive correlation between milk yield and feed efficiency in the study by Britt *et al.* (2003). In the present study, feed efficiency was not influenced by milk yield (kg ECM/cow/day) (table 3), which might be due to that the values of milk yield is the milk delivered to the dairy plant in the present study. This is due to that many of the farmers estimated the values of total milk production on the farms, meaning that the amount of the delivered milk was more accurate and therefore used in the present study.

Even though feed and N efficiency were not correlated to milk yield (kg ECM/cow/day) in the present study (table 3), milk yield in terms of kg ECM per cow and day is negatively correlated to the economic parameter feed cost per kg ECM and positively correlated to milk income over feed cost. However, DMI is not correlated to feed cost per kg ECM or milk income over feed cost (table 3), which might indicate that the milk production influence economy more than the feed consumption does, as assumed by Vandehaar (1998).

5.3 Milk urea nitrogen

Milk urea nitrogen (MUN) have shown to be related to N efficiency in several studies (Huhtanen *et al.,* 2008; Nousiainen, Shingfield & Huhtanen, 2004), but in the present study that kind of relationship was missing (table 3). However, MUN was positively correlated to CP concentration in the diet (table 3), while N efficiency was negatively correlated to dietary CP concentration (table 3). This might in turn indicate that MUN indirectly influences N efficiency through dietary CP concentration according to the present study.

Interestingly, MUN was negatively correlated to the concentration of starch and sugar in the diet (table 3). This result is supported by Rius *et al.* (2010) who determined effects on MUN from differences in dietary energy supply. The reason might be that since the farmers in general uses some kind of computer based feed ration formulation program, the program might take advantage to physiological effects due to protein and easily digestible carbohydrate supplementation. This in turn might lead to a correlation between CP and starch and sugar concentration in the diet. The physiological explanation to the negative correlation between dietary starch and sugar and MUN, might be that easily digestible carbohydrates are used as an energy source for the microorganisms in the rumen and thus the microorganisms are able to convert non protein-nitrogen, such as urea, for protein synthesis as described in McDonald *et al.* (2002). Another explanation could be due to the feed sampling in the present study, since all feed samples were not collected at feeding time.

5.4 Days in milk and calving interval

In the present study, there were no correlation between days in milk (DIM) and variables associated with nutrient efficiency (table 3), which is inconsistent with previous studies where Britt *et al.* (2003) found a negative correlation between DIM and feed efficiency and Huhtanen *et al.* (2008) found that DIM influences N efficiency. The reason to the results of the present study regarding DIM might be that the DIM is received from the milk recording that was made close to the farm visits, but is however not the exact DIM during the visit and during the recording of the other data included in this study. However, the average DIM in the present study is not that far from the average DIM in the study by Britt *et al.* (2003), why similar results might be expected. On the other hand, Britt *et al.* (2003) measured feed efficiency in kg milk/kg DMI while the present study measures feed efficiency in kg ECM/kg DMI, which might affect the difference between the results.

Since the average DIM were 214 and 205 days for farms with TMR feeding and PMR feeding respectively in the present study (table 1a; table1b), the cows were not supposed to be in negative energy balance, which is also indicated by the average BCS at farm level (table 1a; table 1b). Cows with high BCS is shown to have reduced performance (Heuer, Schukken & Dobbelaar, 1999; Markusfeld, Galon & Ezra, 1997), and several farms participating in this study practiced TMR which could lead to an increased risk of over conditioning. However, the present study did not result in any difference in BCS between farms practicing TMR or PMR feeding (table 2).

Since the length of lactation is recommended to be approximately 305 days, followed by two months of dry period before the next calf is born, the CI would preferably be approximately 12 months, which is fairly consistent with the average results of the present study (table 1a; table 1b). However, the maximum CI in the present study was 16.3 months (table 1a). Since milk production declines from peak lactation and onwards (McDonald *et al.,* 2002), and since milk yield is expected to be important for feed efficiency (Vandehaar, 1998) and thus economy (Beever & Doyle, 2007; Garg *et al.,* 2013), a long CI might result in negative effects of the same. Therefore, a suggestion is to shorten the CI on farms that exceeds the recommended CI, in order to improve efficiency in the production which might result in improved feed efficiency and economy.

5.5 Regression equations and correlations

In the present study, the regression equations and the correlations did not contain the same significant (p-value ≤0.05) variables in all cases. For example, feed efficiency is described by N efficiency and dietary concentration of CP in one of the regression equations explaining feed efficiency, while a Pearson correlation between feed efficiency and dietary concentration of CP is missing. However, the dietary concentration of CP is negatively correlated to N efficiency (table 3) and might thus affect feed efficiency. On the other hand, when studying the regression equation for N efficiency containing feed efficiency and ME concentration in the diet, a Pearson correlation between feed efficiency and ME is missing according to table 3. This might somehow illustrate the weakness of the present study and highlight the importance of further studies in this area.

Furthermore, the present study resulted in a positive correlation between feed and N efficiency, meaning that improved feed or N efficiency is followed by an improvement in the other. This was further supported by the multiple regression analyses. However, the positive correlation between feed and N efficiency has not been elucidated in previous studies according to the author's knowledge, why further studies that confirms and highlights this relationship would be interesting since the farmer's benefits from improved N efficiency have seemed to be scarce.

6 Conclusions and further perspectives

In conclusion, the use of TMR or PMR feeding systems did not affect feed efficiency, nitrogen efficiency or milk income over feed cost in the present study. However, improved feed efficiency seems to result in improved profitability and N efficiency together with good health and production in the herd, as well as reduced environmental impact. The benefits from improved feed efficiency suggest that the dairy industry would benefit from a higher focus on feed efficiency in terms of economy and environmental load. Reduced environmental impact seems to be the major result from improved N efficiency. Further studies relating N efficiency and feed efficiency would be interesting in order to elucidate the importance of N efficiency, since the results indicate that the farmer *per se* do not economically benefit from improvement in N efficiency.

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Personal Communication

Åkerlind, C. (2013-06-25) telephone
Åkerlind, C. (2014-04-02) e-mail

Appendix I

Farm		Cow traffic		
Conventional		Organic		
PMR		TMR		
Robot milking		Other milking system		
	Total	SRB	SH	
Number of lactating cows				
Emptying of milk tank		Date of latest milk analysis		
Number of milkings/day				
Milk produced		Milk delivered		
Fat content in milk		Protein content in milk		
SCC		Urea		
Veterinary visits/month (lactating)		Veterinarian		
Length of dry period				
Number of feed places		Number of cubicles		
Number of feed mixtures		Number of groups of cows		
Expected milk output from feed ration		Number of animals/group		Feed advisor?

How are the cows grouped?				
	Copy	Name of analysis	Place of analysis	
Feed analysis				
Cleaning of feed table		Cleaning of mixer wagon		
Unconsumed feed (kg/day)		Kind of mixer		
	Clean	Clots, dried feed	Mould	
Hygiene in mixer wagon				
Routines for drying off		Routines, dry period - lactation		
Feeding of dry cows		When where the cows fed today?		
Other:				

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