Extended Calving Interval and Increased Milking Frequency in Dairy Cows

Effects on Productivity and Welfare

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Doctoral thesis
Swedish University of Agricultural Sciences
Uppsala 2003

Acta Universitatis Agriculturae Sueciae
Agraria 383

ISSN 1401-6249
ISBN 91-576-6426-9

Tryck: SLU Service/Repro, Uppsala 2003

Abstract

Österman, S. 2003. *Extended calving interval and increased milking frequency in dairy cows - effects on productivity and welfare.* Doctoral thesis.
ISSN 1401-6249, ISBN 91-576-6426-9

The general aim of the present work was to investigate the opportunities for a planned extended calving interval (CI) in dairy cattle, and how it would effect production and animal welfare. Furthermore, the effects of combining an extended calving interval with an increased milking frequency (MF) was evaluated.

The milk production per cow has increased dramatically during recent decades. In thirty years average milk production per cow has increased by more than 3000 kg energy corrected milk (ECM), and the development towards still higher milk yields does not appear to be stopping. High milk yields in combination with a minimised CI results in high yields when drying off, problems at the onset of the lactation and bad utilisation of the milk production capacity of the cow. The current management methods for high producing cows also results in a short length of life and must be questioned, both from an ethical and economical point of view.

In total, 72 cows of the Swedish Red and White Breed were introduced to the study, which lasted for three years. There was one conventional CI of 12 months, and one extended CI of 18 months, both of which were tested in combination with two different MF's, 2x and 3x per day. The groups are referred to as 12-2, 12-3, 18-2 and 18-3.

The results presented here show that cows with 18 months CI have as high production, expressed as ECM/day of calving interval, as cows with a 12 months CI and cows in group 18-3 had the highest ECM/day of CI of all groups. An extension of the CI resulted in better feed efficiency compared to the conventional system, and the contents of somatic cells were desirably low throughout the extended lactation. The primiparous cows maintained their production better than the multiparous cows, and an increased milking frequency may contribute to increased comfort in high producing dairy cows. A system with an extended CI, is a less intensive system with fewer risk periods for the cow, and therefore it would increase not only the production, but also the animal welfare and the lifetime of the cow.

Key words: drying off, feed consumption, feed efficiency, lying down, milk production, milk composition, somatic cell count

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Appendix

Papers I-IV

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Österman, S. & Bertilsson, J. 2003. Extended calving interval in combination with milking two or three times per day: effects on milk production and milk composition. Accepted for publication in *Livestock Production Science*.

II. Österman, S., Östensson, K., Svennersten-Sjaunja, K. & Bertilsson, J. 2003. How does extended lactation in combination with different milking frequencies effect somatic cell counts in dairy cows? (Submitted).

III. Bertilsson, J. & Österman, S. 2003. Extended calving interval in combination with milking two or three times per day: How does it effect feed intake and feed utilisation? (Manuscript).

IV. Österman, S. & Redbo, I. 2001. Effects of milking frequency on lying down and getting up behaviour in dairy cows. *Applied Animal Behaviour Science 70*, 167-176.

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List of abbreviations

bST	Bovine somatotropin
CI	Calving interval
DM	Dry matter
ECM	Energy corrected milk
FIL	Feedback inhibitor of lactation
LSCC	Log10 somatic cell count
ME	Metabolizable energy
MF	Milking frequency
MJ	Megajoule
SCC	Somatic cell count
SRB	Swedish Red and White Breed
VFA	Volatile fatty acid
2x	Milking 2 times/day
3x	Milking 3 times/day

Background

Milking is considered to be one of the earliest secondary uses of live animals, stemming from their domestication. The earliest evidence that shows cows being milked is probably a relief from about 3100 BC (Cowie, 1980). It is reasonable to assume that cattle milk already was known as an important food source at this time. Furthermore, it is likely that there was a desire to keep animals that supplied milk in excess of that required to rear their young, so that some milk could be diverted for human consumption. The drive to increase milk yield is still going on, but the modern dairy cow differs a lot compared with the cattle pictured 3100 BC. The most remarkable difference is the capacity for very high milk yields, originated from breeding and increased knowledge about feeding and management.

Originally, the dairy cow was highly seasonal. The calf was born in spring or early summer, so that the milk production was highest in the summer, when there is the greatest access to food. If calves are to be reared successfully for consecutive years, it follows that the sum of lactation, dry period and gestation must be about 12 months in duration. However, the effect of domestication on the animals physiology, is apparent from the almost total lack of seasonality in cow reproductive cycles (Knight, 2001). Furthermore, since the demands for food can be satisfactory fulfilled during the whole year, it is no longer required for calving to take place only in the spring.

Introduction

In the beginning of the 20th century the average milk production was 2500 kg 4 % energy corrected milk, ECM, (Sjaunja et al., 1990) per cow and year in Swedish dairy cows (Swedish Dairy Association, 2002). The milk yield has increased steadily over time, and the increase has become more rapid during recent decades. Since 1960, production has increased by more than 4000 kg ECM in Sweden, and the development is similar in other industrialised countries. In 2001, the average lactation yield for the Swedish Red and White Breed (SRB) was 8 661 kg ECM, with individual cows producing more than 16 000 kg ECM (Swedish Dairy Association, 2002). With the efficient animal breeding, feeding and management systems in use today, this trend does not seem to be changing. This dramatic increase in milk production results in new demands on the management system for the dairy cows, since the current management methods entail a great challenge for the high producing dairy cow. It is therefore of great importance that we improve our knowledge of different management routines, to develop a system which favours both milk production and animal welfare.

Welfare of the dairy cow

Animal welfare issues are important and public support for these matters is increasing. In Sweden, there are well-established guidelines, recommendations and regulations for animal welfare. In the Swedish Animal Welfare Act, (Djurskyddslagen 1988:534), the second paragraph states as follows: “Animals should be well treated and protected from unnecessary suffering and diseases”. The phrasing of this could cause debate, since the expression “unnecessary suffering” is open for subjective opinions. What is unnecessary suffering in the handling of the dairy cows? One common opinion is that a high production level creates suffering.

One factor that could effect the welfare of the dairy cow is the production level. With the high production levels that are seen in modern dairy cows, the production for individual cows can be as high as 50-60 kg per day at the peak of the lactation, which normally occurs after week 8 of the lactation. This means that when cows are milked twice a day, 35-40 kg of milk is removed from the udder at the morning milking. If the cows are milked more frequently than twice a day, there may be advantages for the individual cow. For example, cows with filled udders may have difficulties in performing certain movements, such as lying down and getting up. Furthermore, it may be uncomfortable or even painful for the cow with a filled udder, and since there is an external pressure on the udder when lying down, the effects of a filled udder will be even greater when in this position. Thus, high lactation yielding cattle can benefit from milking 3x per day, as it may involve increased welfare of the dairy cow, and also a gain in productivity, which can be adversely affected by discomfort (Albright, 1987).

Initiation of lactation

Parturition and the onset of the lactation are associated with extreme physiological challenges to the homeostatic mechanisms of the cow. In the course of a lactation cycle, the mammary glands of the cow undergo cyclical phases of development, differentiated function and, finally, involution (Tucker, 1981). Cell proliferation starts in early gestation and rises exponentially until it reaches its maximum soon after parturition (Knight & Wilde, 1993). In the terminal phase of the gestation, the cells differentiate, and close to parturition the mammary cells are converted from a nonsecretory to a secretory state (Tucker, 1981). The initiation of the milk secretion involves a cascade of endocrine changes. For instance, prolactin and growth hormone increase around parturition, while progesterone decreases.

Milk composition

Milk is composed of two liquid phases, an aqueous and a lipid phase. The major components in milk are lactose, protein, water soluble vitamins and minerals in the aqueous phase, and fat and fat-soluble vitamins in the lipid phase. Milk from dairy cows consists of more than 80% water, and the contents of lactose, protein and fat can vary to a small extent. There are, however, variations in milk composition between, for example, breeds, feeding regime and between different stages of the lactation (*e.g.* Mepham, 1983). The composition of milk is also influenced of the milking frequency, see below under a separate heading.

Fat is the most variable component in milk, and in a healthy cows' milk the average fat percent ranges between 3.8% and 4.9% (Jenness, 1985). The composition of the milk fat of ruminants is unique and consists of more than 400 different fatty acids (Christie, 1995). The fat content is also influenced by, for example, the diet and the level of energy intake. Cows with high energy intake generally have a reduced milk-fat content, whereas an increased fat content is the result of a low energy intake (Broster, *et. al.*, 1985). In dairy cows, milk yield and the concentration of fat is inversely related during the lactation (Wheelock, 1980).

Milk protein consists of approximately 80% caseins and 20% whey proteins. The synthesis of milk protein is dependent on essential amino acids, provided by the blood, whereas non-essential amino acids can be synthesised in the secretory cells of the mammary gland. The protein content in milk varies between 3.0% and3.6% (Jenness, 1985). The protein content in milk is, like milk fat content, influenced by breed, nutritional factors, stage of lactation and the milk removal frequency. An increased energy intake of the cow, either by increasing the level of concentrates or by improving the silage quality, increases the protein content in the milk. The type of protein fed can influence milk protein content, and the inclusion of lipids in the diet tends to reduce milk protein concentration (Murphy & O'Mara, 1993). The stage of lactation has a considerable influence on milk protein, particularly at the beginning of the lactation. The colostrum, is exceptionally rich in protein, mainly due to the presence of immunoglobulins from blood. The protein level decreases, rapidly at first, then more slowly until a minimum is reached 5-10 weeks post-partum (Mepham, 1983).

Milk lactose is the main osmotic component in milk (Wheelock., Rook. & Dodd, 1965), providing about half of the osmotic pressure. The remainder is primarily made up of sodium and potassium cations and their corresponding anions. The lactose content of milk is rather consistent, but the variation can range between 4.6% and 4.8% (Jenness, 1985). Lactose is a disaccharide that is synthesised from glucose. Lactose synthesis is dependent on glucose uptake from the blood, since glucose is not produced in the mammary gland. Due to the osmotic characteristics of lactose, it attracts water to the milk and is thereby important for the total milk yield. However, lactose content in milk can be reduced under certain conditions. For example, the lactose content of milk falls in situations when the tight junctions between the milk secreting cells becomes "leaky", *e.g.* during mastitis. The amount of lactose in mastitic milk is reduced by approximately 10 % (Korhonen and Kaartinen, 1995). The decreased lactose level leads to a disturbance between the osmotic balance between milk and blood, and to maintain the balance sodium and chloride ions filter from blood to milk. Their content may therefore increase to 10 times the normal level (Korhonen and Kaartinen, 1995).

Somatic cell count

In normal cows milk the cell content consists of practically only white blood cells, where the monocyte macrophage population dominates (Lee, Wooding & Kemp, 1980). In a healthy mammary gland, defined as a somatic cell count (SCC) $<10^5$/ml milk, most viable somatic cells are macrophages and lymphocytes, but a few are neutrophils and epithelial cells (Kehrli and Shuster, 1994). If there is a microbial infection of the mammary gland, the number and predominant types of somatic cells undergo a rapid transition, to numbers in excess of 10^6 cells/ml and >95% are neutrophils (Kehrli and Shuster, 1994). This transition, from low SCC to a clinical secretion containing a higher SCC, takes only a few hours (Persson, Sandgren & Rodriguez-Martinez, 1992), and is part of a normal defence mechanism against pathogens. The SCC may vary depending on the stage of lactation and parity (Blackburn, 1966). The SCC tends to be slightly higher in early and late lactation, and it also increases with increasing lactation number.

Feed consumption

In the high yielding dairy cow, the onset of the lactation results in a dramatic increase in the requirements for water and nutrients, for example glucose, amino acids and fatty acids. This increase in requirements is met partly by increased voluntary intake and partly by an array of metabolic adaptations (Bell, 1995). Changes which are of major importance for the establishment and maintenance of high milk production, include hypertrophy of the gastrointestinal tract (Tulloh, 1966), increased fatty acid mobilisation from adipose tissue and an increased rate of gluconeogenesis.

Good access to nutrients and water is a prerequisite for the maintenance of a high milk production. Voluntary feed intake is suggested to be regulated by the capacity of the rumen (Forbes, 1995), and dry matter intake (DMI) is also influenced by nutritional factors. When the concentration of produced volatile fatty acids (VFA) is increasing in the rumen, the voluntary DMI decreases (van Soest, 1994). There are also studies that show that there are strong relationships between DMI and metabolically active factors that are mainly produced in the adipose tissue (Zhang, et al 1994). As mentioned above, increased feed intake results in a higher milk yield, and at the same time the milk fat content decreases (Broster et al., 1985). During feed deprivation a rapid decline in milk yield is shown (Reid, Stark & Isenor, 1977; Agenäs et al., 2002).

Persistency of lactation

The persistency of lactation yield is an important factor for the total milk yield during a lactation. Cows with same yields at the peak of a lactation can still have significantly different total yield, due to differences in the persistency of the lactation. A typical lactation curve can be described as increasing from initial yield at calving to maximum peak yield, a plateau maintaining peak yield, and a decrease from peak yield to the end of the lactation (Grossman, Hartz & Koops, 1999). Cows that tend to maintain their peak yield for a longer time than the average cow during a lactation are referred to as persistent. Therefore, with the same total yield, a cow with a flatter lactation curve is considered to be more persistent than a cow with a curve that decreases rapidly after the peak yield.

Primiparous cows have a flatter lactation curve (Swedish Dairy Association, 2002) than multiparous, with a lower peak yield and a less rapid decline after peak lactation than multiparous cows (Bar-Anan & Genizi, 1981; Schutz, *et al.,* 1990) have reported that the persistency of the lactation curve decreased with increasing parity.

Calving interval

The general practice in dairy herds with intensive milk production is to breed cows with the aim of establishing a calving interval (CI) of 12 months. The CI is defined as the time from one calving to another. This traditional breeding system, with 12 months CI, is based on the idea that the production economy benefits from an early conception (Holmann, *et. al.*, 1984; Strandberg & Oltenacu, 1989). In the 1960´s Speicher & Meadows (1967) reported that annual milk production was maximised with CI's of 12 to 13 months and a calving interval of 13 months for primiparous and of 12 months for multiparous cows was suggested by Louca & Legates (1968), for attaining maximum production. In 1969, Wood (1969) published a paper on the mathematical modelling of yield curves, and at this time the intensive concept of maximising peak daily output and minimising calving interval, was totally accepted. However, to achieve a 12 months CI, the insemination of the cow occurs at the peak of production. Consequently, the insemination takes place when the cows are most challenged metabolically (Harrison, *et al.*, 1990). It has also been shown that the risks of fertility problems, such as silent heat and ovarian cysts, increase with increasing milk production (Grohn, Hertl & Harman, 1994). These kinds of fertility problems obviously make an early conception more difficult.

The combination of high milk yields and 12 months CI, leads to an increased risk for a high proportion of cows that have high production levels at the time for drying off. At this stage of the lactation, a high producing dairy cow could still be producing 20-25 kg milk per day. Drying off at high production levels could lead to an increased need for antibiotic treatment due to the greater risk of contracting mastitis (Dossing, 1994). A voluntary prolonged CI would eliminate, or at least reduce, the need for forced drying off and the use of antibiotics with the following lactation approaching. In addition to the increased need for antibiotics at the time for drying off, it also seems wasteful not to utilise the full capacity of the modern dairy cow. It has been found that the full milk production capacity is reached in the 4^{th} lactation.

High milk yields and 12 months CI, the current dominant breeding system, causes general concerns about metabolic diseases. It has been concluded that increasing milk yield leads to an increase in the frequencies of metabolic diseases, such as ketosis and milk fever (Distl, *et al.*, 1989). There are, however, other serious concerns surrounding the current practice and many cows are actually discarded after just one or two lactations. The most common reason for culling is fertility problems, which account for as much as 25% of the culled cows (Swedish Dairy

Association, 2002). Another problem concerning calving, is that a majority of veterinary problems, including milk fever, ketosis, retained placenta and displacement of the abomasum, occur within the first two weeks of the lactation (Goff & Horst, 1997).

Even though several studies suggest an optimal CI of near 12 months, there are studies that have shown an advantage for a longer period of days open and, consequently, an extended calving interval. BarAnan & Soller (1979), studied total productivity over current and following lactations, and found that maximum production was achieved by inseminating primiparous cows not earlier than 70 days postpartum and multiparous at 41 to 90 days postpartum. Furthermore, Weller, Bar-Anan & Osterkorn (1985), stated that the period between calving and insemination affected the milk yield. Cumulative yield of current and following annualised lactations, was greatest at 117 and 98 days open for primiparous and multiparous cows, respectively. Arbel, *et al.* (2001), found in their study, that there was an economic advantage in extending lactations by 60 days in high yielding cows, and that the advantage was greater for primiparous, as opposed to multiparous, cows. When discussing an extended calving interval, there may well be other advantages. For example, Ratnayake, *et al.* (1998), showed that an increase of the CI to 18 months may have a positive influence on reproduction, in terms of a reduced need for the treatment of ovarian disorders and higher conception rates.

Milking frequency

It is well known that milk yield increases with more frequent milking, and in former times, a system where cows were milked three times per day (3x), when they had their peak lactation was common. However, an increased milking frequency (MF) also involve increased expenses, and as early as 1912 there was a discussion in Lantmannen, a Swedish periodical for farmers, if it also could be economical justifiable to increase the milking frequency, from two times (2x) to 3x. With the production levels of today, milking 3x is a possibility to utilise the cows' capacity better.

Regulation of milk yield by MF has, in goat studies, been shown to occur through local mechanisms operation within the mammary gland (Henderson, Blatchford & Peaker, 1983). They showed that when 3x milking was applied to only one gland of the udder, the rate of milk secretion increased in that gland only. Similar results were presented by Hillerton, *et al.* (1990), who showed that milking cows four times per day instead of 2x, led to an significant increase in milk yield only in those glands receiving the extra milking, the control glands were unaffected by the treatment. Wilde, *et al.* (1988), identified a whey constituent in goat milk, the feedback inhibitor of lactation (FIL), which inhibits milk secretion both in vivo and in vitro. When one gland of the udder was milked more frequently, the rate of milk secretion increased only in the more frequently milked gland. In the more frequently milked gland the metabolic capacity of the secretory cells increases. With 3x milking during a longer period, it has been shown that the secretory cells increase in number, compared to the gland that was milked only 2x (Wilde, *et al.*, 1987). The interval between consecutive milkings also seems to have an effect on milk production and composition. Longer intervals between milkings have a negative effect on milk production (Stelwagen & Lacy-Hulbert, 1996.) and milking only once a day has been shown to increase the somatic cell count in milk. Ouweltjes (1998), showed that a longer interval between milkings resulted in lower milk yields per unit time, especially for cows with high production levels.

The effect of MF on milk yield has been studied by several researchers. Milking 3x has been shown to increase milk yield compared to 2x, and it appears that the increase is dependent on parity. (Amos, Kiser & Loewenstein, 1985; Allen, DePeters & Laben, 1986; Gisi, DePeters & Pelissier, 1986) all reported a larger increase in milk yield from primiparous cows with increased MF. On the contrary, Poole (1982) and DePeters, Smith & Acedo-Rico (1985), found that the milk yield response was higher with 3x milking for multiparous cows. Finally, Erdman & Varner (1995), found that primiparous and multiparous cows responded similarly when MF was increased.

There is a great variation in the reports on the response of milk yield to increased MF, and increases between a few percent and up to 30% can be found. Pearson *et al.* (1979) reported a 20% increase in milk yield during the first 150 days of the lactation of cows milked 3x compared with cows milked 2x. The increased yield was due to a prolonged peak yield and a reduction in the rate of the subsequent decline. The response in milk yield to 3x milking was maintained as long as the more frequent milking was applied, and there was also a carryover effect when switching to 2x milking. Poole (1982), also showed that the positive effect of the increased MF remained when the cows, after 20 weeks, were milked only 2x per day. There is also evidence that the effect of increased MF is determined by the stage of the lactation when the increased MF is applied. Szuchs *et al.* (1986), showed that the positive effect of 3x milking was more pronounced after peak yield and increased as lactation progressed.

The influence of 3x milking on the concentration of milk fat and protein is ambiguous in the literature. Several researchers have reported lower concentrations of milk components with more frequent milking (Allen *et al.,* 1986; Szuchs *et al.,* 1986; Barnes, Pearson & Lukes-Wilson, 1990), whereas others observed no significant changes (Amos *et al.,* 1985; DePeters *et al.,* 1985). More frequent milking has also been reported to result in a lower SCC (Allen *et al.,* 1986), consequently the authors suggested that increased MF is beneficial for udder health. However, in a challenge trial, udder health was not affected significantly by the milking frequency (Waterman, *et al.,* 1983). Klei *et al.* (1997) studied the effects of different stages of the lactation, early, mid and late lactation. They found that the percentage crude protein was lower for cows milked 3x than for cows milked 2x during each stage of lactation. Ahrne & Björk (1985) observed a higher content of free fatty acids in milk with increased MF.

Extended calving interval and increased milking frequency

According to Knight (1997), there are two main ways to increase lactation length. One is by enhancing the milk yield, *i.e.* shifting the whole lactation curve upwards and the other is to increase lactation persistency. This is obtained by changing the shape of the lactation curve to reduce the rate of decline in yield after peak lactation. Since an increased MF is known to increase milk yield and move the lactation curve upwards, this could create opportunities for an extended lactation. Therefore, the combination between increased MF and an extended CI is an interesting system for further investigation.

Aims of the thesis

The overall aim of the present thesis was to investigate the opportunities for an extended calving interval in dairy cattle under Swedish circumstances, and how it would affect the animal welfare.

The specific objectives of the study were to investigate:

- …..if an extension of the calving interval had any effects on production parameters, such as milk yield and milk composition and production per day of calving interval.

- …..if cows with an extended calving interval in combination with two different milking frequencies could produce for the entire extended lactation, without an unacceptable reduction of the milk yield, or an extended dry period.

- …..if the response in somatic cell count to lengthening of the calving interval in combination with different milking frequencies would be unacceptably high at the end of the extended calving interval.

- …..if the feed consumption and feed efficiency in cows with an extended calving interval and different milking frequencies would be the same as that for cows with a conventional calving interval.

- …..if different milking frequencies influence certain behaviours essential for the cow's welfare, such as lying down.

Materials and methods

Papers **I-III** in this thesis are based on a three year study, carried out at Kungsängen Reasearch Centre, Swedish University of Agricultural Sciences, SLU, in Uppsala, 1994-1997. Paper **IV** is a part of the three year study. All experimental procedures were approved by Uppsala Animal Ethics Committee. The main part of the experimental procedures are described in the included papers, **I-IV**.

Experimental design and animals

In total, 72 cows from the experimental herd of the Swedish Red and White Breed were introduced to the study. During the first year of the experiment 52 cows, including both primiparous (n=28) and multiparous (n=24) individuals, were introduced to the experiment and allocated into one of four groups. Another 20 cows, all primiparous, were added during the second year of the experiment, equally distributed between the groups. The groups are referred to as:

Group 12-2: 12 months CI and milked 2x per day
Group 12-3: 12 months CI and milked 3x per day
Group 18-2: 18 months CI and milked 2x per day
Group 18-3: 18 months CI and milked 3x per day

The cows with 12 months CI received their first insemination at the earliest 50 days after parturition, and the cows with 18 months CI at the earliest 230 days after parturition. Over the four years, the herd at Kungsängen had an average milk production of 8643 kg/lactation with a fat concentration of 4.4 % and a protein concentration of 3.4 %.

Feeding

The cows were individually fed and had free access to water. Until week 24 in the lactation, the cows were fed a mixture of silage, hay and a concentrate, *ad libitum*, and supplemented with a fixed amount of a separate concentrate. From lactation week 25, the cows were fed a restricted diet of silage, hay and concentrate, according to their calculated requirements (Spörndly, 1995).

Paper I: Milking routines and milk sampling

Cows that were milked 2x per day had a milking interval of 9 hours between morning and afternoon milking and 15 hours between afternoon and morning milking. Cows that were milked 3x per day had 8 hours between milkings.

The milk yield was recorded automatically every day, with a FloMaster™ milk meter (DeLaval, Tumba, Sweden). Milk samples were obtained one day per week, for each separate milking, and fat, protein and lactose content of the milk was determined, by using infrared spectroscopy (Milko Scan 133, Foss Electric, Hillerød, Denmark). The content of fat, protein and lactose were weighted to get daily means according to the yield at the separate milkings.

To have possibilities to compare yields of milk from cows with a different length of calving interval, a standard measurement was used. This measurement, kg ECM/day of CI, where CI is the length of the lactation plus the dry period, enables a comparison over the treatments.

Paper II: Somatic cell count

Milking routines and milk sampling were as described above. The total SCC of milk was determined by using a floro-opto-electronic cell counting method (Fossomatic 90, A/S Foss Electric, Hilleröd, Denmark). Before the statistical analyses of the SCC, the values were transformed to a logarithmic scale with base 10, LSCC, in order to obtain normally distributed data.

Paper III: Feed consumption and feed efficiency

The feed was weighed for each feeding. The individual feed consumption was registered once daily and surplus feed was weighed daily and deducted from what was fed. Daily samples were taken of all feeds and these were pooled for 2-4 weeks periods and analysed for the nutrient components of interest. The cows were weighed and their body condition was assessed every fourth week.

Paper IV: Behavioural study

In this study only 17 cows were included, seven cows were milked 2x and ten cows were milked 3x per day. The individual cows were video-recorded for 24 hours every fourth week, starting four weeks postpartum. The effect of CI was not included in this study, since only the first 16 weeks of the lactation were included.

Lying down and getting up movements and the total standing and lying time were analysed, according to their duration and frequency per observation time unit. The behaviours and movements were analysed over 24 hours, and also for the 4 hours before morning milking.

Concluding results

An additional analysis was performed that examine the effects of treatments on persistency of the lactation, data of which is showed in concluding the results in the thesis. The persistency was calculated as the slope of best-fit linear regression analyses of daily milk yields from week 9 to week 33, from Knight & Sorensen, (2000). This was performed to find out if there were any effects of gestation. Cows with 12 months CI are inseminated around the 8^{th} lactation week, and cows with 18 months CI are not yet inseminated, since they receive their first insemination around week 33.

Statistical analyses

Analysis of variance was performed on all data using the procedure mixed (Litell et al., 1996) in the SAS® system for Windows (SAS Institute, 1996). Models are described in each paper. Papers **I-III** and concluding results included fixed effects of selection line, lactation number, lactation in the study, calving interval and milking frequency and the interaction between calving interval and milking frequency, and the random statement was cow*CI*MF*selection line*.

Paper **IV** included fixed effects of milking frequency, lactation stage, milk yield and udder measurement and the two-way interaction between milking frequency and milk yield. If the interaction was non-significant for behaviour it was deleted from the model.

*The experimental herd at Kungsängen is divided into two selection lines that differ in genetic merit for milk fat content (Åkerlind et al. 1999).

Results and comments

Effects on productivity (paper I and III)

Milk yield and composition

Cows with 18 months CI produced significantly ($P<0.001$) more milk, expressed as kg ECM, and more fat and protein, compared to 12 months CI. Milking 3x per day resulted in significantly ($P<0.01$) higher yields of milk. In cows with 12 months CI, milking 3x increased kg ECM by 12%, the corresponding increase when milking 3x in cows with 18 months CI, was 10% (Figure 1). Milking 3x resulted in milk with lower concentrations of fat and protein. However, due to the higher milk yield with 3x milking, the total fat and protein yield was higher than in cows milked 2x.

There were small differences between primiparous and multiparous cows in total milk yield during the lactation. With 12 months CI, the primiparous had a lower yield in kg ECM than the multiparous cows, and in the 18 months CI the results were reversed.

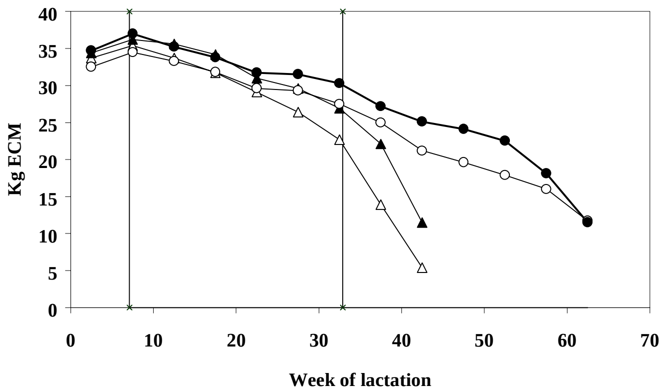

Figure 1. Least square means of averages of 5-week periods of kg ECM yields. The curves represent cows with different calving interval, 12 months (Δ) and 18 months (○). Cows milked 2 times per day are illustrated with unfilled symbols and those milked 3 times per day with filled symbols. Lines represent the time for start of insemination, in the two calving intervals.

Length of lactation and dry period

In cows with a 12 months CI, milking 3x resulted in about 4 weeks longer lactation, compared to 2x (Table 1). The length of the dry period was not influenced by the increased milking frequency in cows with 12 months CI. In cows with 18 months CI the opposite result was found, milking 3x did not cause any differences in the length of the lactation, but the dry period was almost 3 weeks shorter.

Primiparous cows had longer lactations in both 12 and 18 months CI compared to multiparous, 2.5 and 7.5 weeks longer, respectively. The primiparous cows also had shorter dry periods for both CI's, 4.3 weeks shorter for cows with 12 months CI, and 7.4 weeks shorter for cows with 18 months CI.

Production per day of calving interval

Production per day of the calving interval was calculated in order to facilitate a fair comparison of milk yield between cows with different length of the CI. The production, expressed as kg ECM/day of CI, shows that cows in 18-3 yielded significantly more per day than cows in 18-2 (Table 1), and 18-3 also had the highest milk yield of all four groups.

The primiparous cows yielded 1.2 kg ECM/ day less with 12 months CI than the multiparous cows, but 1.1 kg ECM/day more with 18 months CI.

Second lactation in the study

For the second lactation in the study, the cows with 18 months CI had a longer lactation and a significantly shorter dry period, ($P<0.05$), compared to the first lactation (Table 2). In cows with 12 months CI, there were no differences between either the length of the lactation or the dry period, between first and second lactation in the study. The production, expressed as kg ECM/day of CI, shows that cows with 18 months CI manage to maintained their production level in the second lactation in the study.

*Comments on paper **I***

The results in this thesis show that the extended calving interval, in combination with increased milking frequency, increased the average yields of ECM/day of CI. Cows in 18-2 did not yield as much as cows in 18-3 and in addition cows in 18-2 had a prolonged dry period. These results indicate that an extended CI should be combined with an increased MF. There are, however, other aspects to take into consideration. For example, primiparous cows, that are known to have a flatter lactation curve, are also a category of cows that seems to be worth prolonging the CI for.

The higher yields of milk, fat and protein in cows with 18 months CI was not surprising, since their lactation lasted an average of 20 weeks longer. The increased milk yield, between 10-13%, when milking 3x compared to 2x, was also expected, and in accordance with several authors *i.e.* (Waterman *et al.,* 1983; Ipema & Benders, 1992; Klei *et al.,* 1997).

For cows with the 18 months CI, the second lactation in the study resulted in a significantly shorter dry period and a slightly longer lactation, although not significantly so. This occurred despite the fact that the second lactation in the study only contained multiparous cows, which had more difficulties in maintaining their production in the extended lactation. This is in line with Johansson & Hansson (1940), although the yields and genetic merits of the cows were quite different in those days.

Feed consumption and efficiency

When analysing the whole lactation, feed intake tended to be higher for cows milked 3x than for those milked 2x (Table 1). Cows with 12 months CI had a higher average feed intake compared to those with 18 months CI, and cows in 12-3 had the highest feed consumption per day. When calculating on the average ME MJ/kg ECM the cows had used, the cows in 12-2 were found to be less effective than the cows in the other groups (Table 1).

The average live weights differed neither between CI nor between MF. Analyses for differences in feed intake due to remaining effects from earlier lactations did not show any such effects.

*Comments on paper **III***

The results showed that the feed efficiency was at least as good with 18 months CI as with 12 months. In fact, the lowest value of utilised energy per produced amount of milk, was found in 18-3, and gave approximately 7% better feed efficiency compared to 12-2. An extended calving interval also resulted in cows that were easier to feed, the physiological strain placed on the cow by high daily milk yield is diminished and the proportion of roughage in the diet can be increased (Sölkner & Fuchs, 1987).

Effects on somatic cell count (paper II)

As shown in Table 1, with a 12 months CI the LSCC for the last 10 weeks of the lactation, decreased with increased MF. Also when analysing the whole lactation, the somatic cell count was significantly lower in 12-3 compared to 12-2 ($p<0.05$). In cows with 18 months CI, there was no corresponding decrease for cows milked 3x, neither when analysing the whole lactation, nor the last 10 weeks of the lactation separately. Within the 18 months CI, there was a slight, not significant, increase in LSCC when milking 3x instead of 2x.

Analysis on LSCC data showed that primiparous cows, both with 12 months and 18 months CI, had lower LSCC, both during the whole lactation and when analysing the last 10 weeks separately. Primiparous cows with 18 months CI had a LSCC value of 4.67 (anti-logarithm = 46 774) the last 10 weeks of the lactation, the corresponding value for the multiparous cows was 5.12 ($P<0.001$).

*Comments on paper **II***

It is well known that, during normal circumstances, there is a moderate increase in SCC at the end of the lactation. It is of great importance that this increase is no more pronounced when the lactation is extended by extended CI. Analysis of the last 10 weeks of each lactation, showed that the extended CI did not result in any unexpected rise during this part of the lactation. The apparent small increase in group 18-3 compared to 12-3, is an effect of a low number of lactating cows and low milk yield in the 18 months CI group, since not all of the cows in that group managed to maintain milk production during the entire extended lactation. Therefore, the reduction of SCC that could be seen when milking 3x in cows with 12 months CI, did not appear when cows with 18 months CI were milked 3x.

The primiparous cows were more successful in maintaining milk production throughout the extended lactation than multiparous cows. At the time of drying off, the average milk production in cows with 18 months CI was 7.8 and 14.1 kg milk for the multiparous and primiparous cows, respectively. This can explain the higher SCC values for the multiparous cows at the end of the lactation, because it has been considered that increased SCC in late lactation is mainly an effect of the lower dilution of the cells due to low milk yield (Blackburn, 1966; Miller, *et al.,* 1983).

Effects on behavioural measurements (paper IV)

The total duration of standing during the 4 hours before morning milking differed significantly between the groups (Table 2), where cows milked 3x per day had longer total lying time and, consequently, shorter standing time. No such differences between the groups were found when analyses were performed on data for the corresponding hours before afternoon milking (Table 2). The distribution of the total time spent per lying bout also differed significantly between the groups ($P<0.01$). This analysis showed that cows milked 3x had fewer lying bouts shorter than 15 minutes and more bouts longer than 90 minutes, than cows milked 2x. 4 hours before morning milking, cows that were milked 2x also had a longer duration of the getting up movement, and there was an effect of milk amount and udder distension.

*Comments on paper **IV***

The results of the behavioural study show that milking 2x decreases the total lying time during the hours before milking. Cows milked 2x reduced the total lying time by more than 1 hour during these hours, compared to cows milked 3x. It is important to point out that cows milked 3x had their latest milking at 10 pm, while cows milked 2x were milked already at 3 pm. It is reasonable to assume that the higher pressure in the udders of cows milked 2x, which probably get even higher when lying down as a result of the additional external pressure, is an important causal factor behind the differences between the groups. Accordingly, there should be no differences in udder pressure between the two milking frequencies four hours before afternoon milking, since both groups were milked at the same time in the morning. As expected, there were no differences between the groups in total lying time in those hours.

Concluding results

To enhance the general view over the concluding results, see further in Table 1 and Table 2.

Table 1. *The least square means of different variables for cows with 12 or 18 months calving interval (CI) in combination with milking 2 or 3 times/day. The papers from which the values originate are given in brackets*

Group	12-2	12-3	18-2	18-3
No. of lactations (papers **I - III**), 2x and 3x (paper **IV**)	24	29	16	21
Lactation length, weeks (paper **I**)	41.7[a]	45.8[b]	63.8[c]	64.4[c]
Dry period, weeks (paper **I**)	9.3[a]	9.6[a]	14.0[b]	11.2[a]
ECM/day of CI[*] (paper **I**)	22.7	23.4	21.3[a]	24.2[b]
Rate of decline in kg ECM/week, week 9-33	-0.39[a]	-0.32	-0.26	-0.24[b]
LSCC[**], last 10 weeks of the lactation. (paper **II**)	4.88[a] (75 858)	4.66[b] (45 709)	4.83 (67 608)	4.94[a] (87 096)
Feed consumption, ME MJ/day (paper **III**)	227[a]	238[b]	212[c]	223[ac]
Feed efficiency, ME MJ/kg ECM (paper **III**)	5.9[a]	5.7[b]	5.6[b]	5.5[b]

a, b, c: different superscript letters on same line indicate differences ($P<0.05$).
[*] CI= (lactation length + dry period) in days.
[**] LSCC= Log_{10} somatic cell counts. The antilogarithm of LSCC is presented in brackets.

Table 2. *The least square means of different variables for cows with 12 or 18 months calving interval (CI), the first and second lactation in the study, and least square means of lying for cows that were milked 2 or 3 times/day. The papers from which the values originate are given in brackets*

	1st lactation		2nd lactation			
Group	12	18	12	18	2x	3x
No. of lactations (papers **I**), 2x and 3x (paper **IV**)	18	9	18	9	7	10
ECM/day of CI* (paper **I**)	22.1	21.8	24.1	24.6	-	-
Lactation length, weeks (paper **I**)	43.8^{a}	61.9^{b}	44.3^{a}	65.0^{b}	-	-
Dry period, weeks (paper **I**)	10.9^{ac}	15.6^{b}	8.7^{a}	11.0^{c}	-	-
Duration of lying (min), 4h before morning milking (paper **IV**)	-	-	-	-	109^{a}	174^{b}
Duration of lying (min), 4h before afternoon milking (paper **IV**)	-	-	-	-	115	122

a, b, c: different superscript letters on same line indicate differences ($P<0.05$).
* CI= (lactation length + dry period) in days.

Comments on concluding results

The analysis on the persistency, showed that there was a significant difference between 12-2 and 18-3, where 12-2 had a more rapid decline. Furthermore, there were no differences when analysing the MF separately (data not shown), but within CI there was a significant ($p<0.05$) difference, where cows with 12 months CI had a faster decline than those with 18 months CI, -0.35 and -0,25, respectively. These results are not consistent with Knight & Sorensen, (2000), who showed that the persistency to week 33 was significantly improved by milking 3x.

The results show that 12-2 has the lowest feed efficiency, and used most ME MJ/kg ECM produced of all four groups. They also had a more rapid decline in kg ECM after the peak lactation than cows with 18 months CI, indicating an effect of their early insemination. Finally, since there were no differences in somatic cell count during the last 10 weeks of the lactation between 12-2 and cows with 18 months CI, it can be concluded that a system with an extended CI is worth consider when planning the milk production.

A voluntary extension of the calving interval would offer many advantages without investments, and therefore it would be feasible for many dairy farmers to adopt this system. The extended CI studied in this thesis, 18 months, seems to be a logical interval to start with, since an 18 months calving interval allows advantages from seasonal calvings, and alternates between calving groups in spring and autumn. Furthermore, an increased MF supports the capacity for an extended lactation, and therefore a combination of an extended lactation and milking 3x is interesting to evaluate.

General discussion

An alternative to the current production system

Dairy producers and researchers increasingly question the biological feasibility and economic justification of a 12-13 months CI in cows (Rehn *et al.*, 2000; Arbel *et al.,* 2001). Nebel & McGilliard, (1993) stated that an extended CI would be profitable in cows which yielding more than 13500 kg milk/year, and the results in this thesis shows that there are advantages with an extended calving interval even with lower milk yields than that. Consequently, it is time to consider other alternatives for milk production.

The average CI for dairy cows in Sweden is 13.2 months, and milking the cows 2x per day is by far the most common system. However, there is a growing interest in more frequent milking, and an increasing proportion of the dairy cows in Sweden are milked 3x per day. Todays' intensive system, with a minimised CI, high lactation yields, and further increases with more frequent milking, are not optimal for animal welfare and perhaps not even economically efficient. There are several possible ways to change the system for milk production and to emphasise other aspects than a high milk yield.

One system that is gaining ground is the automatic milking system. This allows milking more often than 2x per day and the cows choose, to some extent, when to be milked. However, milking robots are expensive and involve a large economic investment. Another example of a system that is practised to improve herd profitability is the use of bovine somatotropin, bST in the United States. Somatotropin is a hormone, and the mechanism of action of bST involves changes in the metabolism of body tissues so that more nutrients can be used for milk synthesis (Bauman, 1992). The use of bST has been shown to increase peak milk yield as well as increase persistency (van Amburgh, *et al.,* 1997). Therefore, it is most likely that the dairy farmers in the US will turn over to a system with extended lactations as a result of the introduction of bST (Knight, 1997) since this provides better total economy. However, in Sweden and the rest of Europe it is most unlikely that bST will be used to enhance the productivity since it is not allowed to use hormone supplements in the production of milk, and there is also a strong public opinion against such production systems. However, the crucial point is that an extended calving interval may provide increased persistency without the need to supply bST. In addition, extending the CI would also imply advantages for animal welfare.

Increased animal welfare

The results in paper **IV** show that milking 3x per day may contribute to increased comfort in high producing dairy cows, partly due to reduced udder pressure, which permits higher comfort when lying down, as well as increased lying time. There is a gain in avoiding management practices that result in undue stress on the cows, partly because of the poorer production that can be seen in mistreated cows. (Albright, 1987) stated that the productivity of the dairy cow can be adversely affected by discomfort, and that one of the signs of discomfort is increased standing in cattle. (Metz, 1985) showed that a 3 hour deprivation of lying strongly raises the need for this behaviour, and that the recovery was strongest immediately following the deprivation. The cows in paper **IV** had longer standing time before morning milking and with the reasoning that this can lead to increased lying immediately after milking, this finding might have consequences. The teat canal is open for at least 30 minutes after the cluster has been removed, (Schultze & Bright, 1983) and therefore lying down after milking may increase the possibility of mastitis pathogens entering the teat canal and the mammary gland (Johansson, Redbo & Svennersten-Sjaunja, 1999).

The longer time it took for the cows in 2x to perform the getting up movement could also have effects on udder health. An overfilled udder, together with a suboptimal environment, such as slippery floors, may increase the risk of trampled teats. Krohn & Munksgaard (1993), suggested that a hard surface in combination with a distorted lying down movement pattern, caused the higher frequency of teat trampling that they found in their study. Oltenacu & Ekesbo (1994), performed a study that consisted of over 39 000 records of primiparous Swedish Friesian cows, and their results shows that there is a 6-fold increase in the risk of mastitis due to trampled teats. Therefore, increased lying before milking and normal patterns of lying down and getting up would increase the welfare of the cows as well as decrease the risk for trampled teats. It is also reasonable to assume that these effects could be seen with an extended calving interval. The disadvantages shown with an overfilled udder, would be reduced in a prolonged lactation, where a greater part is in the declining phase of the lactation.

Higher production and efficiency

It has been suggested that the average ECM yield would decrease below an acceptable level if a system with extended lactations should be put into practise. The results in paper **I** show that this is not the case. The highest average ECM/day of CI that was found in 18-3, proves that it is possible to maintain the average milk yields with a prolonged CI. An increased MF seems to be a prerequisite to achieve a sufficient daily milk yield, owing to the moderated decline of the lactation curve with a more frequent milking. An additional fact that strengthens this statement, is the prolonged dry period in 18-2. These results show that there could be benefits from extended CI in high yielding cows, and (Arbel et al., 2001) showed that there would be an economic advantage in extending lactations by 60 days in high yielding cows.

The higher feed intake that could be seen in cows milked 3x per day (paper **III**), was balanced by the increased production for those cows. In addition, there was no difference in weight gain, indicating a better feed efficiency for cows milked 3x. Similar results were shown by Amos *et al.,* (1985), their study found that milking frequency did not significantly affect feed intake or weight gain, so apparently efficiency of energy utilisation was increased by milking 3-times daily. Barnes *et al.*, (1990) showed in their study that cows milked 3x tended to weigh less than those milked 2x, suggesting more body tissue was catabolised for milk production, since the DM intake was not altered. Cows in our study, with an extended lactation, also had a better feed efficiency, and cows in 18-3 had the lowest level of ME MJ/kg ECM produced of all groups. It has been shown in a study performed by Sölkner & Fuchs (1987), that highly persistent cows required less concentrates than cows with a poor persistency, to produce the same amount of milk.

This study shows that the LSCC values throughout the lactation do not differ between an extended calving interval of 18 months, compared to the traditional 12 months interval (paper II). Furthermore, the effects of extending the calving interval in combination with different milking frequencies, were that cows in both 18-2 and 18-3 had lower LSCC values than the traditional system, with 12 months CI and milking 2x daily. The reduced number of LSCC that could be seen in 12-3 compared to 12-2, is consistent with other reports *e.g.* (Allen *et al.,* 1986; Klei *et al.,* 1997). Longer intervals between milkings have a negative effect on milk production, and probably also on udder health (Stelwagen & Lacy-Hulbert, 1996; Kelly, *et al.,* 1998). In studies with once daily milking, it was shown that after 17 h from last milking, significant functional changes occur in the udder tissue (Stelwagen *et al.,* 1997). Tight junctions between secretory cells becomes leaky, resulting in components from the blood coming into the milk and an impaired milk quality. Therefore, the higher SCC found in 12-2 compared to 12-3, could be an effect of the uneven milking intervals in 12-2.

Higher persistency

To obtain a more persistent lactation, and create opportunities for an extended lactation, the shape of the lactation curve needs to be changed so that the decline after peak yield is moderated. Although all the factors are not fully understood, some are known to have an influence on persistency, *e.g.* parity, pregnancy the status of the nutrition (Stefanon, *et al.,* 2002), and the shape of the lactation curve is also hereditarily (Gengler 1996). According to Wilde & Knight (1989), milk secretion declines because the tissue fails to maintain its population of secretory epithelial cells. (Wilde, *et al.,* 1997) suggested that elimination of secretory cells during mammary tissue involution is under physiological regulation and occurs by apoptosis, *i.e.* programmed cell death. Since apoptosis exceeds cell division during declining lactation, it is this decrease that is responsible for the reduction in milk yield (Knight, 2000).

More frequent milking is also known as a factor that increases persistency, and Knight & Sorensen (2000) reported that when persistency was measured as the slope of decline between lactation weeks 9 and 33, it was significantly improved by milking 3x compared to 2x per day. Schneider, *et al.,* (1981) showed that the slopes of the lactation curve were different between an early and a late bred group, with insemination at the first heat following 50 and 80 days postpartum, respectively. The late-bred group had a lesser decline in the latter part of the lactation, and this could be an effect of pregnancy, since pregnancy adversely effects milk production. The less rapid decline between lactation weeks 9 and 33 that was shown in cows with 18 months CI compared to those with 12 months CI, indicates that the cows in 12 months CI were adversely affected by pregnancy. The mechanism by which pregnancy influences milk yield is not fully understood, but it is believed to be caused by hormonal control of milk secretion and the partition of nutrients for biological functions (Oltenacu, *et al*., 1980). Furthermore, Stefanon *et al.*, (2002), suggested that it is the sex steroids that maintain the pregnancy that are involved, and oestrogens and progesterone have long been recognised as mammotrophic hormones. The effect of pregnancy on milk yield have been reported to be observed already in the first month after conception (Bar-Anan & Genizi, 1981). The study was performed on primiparous and 3rd lactation cows, and the cows were grouped according to both herd and cow level classes according to milk yield. The decline in yield due to pregnancy had a similar effect on high- and low-producing cows, and within herds the higher yielding cows had less persistent lactations.

Differences caused by parity

The results in this thesis show that the peak yield was less pronounced for the primiparous cows, and that their lactation curve had a generally flatter shape (paper **I**). At the end of the lactation, the primiparous cows with 18 months CI had a higher milk yield than the multiparous cows, this difference was irrespective of MF. The primiparous cows could better maintain the production and at the time of drying off, the primiparous cows yielded on average 10 kg more than the multiparous cows. These results show that an extended calving interval is more advantageous for primiparous cows. This result is consistent with Rehn *et al.,* (2000) who found that when calving intervals of 12 or 15 months were compared, the dry period of the primiparous cows was significantly shorter than that of the multiparous. On the other hand, Arbel *et al.,* (2001) found fewer days dry in the extended CI for the multiparous cows when they compared early versus late breeding.

Generally, primiparous cows are more persistent than multiparous cows. The most plausible reason is that the mammary gland of the cow is not fully developed at the beginning of the first lactation. In a review by Knight & Wilde (1993) it was shown from studies of normal mammary development in goats, that during the first cycle the gestational proliferation of secretory tissue is exponential. At the onset of the lactation, the proliferation continues to some extent until peak yield, when there is a maximum in secretory tissue, which is maintained throughout the peak yield. As milk yield declines, a corresponding decline can be seen in the secretory tissue; consequently it is considered that secretory tissue is closely related to milk yield. After drying off, the loss of secretory cells is accelerated, but the udder does not completely revert to its virgin state. Thus, when the second cycle starts, there is a higher starting point of secretory tissue, and there are physiological conditions for a higher milk yield.

The study presented here, suggests that the cows with an 18 months CI had longer lactations and higher milk yields in their second lactation than they had had in their first. These results are very interesting, although the differences were non-significant. The numerically, higher milk yield in the second lactation in 18 month CI cows may be caused by the fact that the second lactation in the study only included multiparous cows, whereas the first lactation included both multiparous and primiparous cows. Since it is well known that multiparous cows generally have a higher milk yield than primiparous, but also are less yield persistent, the results from the second lactation in the study are extremely interesting.

It is possible that the cows derived advantage from the prolonged first lactation when they entered the second lactation. However, it is more likely that the higher milk yield in the second lactation is due to the long, 15.6 week, dry period between the first and second lactation in the experiment. The dry period involves changes in the mammary tissue that promote increased milk production during the following lactation, such as the replacement of old mammary epithelial cells and an increase in the epithelial component of the mammary tissue (Capuco, Akers& Smith, 1997). Funk, Freeman & Berger (1987), showed that cows with a dry period of 40 days or less produced markedly less during the following lactation. Cows with a longer dry period than 60 days had a slightly lower production, whereas cows with a dry period of approximately 60 days produced most milk the following lactation. It is common to dry off cows early, if there are problems with the SCC for example, which results in a longer dry period. Therefore, it is possible that the negative effect on milk yield that is often found in the following lactation, is not derived from a longer dry period as such, but actually is an effect of problems in the previous lactation. Since this is not the case in our study, the long dry period did not have any negative effects on milk yields in the following lactation.

Effects on early lactation and fertility

With a production system with extended CI's, a smaller portion of the lifetime of the cow would be in connection to the parturient period, and this fact would be an advantage for animal health and thereby milk production and dairy economics. The onset of the lactation involves an enormous metabolic challenge for the high-yielding dairy cow. The energy requirement for a dairy cow just before parturition is 85 MJ/day if the cow weighs 600 kg (Spörndly, 1995). This increases rapidly after parturition, and at the peak of lactation the requirements are at least threefold compared to late gestation. At this stage of the lactation there is a metabolic imbalance, caused by a lower energy intake than output. A negative energy balance during early lactation results in an increased risk of a variety of metabolic diseases (Collier, 1985). Drackley (1999), stated that as much as 60% of health costs are incurred in the first 45 days of the lactation. The diseases that are associated with parturition, such as milk fever, ketosis and retained placenta, contribute to some of these costs. However, these diseases almost always occur as single-figure incidences. In addition to metabolic diseases, a majority of infectious diseases, especially mastitis, become clinically apparent during the first two weeks of the lactation (Goff & Horst, 1997). The high risk for these diseases extends through to peak lactation, *i.e.* the time of the metabolic imbalance (Knight, 2001). A 12 months CI necessitates a resumption of the reproductive functions after calving during the period of metabolic imbalance, and an extended CI would prolong the time available for this resumption.

The results on fertility in our study show no negative effect of an extended CI, by delaying the first insemination to 230 days postpartum. There were no significant effects on fertility, based on conception rate, in our study between 12 and 18 months CI (Ratnayake *et al.,* 1998). The study performed by Ratnayake *et al.* (1998) also included another herd that was managed for either 12 or 15 months CI. In that herd, a trend of higher conception rates was observed in the cows with 15 months CI, compared to 12 months, and those results are in agreement with (Schindler, *et al.,* 1991).

One opinion that seems to be established among many dairy farmers is that heat detection becomes more difficult with time from calving. If that is the case, this would be a disadvantage with an extended calving interval. When aiming at a CI of 12 months, it is necessary to have an early resumption of the reproductive functions after calving, since the first insemination must occur around 50-60 days postpartum. Schneider *et al.* (1981) performed a study where cows were assigned to an early or a late bred group, inseminated 50 and 80 days postpartum, respectively. The late-bred group needed more inseminations to conceive, 1.96 versus 1.50 inseminations per conception. In the late-bred group cows with reproductive problems needed significantly more services than the healthy cows, but no difference was found in the early bred group. This indicates, according to the authors, that the late-bred group had lower fertility and that the best time for insemination was passed. Knight & Sorensen (1998) also found a lower reproductive success when inseminating late in the lactation, aiming at a CI of 18 months. In their study, although the numbers of inseminations per cow was greater in the extended lactation group, 2.25, compared with the 1.83 in the normally bred group, the difference was not significant. On the contrary, Schindler *et al.* (1991), found that in multiparous cows first inseminated at day 35-59 and 60-90 days postpartum resulted in lower conception rate than a later insemination at 120-150 days postpartum but in primiparous cows there was no such effect.

There is a considerable difference between the length of the CI in our study compared to two of the other studies mentioned above. Schneider *et al.* (1981), only delayed the insemination by 30 days. It is possible that a short delay of the first insemination is a disadvantage for the conception rate, whereas an insemination at day 120 and onwards, *i.e.* when the cows have had their peak lactation and are in the declining phase of the lactation, has no negative effects. However, it is difficult to draw any conclusions between the contradictory results, since there may have been differences between the management and feeding regimes.

Reduced risks at drying off

High yielding cows with a CI of 12-13 months, often have a drying off at high yields. Drying off at high yields is not the best way to use the capacity of the cow, and it can also lead to problems. Dossing (1994), showed that cows which at the last milk recording before drying off had a milk yield that exceed 10 kg showed a greater risk of contracting mastitis in the dry period than cows with a yield less than 10 kg. As mentioned earlier there is an increasing interest in more frequent milking. With the known response of higher milk yields when milking 3x instead of 2x e.g. (Poole, 1982), the average milk yields at the time for drying off will be even higher than the levels of today. This is apparently a problem and high production levels at the time for drying off also involves more use of antibiotics, and in Sweden there is a effort to use less antibiotics. There are, however, other ways that are available for drying off the dairy cow, such as a reduced MF. With a system with milking 3x per day, it is possible reduce the MF to 2x per day, and reduce to milking to only once per day before drying off. Since there might be undesirable changes (Kelly et al., 1998) in milk quality with milking only once per day, this is an uncertain method. Other, hopefully not frequently used, methods for drying off cows, is a sharp reduction of the feed or even withdrawal of water. None of these methods is desirable or beneficial for the welfare of the dairy cow.

By extending the calving interval to 18 months, the milk yield at the time of drying off will be lower, and therefore there is a reduced risk for any doubtful method for ceasing the milk production, including the need for the use of antibiotics. The cows with a 12 month CI in the experiment included in this thesis, had an average milk production of 16.6 kg milk at the time for drying off, and similar daily yields are not unusual in commercial herds when a conventional CI is applied. An extension of the CI to 18 months resulted in an average milk yield of 10.9 kg, and the primiparous cows, that are more yield persistent, still yielded 14.1 kg milk at the time for drying off. These milk yields show that an extension of the CI results in more suitable production levels at the time for drying off. In addition to that the result demonstrates that the primiparous cows managed the extended lactation better.

Economic aspects

With modern production levels, there are weighty reasons for an extension of the CI. However, if there are to be any changes in the current production system there must also be an economical advantage, or at least no disadvantage, with an extended CI. The experimental work included in this thesis indicates that an extension of the CI could be economically advantageous. With the knowledge that a delay in the time for insemination results in a less rapid decline in milk yield, it can be concluded that cows with an extended lactation are more yield persistent, and in combination with an increased MF, the effects on the persistency is even greater. According to Dekkers, Ten Hag & Weersink (1998), the economic value of persistency consists of four main components: the effects of persistency on health costs, reproductive performance, feed costs and differential milk production for non-standard lactation length. The results in this thesis, show that an extended lactation can fulfil these components.

According to Knight (1997), the aspect of the cows' lifetime productivity has been almost totally disregarded because of the use of 305 day yield statistics. When 305-days lactation yield is one of the traits in the breeding goal, the economic value of persistency and the fact that lactation length often differ from 305-days is not considered (Dekkers, Ten Hag & Weersink, 1998). When lactation length is greater than 305 days and for a given 305-day yield, cows with higher persistency will have higher lactation yields than cows with low persistency, but lower yields in short lactations. The economic consequences of a short lifetime can be of great importance. In Sweden, the average productive life of dairy cows are only 2.6 years (Swedish Dairy Association, 2002), and this result in high expenses for recruitment. A system with extended calving intervals results in fewer calves, but with the new reproductive technologies available that result in many offspring from one mother, this is a smaller problem. My opinion is that the system with an extended CI, is a less intensive system with fewer risk periods for the cow, and would increase both the animal welfare and the lifetime of the cow. Therefore, this system should also be defensible economically, and I hope that a change in our present system is not far away.

Conclusions

- Cows with an extended calving interval have as high production, expressed as ECM/day of calving interval, as cows with a conventional calving interval. An increased milking frequency in combination with an extension of the calving interval resulted in the highest ECM/day of calving interval of all four groups. Milking 3x resulted in lower concentrations of fat and protein.

- Milking 3x per day resulted in longer lactations in cows with 12 month calving intervals, but in cows with 18 month calving intervals, there were no differences in lactation length when milking 2x or 3x.

- An extended calving interval in combination with 3x milking, resulted in as long dry period as for the cows with a 12 months calving interval, whereas milking 2x led to a prolonged dry period in cows with 18 months calving interval.

- The primiparous cows had a higher production of ECM, longer lactation and shorter dry period in the extended calving interval than the multiparous cows. An extension of the calving interval for the primiparous cows is therefore recommended.

- An extension of the calving interval results in better feed efficiency compared to the conventional system.

- There was no difference in the response in somatic cell count at the end of the prolonged lactation compared to the conventional interval, and the contents of somatic cells were desirably low throughout the extended lactation.

- An increased milking frequency may contribute to increased comfort in high producing dairy cows.

Populärvetenskaplig sammanfattning

Kornas hälsa och förmåga att producera mjölk, påverkas framför allt av genetiska faktorer, utfodring och skötsel. Dagens intensiva mjölkproduktion ställer enormt höga krav på våra mjölkkor, och alltfler börjar ifrågasätta om det system vi har, med ett kalvningsintervall runt 12 månader och mjölkning två gånger om dagen, är det mest gynnsamma. Självklart är detta intressant ur ett ekonomiskt perspektiv, och det ställs också krav från både lagen och konsumenterna, att hanteringen av mjölkkorna är gynnsamma för djuren. I Djurskyddslagens 2 § står det att ”Djur skall behandlas väl och skyddas mot onödigt lidande och sjukdom”. Det kan diskuteras vad detta innebär, och om vårt produktionssystem som sådant medför onödigt lidande. Målet bör dock vara att hög produktion inte sker på bekostnad av djurens välbefinnade.

Under tiden närmast efter kalvningen täcks inte behovet av näringsämnen för mjölkproduktion av foderintaget, vilket leder till en negativ näringsbalans och kon måste bryta ned kroppsreserver för att täcka behovet för mjölkproduktion. Detta innebär stora påfrestningar på ämnesomsättningen och medför en ökad risk för flera metaboliska sjukdomar, och man räknar med att de första 45 dagarna av laktationen står för 60% av alla kostnader för sjukdomar. Det är dels sjukdomar som är förknippade med kalvningen, som kvarbliven efterbörd och kalvningsförlamning, men även den största andelen juverinflammationer uppträder inom två veckor efter kalvningen. Dessutom innebär en hög avkastning att vid tidpunkten för sinläggning har många kor fortfarande en hög produktion, med ökade problem vid sinläggningen och ökad antibiotikaanvändning till följd. Ett förlängt kalvningsintervall innebär att en mindre del av kons livslängd blir kopplat till tiden kring kalvning, och dessutom skulle sinläggningen underlättas.

En förutsättning för att kunna förlänga kalvningsintervallet, är att man lyckas uppnå en uthållig laktation. Det finns flera faktorer som inverkar på uthålligheten i laktationen, bland annat dräktighetsstadium, näringsstatus och om det är en ko i sin första laktation eller en äldre ko. En faktor som är relativt enkel att påverka och som har visat öka uthålligheten i laktationen är mer frekvent mjölkning. Då antalet mjölkningar ökas från två till tre gånger om dagen ökar avkastningen vanligen mellan 10-15%, vilket medför en mer uthållig laktation. Om kalvningsintervallet förlängs, hur påverkas då effektiviteten i produktionen med mjölkning 2 gånger jämfört med 3 gånger per dag?

Denna frågeställning var bakgrunden till ett fyrårigt forskningsprojekt som genomförts vid Kungsängens forskningscentrum, SLU. I försöket har effekterna av ett förlängt kalvningsintervall studerats, i kombination med mjölkning två eller tre gånger om dagen. Totalt ingick 72 kor i försöket, alla av SRB ras, där hälften styrdes mot ett traditionellt 12 månaders kalvningsintervall och hälften mot ett förlängt intervall på 18 månader. Inom båda kalvningsintervallen mjölkades hälften av korna 2 gånger (grupp 12-2 och 18-2) och andra hälften 3 gånger om dagen (grupp 12-3 och 18-3). Inom grupperna var det jämn fördelning mellan förstakalvare och äldre kor. Intervallet mellan mjölkningarna var 9 och 15 timmar vid mjölkning 2 gånger om dagen, medan intervallet mellan mjölkningarna var 8 timmar för de som mjölkades 3 gånger om dagen. I detta försök studerades om det blev några skillnader i mjölkproduktion, laktationens och sinperiodens längd, foderkonsumtion och fodereffektivitet samt mjölkens innehåll av celler mellan de olika grupperna. Dessutom studerades mjölkningsfrekvensens inverkan på grundläggande beteenden, exempelvis inverkan på kornas totala liggtid samt sätt att lägga och resa sig.

Effekter på produktionen i de olika grupperna utvärderades genom att mängden energikorrigerad mjölk per dag, ECM/dag inom kalvningsintervallet, beräknades (Tabell 1). Detta mått på produktionskapaciteten möjliggör en jämförelse mellan de olika intervallen, eftersom den tar hänsyn till både laktationens och sinperiodens längd. Grupp 18-3 hade lika lång sinperiod som de bägge grupperna med 12 månaders kalvningsintervall, medan sinperioden blev förlängd i grupp 18-2 beroende på att dessa kor hade låg avkastning i slutet av laktationen. Mjölkning tre gånger om dagen var alltså en viktig faktor för att få en uthållig laktation hos korna med 18 månaders kalvningsintervall.

De kor som var i sin första laktation, förstakalvarna, hade högre produktion av kg ECM och kg ECM/dag inom kalvningsintervallet, dessutom en längre laktation och en kortare sinperiod än de äldre korna. Förstakalvare har en jämnare produktion under sin laktation, och därmed en mer uthållig laktation. Vidare visade resultaten att konsumtionen av foder var lägre för bägge grupperna med förlängt intervall, som en följd av att de har fler dagar med lägre produktion. Korna i grupp 18-3 hade det bästa foderutnyttjandet per producerad kg ECM, dvs det gick åt mindre mängd energi per kg ECM.

Mjölkens innehåll av celler stiger naturligt i slutet av laktationen och därför är det viktigt att vara uppmärksam på att innehållet inte ökar mer i slutet av en förlängd laktation än i en normallång laktation. Mjölkning 3 gånger om dagen medförde en sänkning av cellerna i grupp 12-3 under de sista 10 veckorna av laktationen jämfört med 12-2, men en motsvarande sänkning fanns inte hos grupp 18-3 jämfört med 18-2. Trots detta var det inte några säkra skillnader mellan de båda grupperna med 18 månaders kalvningsintervall och 12-2. Med andra ord ger inte en förlängning av kalvningsintervallet högre antal celler i mjölken i slutet av laktationen.

Sist, men inte minst, medförde en ökning av mjölkningsfrekvensen från två till tre gånger om dagen att vissa grundläggande beteenden utfördes i större utsträckning De kor som mjölkades 3 gånger om dagen låg ned längre tid under timmarna före morgonmjölkningen, vilket förmodligen berodde på det lägre juvertrycket som dessa kor hade tack vare den mer frekventa mjölkningen. Detta kan påverka juverhälsan. Försök har visat att kor som hindras att ligga ner, till exempel av obehag av ett högt juvertryck, tar igen detta med att lägga sig när tillfälle ges. Detta skulle innebära att korna som mjölkas 2 gånger om dagen lägger sig ner direkt efter mjölkningen. Det är inte önskvärt, eftersom spenkanalen fortfarande är öppen ungefär 30 minuter efter mjölkning, och därmed är det lätt för bakterier att ta sig in i juvret och orsaka juverinflammationer. Mjölkning 3 gånger om dagen med jämnt intervall mellan mjölkningarna skulle därmed kunna innebära mindre risk för juverinflammationer.

Sammantaget visar resultaten i denna avhandling att produktionen kan upprätthållas med ett förlängt kalvningsintervall, och att kombinationen med mjölkning 3 gånger per dag ger den högsta produktionen och den bästa fodereffektiviteten av alla grupper. Ett system med ett förlängt kalvningsintervall är ett system som kan hävda sig ur lönsamhetssynpunkt, särskilt om det kombineras med mjölkning 3 gånger om dagen. Vidare visades att kor som är i sin första laktation har bättre förutsättningar för att klara av ett förlängt kalvningsintervall, eftersom de har en uthålligare avkastning. Eftersom systemet innebär färre dagar i riskperioden kring kalvning, medför ett förlängt kalvningsintervall att hög produktion går att förena med bra välfärd för kon.

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Acknowledgements

The Swedish Farmer's Foundation for Agricultural Research, and the intradisiplinary research program 'Animal production, -health and –welfare' at the Faculty of Agriculture, Landscape Planning and Horticulture, Swedish University of Agricultural Sciences, are gratefully acknowledged for the financial support that made it possible to perform these studies.

Det krävs många personer för att ge en person möjligheten och kraften att orka skriva en liten bok - tack alla Ni, för stort och smått! Jag vill dock rikta mitt speciella tack till:

Först av alla, min fantastiske huvudhandledare docent Jan Bertilsson, tillika den ende handledare som jag har lyckats behålla…..! För Ditt osvikliga engagemang och Din 100%-iga uppbackning! Tack även för Din enastående förmåga att hitta Den Viktiga Siffran i en aldrig sinande ström av sådana. Och, inte minst, för att Du tror på mig, tror jag, och för att Du delar med Dig av Dina kunskaper, vet jag!

Utan docent Kerstin Svennersten-Sjaunja, hade det jag inte jobbat i detta roliga projekt! Tack för att Du sökte, och fick, pengar till projektet och för att Du är en idékläckare utan dess like!

En handledare som jag tyvärr inte lyckades behålla är docent Ingrid Redbo. Tack för att Du har fått mig att förstå vikten av att förstå (hur djur gör), och för Dina kloka synpunkter i stort och smått!

Stort tack också till docent Karin Östensson, för ovärderlig hjälp vid författandet av cellartikeln, och för att mötena med Dig aldrig har varit tråkiga, trots att ämnet för mötena är något så föga upphetsande som celler!

Docent Ulf Emanuelson lyckades jag inte heller behålla i min handledargrupp…. Stort tack för att Du var med och styrde upp mig i början av min doktorandtid!

Tack även till statsagronom Jan Philipsson för att Du startade och ledde temaprogrammet 'Animal production, -health and –welfare' med den äran!

Givetvis vill jag tacka all personal i Ladugården, för att Ni skötte korna och höll i tåtarna, och för att Ni inte sprang i vägen för mina videokameror!

Tack också till Märta Blomkvist som lyckas hålla reda på vem-som-är-vem bland alla kor i ladugården och Ladislav Simko för att Du lyckades hålla reda på detsamma bland mjölkproverna!

All hjälp som jag fick av alla Er på laboratoriet på Kungsängen glömmes icke bort! Tack för den, och för att Ni vågade låta mig härja fritt i era lokaler! Tack också till Gunilla Drugge-Boholm för mjölkanalyser.

Statsagronom Erling Burstedt, min chef på Kungsängen och numera även prefekt för institutionen. Tack för att Du erbjuder en trevlig och stimulerande miljö att arbeta i och för att Du är lyhörd för en timid doktorands önskemål!

Dr Maria Neil, studierektor för doktoranderna vid vår institution. Tack för att Du på ett föredömligt sätt har lotsat mig genom alla papper och krav som ska fyllas och uppfyllas, och för Ditt alltid trevliga bemötande!

Alla kollegor på institutionen och, framför allt, på Kungsängen. Den atmosfär som erbjuds på Kungsängen - tack vare Er alla - är en fröjd att arbeta i! Det är alltid spännande att stega korridoren ner för att se vad som erbjuds i fikarummet, både i form av förtäring och diskussioner!

Anne-Marie Karlsson, sekreterare och spindel i nätet. För att Du alltid är positiv och medkännande, och för att Du har lyckats hålla reda på mina ledigheter och när jag måste börja jobba igen….!

Dr Ulla Engstrand, vad hade doktorandlivet varit utan Dig och Dina kunskaper i statistik? Enkelt, det hade varit bra mycket tråkigare, bra mycket svårare och bra mycket längre! Stort tack!

Gunnar Pettersson, tack för att man alltid kan bolla idéer med Dig och för Dina enorma, och fantastiskt användbara, kunskaper i SAS!

Ellen Ekdahl, för att Du alltid rycker ut när jag kommer skrikande i korridoren! Vissa människor sägs ha djuröga, men Du har definitivt maskinöga! Eftersom jag och maskiner inte talar samma språk, är det värdefullt att känna en tolk!

Docent Richard Hopkins för att Du omvandlade min svengelska till engelska, och för att Du är så extremt snabb och hjälpsam!

Professor Yvonne Ridderstråle, Dr Maria Åkerlind och Dr Annsofie Wahlström för att Ni ingick i den kreativa skrivargrupp som vi bildade. Det vill säga, Ni var kreativa - jag tittade mest på video…

Dr Ingrid Mossberg, min mentor och kontakt med livet utanför! Tack för att Du har tagit Dig an mig och stöttat mig, och för alla kloka synpunkter på allt mellan himmel och jord!

Alla doktorandkollegor under årens gång, Ni börjar bli rätt många nu! Framförallt vill jag tacka Dr Maria Åkerlind, för att Du förgyllde min dagar i början av min utbildning med vänskap och godis på oväntade ställen, Ewa Wredle för att Du har gjort mitt sista doktorandår till ett år att minnas – Din soffa är ju ett dessutom ett klart lyft för Ditt rum, Martin Odensten, för att Du är en allmänt trevlig person och delar mitt TV-intresse, Torsten Eriksson, för att Du, med orubbat lugn, alltid tar Dig tid att hjälpa mig med små och stora datorproblem, som för Dig verkar vara obefintliga!

Kicki Markusson för att Du hjälpte mig att genomföra mitt första försök, för alla tidiga mornar Du delade med mig och för Din positiva inställning!

Adrienne Ekelund, för Din vänskap - Du är faktiskt en av få som har känt mig så länge att Du kan intyga att jag kan mjölka en ko, inte bara räkna (på) dem!

Anna Nilsson för all värdefull hjälp mot slutet, det gjorde skillnad! Tänk vad små, små ord kan göra stora saker, det finns weighty reasons att väga dem på guldvåg!

Dr Anki Roth, för att Du delar allt mellan himmel och jord med mig, det uppskattar jag! För allt stöd genom åren, inte minst när vi sysslade med tunga saker…..

Dr Tina Lindström, för att Du delade alla mina tankar och promenader under Din tid på institutionen, och för Din klarsynthet och förmåga att ge mig perspektiv på min tillvaro.

Dr Sigrid Agenäs, för Du läser manus som ingen annan, och vågar kritisera desamma som ingen annan! För Din diskussionsbenägenhet, klarsynthet och Dina synpunkter på viktiga saker. Och inte minst för Din vänskap och all uppmuntran - i form av ord och handling!

Dr Annsofie Wahlström, för Din vänskap och Ditt stöd genom alla åren, för att Du gav mig en andra chans att göra ett första intryck! Och för Din förmåga att ifrågasätta saker som kan tyckas självklara – det är extremt givande!

Dessutom ett jättetack till tecknaren Jan Berglin, för att Du åtog Dig att teckna mig i mitt desperataste tillstånd! Dina träffsäkra teckningar är oslagbara, jag bugar och bockar! Kvirrevitt!

Mina föräldrar Mona och Thomas Lundblad, som har ingjutit i mig att ingenting är omöjligt, och för all hjälp - såväl ekonomisk som fysisk. Inte minst för alla promenader med Eskil, jag får väl hjälpa Er med nya höftleder vad det lider! Mina kära syskon Åsa, Jenny och Anders och deras familjer, som står för det sociala skyddsnätet i mitt liv, för att Ni alltid finns till hands när Ni behövs på ett eller annat sätt!

Claes, för att Du har valt att dela Dina dagar med mig, även de genomskinliga. För Ditt stöd och Din enastående förmåga att balansera mig när jag med mitt humör, hrrrmm nåja, åker berg-och-dalbana genom livet! Och så Kajsa och Mårten, utan Er hade detta arbete förmodligen varit klart långt tidigare, men det hade tveklöst varit oändligt mycket tråkigare!