The effect of dry period length on milk production, health and fertility in two cow breeds

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Cover: ”Den 18 november. Fick vingar och kunde flyga. Flög till solen. Flög ovanför solen och ovanför alla regnbågar och stjärnbilder och där låg paradiset och det var en hage… (ur ”Ur en kos dagbok” av Beppe Wolgers och Olof Landström, Rabén & Sjögren, 1973) Copyright Olof Landström.

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Abstract

The transition from not producing milk during the dry period to the huge nutrient demands as milk production rapidly increases after parturition imposes significant metabolic strain on high-yielding dairy cows. The drying-off procedure is also demanding and high milk yield at dry-off increases the risk of mastitis and metabolic problems. A dry period of approximately 8 weeks is generally recommended, but a shorter dry period might reduce the metabolic strain on high-yielding cows at dry-off and in early lactation. This thesis investigated the effects of different dry period lengths on the health and performance of two cow breeds.

An experimental trial was conducted in which multiparous Swedish Red (n=43) and Swedish Holstein (n=34) cows were blocked by breed and parity, and then randomly allocated to two different treatments; a conventional DP of 8 weeks (8W) or a short DP of 4 weeks DP (4W). An observational study was performed using data on 78 577 lactations from cows enrolled in the Swedish Official Milk Recording Scheme.

The experimental and observational studies both showed that shortening the dry period resulted in a reduction in milk yield during the following lactation. However, when the milk produced during the extended lactation was added, the difference diminished. Feed intake was virtually identical between cows subjected to a short and conventional dry period. The reduced milk production while feed intake was maintained in 4W cows improved their energy balance markedly. Cyclicity and commencement of luteal activity was not affected by dry period length in the experimental study and no effects of dry period on health and fertility traits were observed in the observational study. However, culling rate was lower in cows with a shorter dry period. Cows of the different breeds and of different parities responded similarly to changes in dry period. The volume of colostrum was reduced, but the protein content was higher, in cows with a short dry period. The Immunoglobulin G status of calves was not affected by the dry period of their dam. Tests on dry period >70 days showed it was not favourable, due to low milk production, increased risk of culling and decreased fertility.

In conclusion, this thesis shows that energy balance and metabolic status improve, but not health and fertility, in cows subjected to a short dry period. The reduction in milk yield after calving is compensated for by additional yield prior to calving.

*Keywords:*Dry period length, feed efficiency, milk yield, metabolism, fertility, colostrum

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Anpassad sintid hos mjölkkor - inverkan på mjölkavkastning, djurhälsa och fertilitet

Sammanfattning

Övergången från att inte producera mjölk alls under sintiden till den snabba ökningen i mjölkproduktion efter kalvning medför att näringsbehovet kraftigt ökar, det i sin tur orsakar en betydande metabolisk påfrestning på den högavkastande mjölkkon. Själva sinläggningen är också krävande och en hög mjölkavkastning vid sinläggningen ökar risken för juverinflammation och metaboliska problem. Generellt rekommenderas en sintid om cirka 8 veckor, emellertid kan en förkortad sintid minska risken för metaboliska störningar hos högavkastande kor både vid sinläggning och i tidig laktation. Det övergripande syftet med avhandlingen var att undersöka hur olika sintidslängder påverkar mjölkavkastning, hälsa och fertilitet hos mjölkkor. Denna avhandling är baserad på en experimentell studie och en observationsstudie baserad på 78 577 laktationer från kor anslutna till det svenska officiella mjölkregistreringssystemet, kokontrollen. I den experimentella studien deltog kor av olika ras (svensk röd och vit boskap, n = 43, och svensk Holstein, n = 34) och paritet och allokerades sedan slumpmässigt till två olika behandlingar; en konventionell sintid om 8 veckor eller en kort sintid om 4 veckor. Kor med kort sintid hade lägre mjölkavkastning i tidig laktation i både den experimentella- och observationsstudien. Men när mjölken som producerades innan sinläggningen räknades med minskade emellertid skillnaden. Foderintaget var praktiskt taget identiskt mellan kor som utsattes för kort respektive konventionell sintid. Den låga mjölkavkastningen och bibehållna foderintaget hos 4 veckors korna förbättrade energibalansen markant. Det var ingen skillnad i kornas förmåga att komma igång med sina brunstcykler igen efter kalvning och inga andra hälso- eller fertilitetskillnader kunde ses i den experimentella studien mellan de två sintidsgrupperna. Kor av olika raser och kor av olika ålder svarade lika på förändringar i sintidslängd. Volymen råmjölk minskade men proteininnehållet var högre hos kor med en kort sintid. Kalvens IgG-status påverkades inte av mödrarnas sintidslängd. En sintid längre än 70 dagar var inte gynnsam på grund av låg mjölkproduktion, ökad risk för utslagning och försämrad fertilitet.

Sammanfattningsvis visar denna avhandling att energibalansen och metabolismstatus förbättrades men inte hälsa och fertilitet hos kor med kort sintid. Mjölkavkastningen efter kalvningen minskade i tidig laktation men kompenserades av den extra mjölk som producerades innan kalvning.

Keywords: sintidslängd, fodereffektivitet, mjölkavkastning, metabolism, fertilitet, råmjölk

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Några ord om kor

Ost. Smör. Grädde. Filmjölk. Yoghurt. Entrecôte. Mjölkchoklad. Café au lait. Allt jag älskar att äta kommer från en ko. Jag älskar att i den svala friska vårkvällen höra fågelsången, känna lukten från slånbärsbuskarna, ljudet från betande ko-mular, ett stamp och en svansviftning. Känna glädjen i allt som vaknar till liv. Luta huvudet mot en varm ko som tagit paus för att idissla, känna det rytmiska tuggandet genom hela hennes kropp. Njuta av doft från kattfot, mandelblom och gullviva (var han månne i en kohage, Rönnerdahl?). Något som snabbt sveper förbi, en ladusvala, eller en var det en fladdermus? Jag är så glad över att mina barn får uppleva det. Om jag får barnbarn så hoppas jag innerligt att de också får göra det.

Och så älskar jag lukten av ensilage.

Så TACK Majros, Baronessa, Blomma, Bönan, Donna, Eda, Lilja, Hjärtros, Kronros, Rosa, Dagny, Brita, Fanny, Nancy, Nora, Märta, Ofelia, Perla, Prima, Sara, Stjärna, Eva, och alla ni andra 309 978 fantastiska, snälla, dumma, söta, kloka, fula, tjocka, smala, mjuka, varma, tillgivna, sparkiga, råmande, rogivande, idisslande, illa-luktande, go-luktande, gulliga svenska kor för allt ni förser oss med.

Jag är er evigt tacksam.

Dedication

Till mamma, tack för allt ♥

Cows are delicious.
Chris O'Hara

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Andrée O'Hara E., Omazic A., Olsson I., Båge R., Emanuelson U. & Holtenius K. (2018). Effects of dry period length on milk yield and energy balance in two cow breeds. *Animal* 12 (3), 508-514.

II Andrée O'Hara E., Båge R., Emanuelson U. & Holtenius K. (2019). Effects of dry period length on metabolic status, fertility, udder health and colostrum production in two cow breeds. *Journal of Dairy Science* 102 (1), 595-606.

III Andrée O'Hara E., Holtenius K., Båge R., von Brömssen C. & Emanuelson U. Effects of dry period length on milk yield, health, and fertility in two dairy cow breeds - an observational study. (submitted to *Preventive Veterinary Medicine*)

Papers I-II are reproduced with the permission of the publishers.

The contribution of Elisabeth Andrée O'Hara to the papers included in this thesis was as follows:

I. Performed a major part of the study during year 2. Performed most of the statistical analysis and wrote the manuscript with regular input from the supervisors. Corresponded with the journal and revised the article under supervision.

II. Performed a major part of the study during year 2. Performed most of the statistical analysis and wrote the manuscript with regular input from the supervisors. Corresponded with the journal and revised the article under supervision.

III. Was involved in planning the study. Performed the majority of the data analysis and wrote the manuscript with regular input from the supervisors.

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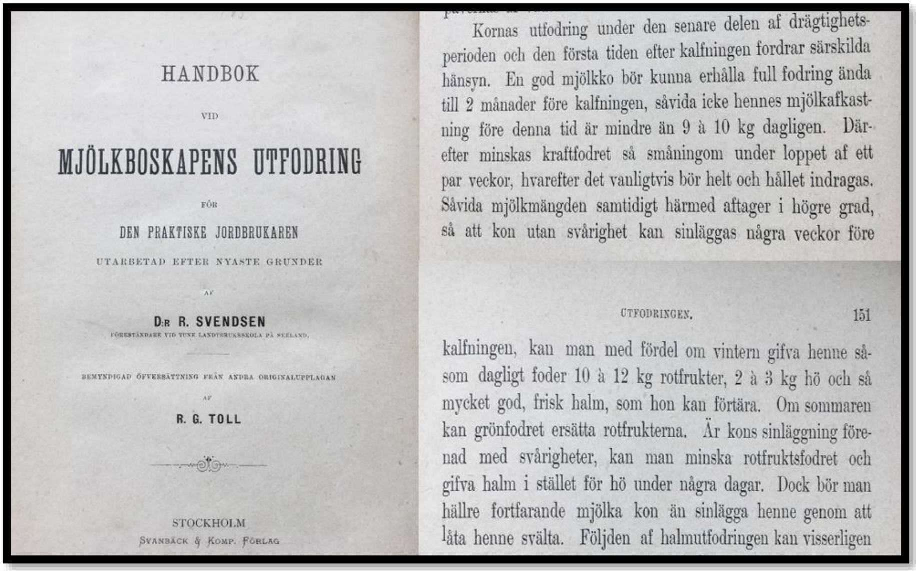
Abbreviations

4W	4 weeks
8W	8 weeks
AI	Artificial Insemination
BCS	Body Condition Score
BHB	β-hydroxybutyrate
CLA	Commencement of Luteal Activity
DIM	Days in Milk
DMI	Dry Matter Intake
DP	Dry Period
DPL	Dry Period Length
ECM	Energy-corrected Milk
IgG	Immunoglobulin G
IGF-I	Insulin Growth Factor I
IMI	Intramammary Infection
MEC	Mammary Epithelial Cells
NEB	Negative Energy Balance
NEFA	Non-esterified Fatty Acids
PV30	Pregnancy rate within the first 30 days after the herd's predicted voluntary waiting period (defined as DIM when 10% of cows in the herd are inseminated)
RFI	Residual Feed Intake
RQUICKI	Revised Quantitative Insulin Sensitive Check Index
SCC	Somatic Cell Count
SH	Swedish Holstein (breed)
SOMRS	Swedish Official Milk Recording Scheme
SR	Swedish Red (breed)

1 Background



HANDBOK

VID

MJÖLKBOSKAPENS UTFODRING

FÖR

DEN PRAKTISKE JORDBRUKAREN

UTARBETAD EFTER NYASTE GRUNDER

AF

D:R R. SVENDSEN

FÖRESTÅNDARE VID TUNE LANDTBRUKSSKOLA PÅ SEELAND.

BEMYNDIGAD ÖFVERSÄTTNING FRÅN ANDRA ORIGINALUPPLAGAN

AF

R. G. TOLL

STOCKHOLM

SVANBÄCK & KOMP. FÖRLAG

Kornas utfodring under den senare delen af drägtighetsperioden och den första tiden efter kalfningen fordrar särskilda hänsyn. En god mjölkko bör kunna erhålla full fodring ända till 2 månader före kalfningen, såvida icke hennes mjölkafkastning före denna tid är mindre än 9 à 10 kg dagligen. Därefter minskas kraftfodret så småningom under loppet af ett par veckor, hvarefter det vanligtvis bör helt och hållet indragas. Såvida mjölkmängden samtidigt härmed aftager i högre grad, så att kon utan svårighet kan sinläggas några veckor före

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kalfningen, kan man med fördel om vintern gifva henne såsom dagligt foder 10 à 12 kg rotfrukter, 2 à 3 kg hö och så mycket god, frisk halm, som hon kan förtära. Om sommaren kan grönfodret ersätta rotfrukterna. Är kons sinläggning förenad med svårigheter, kan man minska rotfruktsfodret och gifva halm i stället för hö under några dagar. Dock bör man hällre fortfarande mjölka kon än sinlägga henne genom att låta henne svälta. Följden af halmutfodringen kan visserligen

Figure 1. A dry period of only a few weeks was applied in 1889. This "*Handbook of Feeding Dairy Cattle*" was originally written by R. Svendsen and translated by R.G. Toll.

1.1 Swedish Milk Production

As in many industrialised countries, Swedish milk production has been transformed from small-scale farms with a few cows to large-scale units with great numbers of animals per herd. Under animal welfare regulations introduced in 1988, cows in Sweden must be permitted to graze outdoors during the summer months (SFS 2019:66). It is possible that this has to some extent inhibited the introduction of the very large dairy units seen in other countries, since the milk producer has to have pasture near the milking parlour. The number of dairy cows in Sweden has decreased in recent decades, from 428 000 in 2000 to 310 000 in 2018 (Swedish Board of Agriculture, 2019). The number of dairy herds also declined in that period, from 12 700 in 2000 to 3500 in 2018. The number of cows per herd increased three-fold during the period, from 33 to 91 cows per herd and, although milk production per cow increased, total milk production in Sweden decreased, from 3 300 000 ton in 2000 to 2 700 000 ton in 2018 (Swedish Board of Agriculture, 2019). Around 80% of all dairy cows in Sweden are enrolled in the Swedish Official Milk Recording Scheme (SOMRS), which records milk production. In 2000, the average annual energy-corrected milk (ECM) production per cow was 8600 kg and in 2018 it was 10 100 kg (VÄXA Sverige, 2019a).

There are two main dairy breeds in Sweden, Swedish Holstein (SH) and Swedish Red (SR). In 2018, approximately 56% of the cows in the SOMRS were of the SH breed and they produced 10 493 kg ECM per cow, while approximately 35% were of the SR breed and they produced 9703 kg ECM per cow (VÄXA Sverige, 2019a). Until recently, the SH cow breed was intensively selected world-wide for milk production traits, while the breeding goals in Sweden for several decades have focused on high milk yields and functional traits like health and fertility for both SH and SR cows (Eriksson *et al.*, 2017). However, the SH breed is still influenced by continuous imports of genetic material. Apart from the yield and functional traits, the Swedish breeding goals for the SR breed include calf vitality and profitable meat production (NAV, 2019).

Disease incidence data (number of reported disease events per 100 completed/interrupted lactations) in dairy cows enrolled in the SOMRS in recording year 2017/18 indicate a lower incidence for SR than SH cows (SH=24.7, SR=19.1) (VÄXA Sverige, 2018). The disease incidence was distributed as follows in that recording year: clinical mastitis (SH=10.3, SR=8.3), leg and hoof diseases (SH=3.1, SR=2.5), feeding-related diseases (SH=1.3, SR=1.0), paresis (SH=2.5, SR=1.7), retained placenta (SH=0.7, SR=0.6), metritis (SH=1.3, SR=0.7), calving assistance (SH=0.3, SR=0.3) and miscellaneous diseases (SH=5.1, SR=4.0).

The SOMRS also provides information about the type of management system used. New barns, built from 2007 onward, have to be loose housing systems and 75% of the cows in the SOMRS are kept in loose housing systems, while the rest are kept in tied stalls. Of the cows in the SOMRS, 41% are milked in automatic milking systems and 18% are kept in organically managed herds (VÄXA Sverige, 2019a).

A typical lactation year for Swedish cows is presented in Figure 2. The average age at first calving is 27 months for cows of the SR breed and 27.4 months for cows of the SH breed. The average calving interval is 12.9 months and 13.3 months for SR and SH cows, respectively. The cows are inseminated at around day 83 after calving (VÄXA Sverige, 2019a). One of the larger health and management organisations in Sweden recommends a dry period length (DPL) of 6-10 weeks and the recommended procedure for drying off is to reduce feed during the week before dry-off. If the cow is producing 15-25 kg/day in the week before dry-off, the routine is to not milk on the first day, milk once on the second day, milk once on the fifth day and then not milk again (VÄXA Sverige, 2019b). However, the routine may vary from herd to herd.

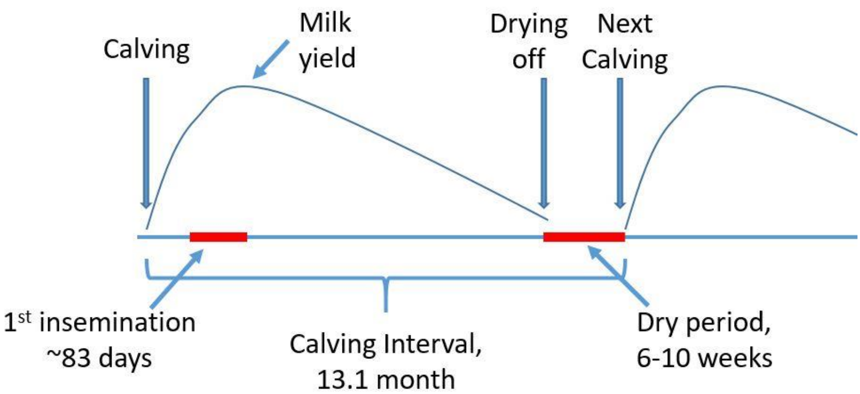

Figure 2. Schematic diagram of the lactation year in the dairy cow, illustrating the calving interval and dry period commonly applied in Sweden (VÄXA Sverige, 2019).

1.2 Dry Period Length and Milk Yield

The dry period (DP) is generally recommended to be 6-8 weeks, which derives from recommendations as far back as the early 1900s (Arnold & Becker, 1936). In recent decades, however, the DPL has attracted renewed interest and it has been debated whether the recommendation of 6-8 weeks is still accurate. The underlying data for this debate are from early studies by Arnold and Becker (1936) and studies in the 1970s and 1980s (Schaeffer & Henderson, 1972; Dias & Allaire, 1982). These studies all conclude that a DP of 6-8 weeks is optimal when considering milk yield in the following lactation.

Modern experimental studies have shown different results regarding milk yield after a shortened (28-34 d) or omitted DP. Some studies report that postpartum milk yield is not affected by a shortened DP (Santschi *et al*., 2011b), but a majority of the relevant studies report a decrease in milk production of 1% up to 32% when shortening or omitting the DP (Rastani *et al*., 2005; Kuhn *et al*., 2007; Watters *et al*., 2008; Steeneveld *et al*., 2013). The reasons for the reduction in milk production in the following lactation are still not fully understood, but several hypotheses have been proposed (Pezeshki *et al*., 2010; Collier *et al*., 2012). The first, put forward by Arnold and Becker (1936), suggests that cows with a short DP produce less milk because of insufficient body reserves due to having too short a non-lactation time to restore body weight and body condition. However, Swanson (1965) and Lotan and Adler (1976) showed that, despite an increase in body weight during the DP, cows with a short DP still produced less milk than cows with a conventional DP, thus refuting the theory of Arnold and Becker. Smith *et al.* (1967) hypothesised that cows with a short DP produce less milk because of the influence of galactopoietic hormones but, after performing experimental studies, rejected that hypothesis. It was then suggested that the reduction in milk yield is due to a reduced number of mammary epithelial cells (MEC). This theory was also disproven, this time by Swanson *et al*. (1967) and Capuco *et al*. (1997). Those studies showed that there was no difference in DNA concentration, dry fat-free tissue weight, total DNA content or number of alveoli per tissue section in quarters from cows with a six-week difference in DPL. Another hypothesis, proposed by Capuco *et al.* (1997), is that the reduction in milk yield is caused by the mammary gland not being given enough time to promote cell turnover and replace senescent MEC during late gestation.

Later, Pezeshki *et al*. (2010) attributed the reduced milk yield in cows with a shortened DP to less developed mammary glands (Figure 3). The early involution of the mammary gland may be inhibited when the cow is dried off later in lactation and closer to parturition. The lower milk yield at dry-off may reduce the physical distension of the mammary epithelium. The presence of pro-apoptotic factors in milk may thus be reduced during milk stasis in a later state of lactation. The progressing pregnancy may also influence the proliferation and involution in the mammary gland by the increasing presence of lactogenic and mammogenic hormones, in comparison with that in cows with a conventional DP (Pezeshki *et al*., 2010) (Figure 3).

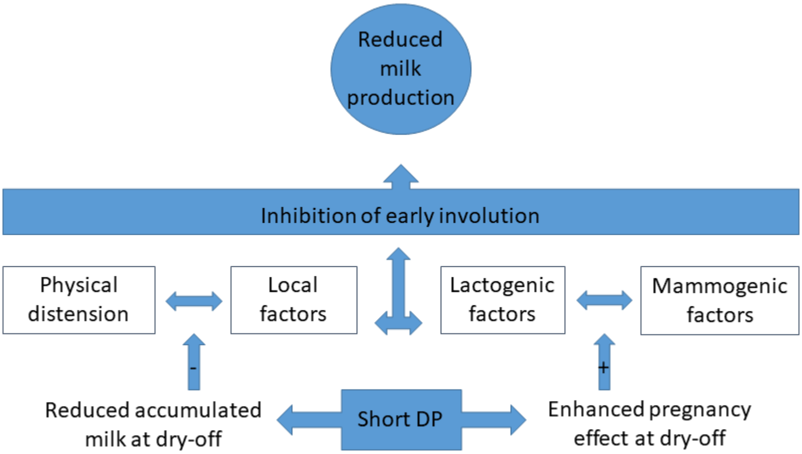

Figure 3. Illustration of a hypothesis for why milk yield is reduced in cows with a shortened dry period (DP). Modified from Pezeshki *et al*. (2010).

Genetic progress and improved feeding and management systems have contributed to a dramatic increase in milk production in (Swedish) dairy cows. Current Swedish recommendations for DPL may not be relevant for the dairy cow breeds of today. Previous studies generally do not account for the reason to why the cow had a short DP. Rather, they evaluate the effect on milk yield of cows with pre-term parturition, spontaneous abortion, twin births and missing breeding or dry-off dates in a retrospective perspective (Bachman & Scharier, 2003). Moreover, the low number of cows used in the studies limits the possibilities to verify small changes in milk production (Pezeshki *et al*., 2010). Furthermore, the additional milk produced during the extended lactation prepartum is not included in the milk yield calculations in the early studies. According to Capuco *et al*. (1997), the process of mammary involution is completed by day 25 and sufficient proliferation has occurred by that time. It may thus be reasonable to question whether a 60-day DP is required for all cows.

1.3 Milk Composition

Milk composition varies over the lactation to meet the requirements of the growing calf. However, milk is also harvested for human consumption and the properties of the milk are crucial for its industrial use for different dairy products, such as cheese and yogurt. Milk composition also determines the price paid to the milk producer. In rough terms, milk contains 5% lactose, 4%

fat, 3% protein and 87% water, plus vitamins and minerals. The composition of the milk is affected by the state of lactation, but also by pregnancy, calving interval, genetics and physiology of the cow, environment, milking routines and nutrition (Jenkins & McGuire, 2010).

Lactose is a disaccharide consisting of one glucose molecule and one galactose molecule. Lactose, which is highly osmotic, is formed from glucose in the Golgi apparatus of the MEC. It contributes about 50% of the osmotic pressure of cow's milk. Milk secretion is mainly driven by mammary lactose synthesis (Linzell & Peaker, 1971). The daily variation in lactose concentration is low, the coefficient of variation being 0.9% (Forsbäck *et al*., 2010). The length of the DP could also be a factor influencing the composition of the milk. However, in most studies lactose content has been shown not to be affected by DP length (van Knegsel *et al*., 2014; Shoshani *et al*., 2014).

Milk fat consists to 97-98% of triglycerides, with the rest of the fat consisting of phospholipids and cholesterol forming membranes around the fat droplets. About half of the fatty acids are synthesised *de novo* in the MEC from smaller compounds, principally β-hydroxybutyrate (BHB) and acetate. The rest are pre-formed fatty acids that are taken up from the blood, originating from feed or mobilised body resources. The fatty acids are then esterified with glycerol to form triglycerides (Sjaastad *et al*., 2003). There is a large day-to-day variation in the milk fat concentration, the coefficient of daily variation being up to 7% per day (Forsbäck *et al*., 2010). Milk fat content has been shown in most studies to be unaffected by DPL during the following lactation (Gulay *et al*., 2003; Pezeshki *et al*., 2007; Bernier-Dodier *et al*., 2010; Santschi *et al*., 2011b; Safa *et al*., 2013; Cermacova *et al*., 2014; Weber *et al*., 2015). However, Rastani *et al*. (2005) and van Knegsel *et al*. (2014) found an increase in milk fat content when shortening the DP, while milk fat content was decreased in a study by Shoshani *et al*. (2014) after a shortened DP.

Proteins are synthesised in the rough endoplasmic reticulum of the MEC and transported to the Golgi apparatus. Amino acids are taken up from the blood and non-essential amino acids can be transaminated in the MEC. Milk protein consists of about 80% caseins, phosphorylated proteins that bind calcium. Caseins are major phosphorus sources for the offspring. They are also required for cheese making. The rest of the protein fraction consists of lactalbumins and lactoglobulins (whey proteins), immunoglobulins, enzymes and other proteins with specific functions (Linzell & Peaker, 1971). The milk protein percentage has been reported to be unaffected (Gulay *et al*., 2003; Cermacova *et al*., 2014) or increased postpartum in cows with a shortened or omitted DP (Rastani *et al*., 2005; Watters *et al*., 2008; van Knegsel *et al*., 2014).

1.4 Energy Balance and Metabolic Status

The transition from not producing milk, and thus relatively low nutrient requirements, to the huge nutrient demands as milk production rapidly increases after parturition involves major metabolic changes for the dairy cow. The cows are generally not able to consume enough feed to cover their energy requirements and they enter a stage of negative energy balance (NEB) (Drackley, 1999). The energy balance is calculated by subtracting the energy requirements from the energy intake (Volden, 2011). Negative energy balance postpartum is naturally occurring, not only in the dairy cow but also in most other mammalian females. For example, lactating grey seals experience a great energy deficit because they do not eat while nursing and they produce milk with a fat content of approximately 50% (Stewart & Lavigne, 1984).

When the cow experiences NEB, energy is mobilised from body reserves. Stored triglyceride esters in the adipose tissues are split into non-esterified fatty acids (NEFA) and glycerol by hormone-sensitive lipases, *i.e.* by lipolysis (Adewuyi *et al.*, 2005). Non-esterifed fatty acids are released into the blood, thus elevating the concentration in blood plasma (Adewuyi *et al.*, 2005), but a significant fraction of the NEFA is taken up by the liver. This organ is very metabolically active and it requires significant amounts of energy, which are generated by β-oxidation of NEFA (Herdt, 2000). Non-esterifed fatty acids can also be partly oxidised to ketone bodies, mainly β-hydroxybutyrate (Bell *et al.*, 1995). This occurs especially when the cows are in deficit of glucose. A fraction of the NEFA that enters the liver is re-esterified to triglycerides and exported as very low density lipoproteins (VLDL). The availability of VLDL is limited and in the case of intense re-esterification the surplus of triglycerides generated is stored in the liver (Herdt, 2000). Excessive inflow of NEFA and re-esterification in the liver can cause fatty liver and ketosis (Herdt, 2000). Elevated levels of NEFA in blood plasma are partly an indication of NEB. The cow is able to cope with NEB, although not for a prolonged period of time (Gross & Bruckmaier, 2019). Other metabolites, hormones or peptides that are related to the metabolism and energy balance of the cow are BHB, glucose, insulin and insulin-like growth factor I (IGF-I) (Butler *et al.*, 2003). Cows in NEB decrease their body condition and this may be observed by scoring the cow's body condition (Wildman *et al.*, 1982).

In cows, as in other ruminants, virtually all dietary carbohydrates are fermented to volatile fatty acids in the rumen. Hence, these animals rely on gluconeogenesis in the liver for their glucose supply (see *e.g.* Sjastaad *et al.*, 2003). The principal gluconeogenic substrates are propionate from rumen fermentation of carbohydrates and glucogenic amino acids.

Several factors contribute to a reduction in circulating insulin in blood plasma in cows postpartum. These factors include a drop in plasma glucose and reduced response of the pancreatic β-cells to glucose (Holtenius *et al*., 2003). Insulin is a key hormone regulating metabolic adaptations in the transitioning cow. The reduced insulin activates glucogenolysis, lipolysis and proteolysis in order to support the mammary gland with substrates for milk synthesis. The uptake of glucose by MEC occurs mainly by non-insulin dependent glucose transporter-I (GLUT-1), while insulin dependent transporters, primarily GLUT-4, are virtually absent in MEC (Zhao *et al*., 1996). Thus, the drop in insulin, combined with reduced responsiveness to insulin in muscle and adipose tissue (De Koster & Opsomer, 2013), shunt glucose to the mammary glands for lactose synthesis. The "Revised Quantitative Insulin Sensitive Check Index" (RQUICKI) was developed by Perseghin *et al*. (2001) as a way to estimate insulin sensitivity can in humans. Later, this index was tested in dairy cows (Holtenius & Holtenius, 2007). However, RQUICKI is apparently not associated with insulin sensitivity in dry dairy cows (Alves-Noresa *et al.*, 2017). Nevertheless, RQUICKI is useful in detecting cows with metabolic diseases and obesity (Leiva *et al*., 2014; Guyot *et al*., 2017). It has also been shown that cows in herds with a high incidence of clinical ketosis and abomasal displacement have lower RQUICKI values than cows in herds with low incidences of those diseases (Stengärde *et al*., 2010). It is possible that in dairy cows, RQUICKI mainly reflects insulin's ability to inhibit lipolysis.

The major advantage of shortening or omitting the DP, and thus decreasing milk yield in early lactation, is improved EB. Several studies indicate that a shortened DP reduce the length and depth of NEB in dairy cows (Gümen *et al*., 2005; van Knegsel *et al*., 2014). Furthermore, a shortened DP apparently improves the metabolic status of the cow, as reflected by a less marked increase in NEFA (Pezeskhi *et al*., 2007; Watters *et al*., 2008; Klusmeyer *et al*., 2009; Shoshani *et al*., 2014), while the concentrations of glucose and insulin in plasma increase (de Feu *et al*., 2009; Chen *et al*., 2015a). The body condition score (BCS) of cows with a shortened DP, did not drop to the same extent in early lactation as for cows with a conventional DP in the studies by Watters *et al*. (2008) and Shoshani *et al.* (2014).

1.5 Udder Health

A healthy udder is vital for milk production. However, among Swedish dairy cows, mastitis shows the highest incidence of all diseases and udder health problems are one of the most common reasons for culling (VÄXA Sverige, 2019). Intramammary infection (IMI) most commonly occurs when pathogenic bacteria enter the teat canal and colonise the mammary tissue. The ensuing inflammatory reaction, mastitis, is the body's response aimed at eliminating the invading microorganisms and repairing the damage. White blood cells, such as macrophages, neutrophils and lymphocytes, migrate from the peripheral circulation to the udder (Bradley, 2002). The somatic cell count (SCC) in milk increases because of this, from about 100 000 cells/mL or less in milk of a healthy cow up to several millions of cells per mL in a cow with an inflammatory response (Sordillo *et al*., 1997). Intramammary infections and SCC values of >200 000 cells/mL during the DP increase the risk of mastitis in the subsequent lactation (Pantoja *et al*., 2009). Mastitis can either be clinical, with local or systemic signs of illness and abnormal milk, or subclinical, with no visible clinical signs or milk changes, but with increased SCC. There are several direct and indirect diagnostic tests available for detecting IMI, but SCC is considered one of the most reliable udder heath indicators (Nyman *et al*., 2016). A cut-off value of 200 000 cells/mL is commonly used to minimise errors in studies evaluating IMI and mastitis incidence, although it is not considered the actual physiological limit for a healthy or unhealthy udder quarter (Schukken *et al*., 2003). Mastitis in Swedish dairy cows is most often caused by *Staphylococcus aureus* (21.3%), *Escherichia coli* (15.9%), *Streptococcus dysgalactiae* (15.6%) and *Streptococcus uberis* (11.1%) (Ericsson Unnerstad *et al*., 2009). Milk yield and composition are affected by the inflammation, as fat and lactose content decrease and the protein fraction changes (serum protein increases, while the casein fraction decreases).

The rate of new infections is high at dry-off and during colostrogenesis, close to calving, while the risk of a cow developing mastitis is lowest in the middle of the DP in cows with a conventional DPL (Bradley & Green, 2004). Blanket treatment of dry cows with antibiotics is commonly used in many countries to cure and prevent IMI and mastitis during the DP (Robert *et al*., 2005). It is not the general practice in Sweden, where individual, selective dry cow therapy is commonly applied. However, concerns about antibiotic resistance have been raised and several other countries, for example the Netherlands, are now implementing selective dry cow treatment instead (van Hoeij *et al*., 2018).

High milk yield at dry-off also increases the risk of IMI or mastitis at calving (Rajala-Schultz *et al*., 2005). A shortened DP has been suggested to improve udder health, since the milk yield at dry-off is lower when the cow is dried off later in lactation. However, research to date has not been able to demonstrate an improvement or deterioration in udder health when shortening the DP. Kuhn *et al*. (2006) recommend a dry period of >50 days to prevent IMI. Some studies indicate a decrease in SCC following a shortened DP

(Santchi *et al*., 2011b), while others report no differences in SCC (Gulay *et al*., 2003; Rastani *et al*., 2005; van Knegsel *et al*., 2014) or mastitis incidence (Enevoldsen & Sorensen, 1992; Pezeshki *et al*., 2008; van Hoeij *et al*., 2016). In the studies by Kuhn *et al*. (2006), Khazanehei *et al*. (2015) and Sawa *et al*. (2015), SCC instead increased when shortening the DP.

1.6 Fertility

The oestrus cycle is normally 21 (18-24) days in dairy cows, and the cow is permanently polyoestrous, ovulating all year round. However, immediately after calving a period of physiological anoestrus occurs. Commencement of luteal activity (CLA) is determined as the first rise in progesterone after parturition. In a study by Nyman *et al*. (2014), average CLA in different countries was found to be: Sweden 30.6 d, the Netherlands 33.0 d, Ireland 34.1 d and UK 27.3 d. After ovulation, the ruptured ovarian follicle transforms into a progesterone-producing corpus luteum. Progesterone has several physiological functions; it prepares the uterus for pregnancy, maintains the pregnancy if fertilisation occurs, prevents the cow from showing signs of oestrus and contributes to growth and differentiation of the mammary tissue and preparation for milk synthesis (Sjaastad *et al*., 2003). Progesterone is detectable in *e.g*. peripheral blood and milk. If repeatedly measured, it is a suitable indicator of cyclicity in dairy cattle (Bulman & Lamming, 1978). The pattern of progesterone concentration has been defined as “normal” (A) or three different types of “disturbed” progesterone profiles (B, C, D), as described by Petersson *et al*. (2006).

With a calving interval of around 12-13 months, the cow has to become pregnant at three months into lactation. Thus, first insemination usually occurs around the same time as the peak of lactation (see Figure 2). Even though the cow has recovered from the deep NEB in time for insemination, the magnitude of the NEB could still influence the chances of the cow becoming pregnant (Butler & Smith, 1989). Early onset of cyclicity after calving is beneficial for a cow’s fertility later during the insemination period, but severe NEB may delay the resumption of cyclicity. Endocrine and biochemical changes associated with deep NEB can change the microenvironment of the growing gamete and also affect the ability to develop, mature and ovulate a follicle, form a corpus luteum and maintain early pregnancy (Leroy *et al*., 2008).

It has therefore been suggested that the reduced milk production and improved EB in early lactation when shortening the DP could contribute to enhanced fertility (Grummer, 2007). Watters *et al*. (2009) found a reduction in days to ovulation when cows were assigned a DP of 34-d compared with a DP of 56-d. However, when progesterone profiles in cows with different DPL were evaluated by Chen *et al.* (2015b), cows with a 30-d DP had the same proportion of normal resumption of ovarian cyclicity as cows on a 60-d DP. Moreover, days to luteal activity, luteal phase length and cycle length did not differ between the two groups during the two first oestrus cycles. In addition, no effects on pregnancy rate or days open were found in the studies by Pezeskhi *et al*. (2008) and de Feu *et al*. (2009) when comparing cows subjected to different DPLs.

1.7 Colostrum and Calf Health

Calves are born agammaglobulinaemic because of the physiology of the bovine placenta, and are instead provided with large amounts of immunoglobulins from the colostrum. The colostrum contains immunoglobulin A and immunoglobulin M, but 85-90% of the immunoglobulin fraction consists of immunoglobulin G_1 and G_2 (Larson *et al.*, 1980). The colostrum also contains other useful constituents for the newborn, such as maternal leukocytes, growth factors, cytokines, non-specific antimicrobial factors and vitamins and minerals. In addition, it has a greater content of energy, fat and other proteins than regular milk (Foley *et al*., 1978). The nutrients in colostrum are accumulated in the mammary gland several weeks before parturition, and accumulation stops immediately after parturition (Foley *et al*., 1978).

The quality of the colostrum depends on several factors, for example parity, breed, vaccinations, health and nutritional status of the cow (McGuirk *et al*., 2004). One concern about shortening the DP is the quality of colostrum. Some studies report decreased colostrum quality in terms of protein and/or immunoglobulin G (IgG) content when shortening the DP (Pritchett *et al*., 1991; Gavin *et al*., 2018). In experimental studies in which cows were assigned to a short DP, colostrum volume was found to decrease (Mayasari *et al*., 2015). However, it was still sufficient to feed the calf its first meal and the quality of the colostrum was not negatively affected (Rastani *et al*., 2005; Watters *et al*., 2008; Mayasari *et al*., 2015).

Only a limited number of published studies deal with the effects on the calf of deliberately subjecting the dam to a short DP. Birth weight was found not to be affected in studies by Rastani *et al*. (2005) and Mayasari *et al*. (2015). Mayasari *et al*. (2015) also studied the uptake of natural antibodies, through titres in plasma, and found no difference in IgG in calves born to dams with a 30-d or 60-d DP. Mulder *et al*. (2017) found no associations between calves with serum IgG concentrations below 10 g/L and different DPL of the dam (<41 d, 42-60 and >60 d).

2 Aims

The aim of this thesis was to investigate the effect of a shortened dry period on cows of Swedish Red and Swedish Holstein breed, and on their calves. Specific objectives were:

- To compare, in an experimental set-up, a shortened 4-week dry period and a conventional 8-week dry period in relation to breed and parity, and study the effects on:
  - Milk yield, milk composition, dry matter intake, energy balance and residual feed intake (Paper I).
  - Metabolic status, udder health and progesterone profile (Paper II).
  - The amount and quality of colostrum and uptake of IgG in the calves from the cows (Paper II).

- To study dry periods varying from 30 to 89 days in cows of different breeds and parities and determine the relationships with ECM yield, health, culling and fertility, in an observational study based on data from herds affiliated to the Swedish Official Milk Recording Scheme (Paper III).

3 Material and methods

For detailed descriptions of the methods used in the experimental study and observational study on which this thesis is based, see Papers I, II and III.

3.1 Experimental study

The experimental study was conducted at Lövsta Swedish Livestock Research Centre during the period 2012-2014. The experimental design and all handling of animals were approved by Uppsala Ethics Committee, Sweden (C217812/13).

3.1.1 Animals and Management

Multiparous cows of the SR (n=43) and SH (n=34) breeds were blocked by breed and parity and then randomly allocated to two different treatments; a conventional DPL of 8 weeks (8W) or a short DPL of 4 weeks (4W). The cows were studied from 10 weeks before expected calving to 12 weeks postpartum. All cows included in the study yielded at least 15 kg milk/d at 10 weeks prepartum and had a healthy udder. Information about udder health was obtained from the SOMRS and was based on individual somatic cell counts (SCC) from three consecutive monthly test milkings, corrected for milk yield, breed, parity and days in milk. Dry cow antibiotic therapy or teat sealants were not administered at dry-off or during the DP. Cows in the 8W group were milked until 8 weeks before the expected calving date, while cows subjected to the 4W treatment were milked until 4 weeks before the expected calving date. Milking was carried out in an automatic rotary system (DeLaval AMR™, Tumba, Sweden) twice a day, at 05.30 h and 15.30 h. Due to farm practicalities, 13 of the cows were milked in a voluntary milking system (VMS; DeLaval, Tumba, Sweden) for the last 6-12 weeks of the study. All cows were kept indoors in a loose-housing system, with free access to cubicles with rubber mats and wood shavings. The calves were kept outdoors in individual calf hutches with straw bedding.

3.1.2 Blood Sampling and Laboratory Analysis of Insulin, Glucose, NEFA, IGF-1, IgG and Total Protein

Blood samples were drawn from the coccygeal artery or vein in cows, and from the jugular vein in calves, into heparinised 10-mL vacuum tubes with lithium heparin as anticoagulant. The calves were sampled once during days 2-9 and once during days 56-64, at approximately 11.00 h in all cases. The blood sampling scheme applied for cows is shown in Figure 4.

The samples were centrifuged at +4 °C within 1 h of sampling and plasma was stored at -20 °C until further analysis. After thawing, plasma was analysed for glucose using an enzymatic colorimetric kit. The concentration of insulin was analysed using a commercial enzyme immunoassay method adapted for bovine blood. The concentration of NEFA was analysed using an enzymatic colorimetric test. The concentration of IGF-1 was determined using a commercial enzyme immunoassay. The concentration of BHB in plasma was analysed with a kinetic enzymatic method and was only analysed for the 45 cows sampled during year 2. The concentration of IgG in plasma from calves was determined using a two-site enzyme-linked immunoassay on a combined shaker and plate reader. Blood plasma samples from calves were analysed for total protein in plasma immediately after centrifuging, using an optical refractometer.

3.1.3 Milk and Colostrum Sampling and Laboratory Analysis of Milk Composition

Milk yield was automatically recorded at each milking session. Milk samples (25 mL) for milk composition analysis were collected from the afternoon milking and the following morning every fourth week, into tubes prepared with bronopol, and stored at + 4 ºC until analysis. They were analysed on the day after sampling for composition of fat, protein and lactose by infrared Fourier transform spectroscopy. Energy-corrected milk was calculated according to Sjaunja *et al*. (1991). Milk SCC was analysed using fluorescence-based cell counting. The concentration of progesterone was determined in milk samples collected twice weekly from 2 to 12 weeks postpartum, using a commercial ELISA. Colostrum was weighed manually for the first five milkings and a milk sample of 25 mL was collected during the first and fifth milkings.

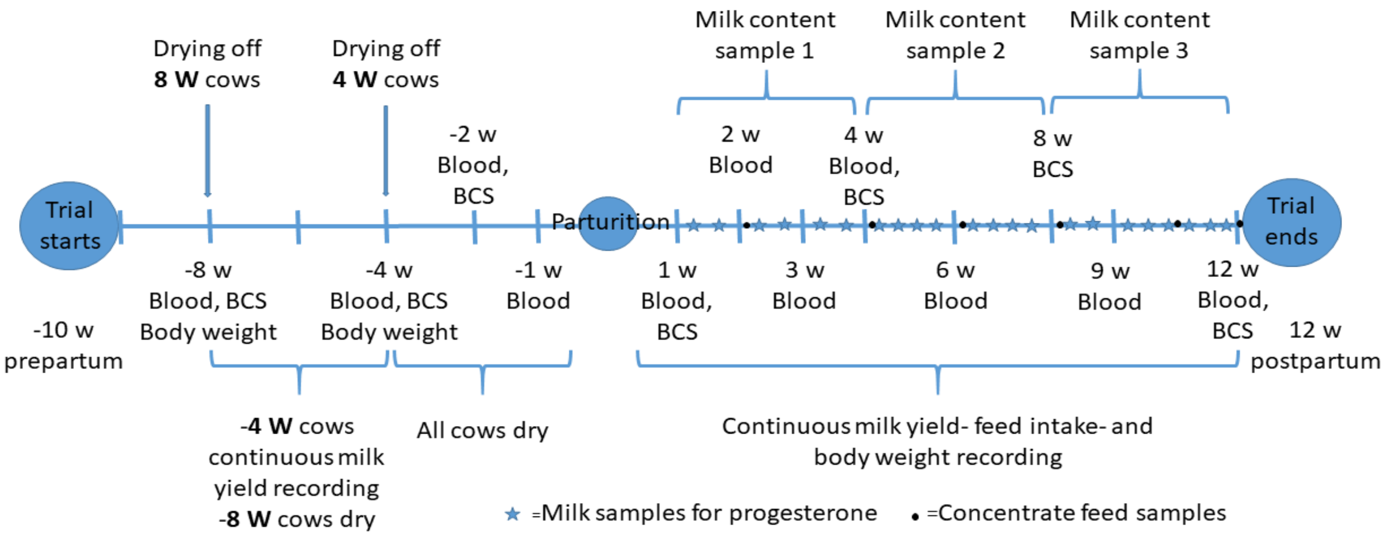

Figure 4. Sampling scheme used for cows in Papers I and II; blood, body condition score (BCS), body weight, milk, feed intake and concentrate feed. Silage sample collection is not included in the diagram, but was performed Monday to Friday every week and then pooled into one sample per two weeks.

3.1.4 Progesterone Profiles

Progesterone concentrations were plotted for each cow and classified into four different profiles according to Petersson *et al*. (2006): A) Normal cyclicity, first rise in progesterone before d 56 postpartum, followed by regular cyclicity; B) delayed cyclicity with low progesterone for at least 56 days after calving; C) cessation of cyclicity, with a normal onset but cyclicity interrupted with low progesterone for at least 14 days; and D) prolonged luteal phase, with a normal onset but with extended periods of high progesterone of at least 20 days.

3.1.5 Rations and Diets

Dry cows were fed approximately 4 kg dry matter (DM) of grass silage per day and had *ad libitum* access to straw, but did not receive any concentrate. Feed intake was not recorded for the dry cows. The lactating cows were fed silage and concentrate separately. They received 5 kg DM concentrate/d after parturition and the amount was then increased by 0.4 kg DM/d to a maximum level of 15 kg DM/d. All cows were equipped with neck transponders and concentrate was fed individually in feeding stations. The feeding system was able to distribute and record consumption of concentrates. Silage was provided *ad libitum* and individual silage intake among lactating cows was recorded using BioControl feed bunks. Water and mineral mixture were available *ad libitum*.

All calves were fed 2.5-3 L of colostrum with a nipple bucket within 12 hours of birth.

3.1.6 Body Weight, Body Condition Scoring and Energy Balance

Body weight (BW) was automatically recorded after each milking, and a weekly average was calculated for weeks 1, 4, 8 and 12 postpartum. Body condition score was rated by two trained individuals using a five-point scale (Gillund *et al*., 1999) with quarter-points increments, where 1 is severe undercondition and 5 is severe obesity.

Energy balance (EB) and residual feed intake (RFI) were calculated as follows:

$$EB = ((NE_{intake})-(NE_{maintance} + NE_{lactation})$$

$$RFI = (NE_{intake})-(NE_{maintance} + NE_{lactation} - NE_{mobilisation} + NE_{deposition})$$

where NE is net energy and NE_{intake}, $NE_{maintance}$, $NE_{lactation}$, $NE_{mobilisation}$ and $NE_{deposition}$ were calculated according to the NorFor system (Volden, 2011).

3.1.7 Statistical Analysis

The data obtained were analysed using the statistical software SAS® (2012; SAS Institute Inc., Cary, NC, USA). The PROC MIXED model with repeated measurements was used to study plasma metabolites, BW, BCS and the daily average per cow and lactation week for milk production, feed intake, EB and feed efficiency measurements. PROC MIXED was also used when analysing the overall average milk composition and total yield, using one data point per cow for the experimental period, but the only random effect in the model was then year. Multiparous cows (parity 3 or older after parturition) formed one parity class (parity ≥ 3) and all cows approaching their second parturition another (parity 2). Interactions between treatment and breed, treatment and parity class, and treatment and lactation week were included in all models, but taken out of the model when not significant ($P>0.05$). Least square means (LSM) were calculated using the SAS statement LSMEANS/PDIFF. The data on SCC, insulin and the plasma metabolites NEFA and IGF-1 were $\log_{10}$-transformed before statistical analyses to achieve normally distributed residuals. Colostrum parameters and days to first rise in progesterone were statistically evaluated with the same mixed model as presented above, only without lactation week, cow and a correlation structure for time. Progesterone profiles were divided into two groups, normal (A) and disturbed (B-D), and treatment effects were evaluated by a Chi2 test provided by OpenEpi (2013). The same programme was used to evaluate proportion of animals suffering from mastitis or fertility-related diseases.

For calves, total protein and IgG in plasma were statistically evaluated by only comparing treatments with the Wilcoxon rank sum test, because the residuals were not normally distributed and transformation did not improve their distribution.

3.2 Observational Study

3.2.1 Data from the Swedish Official Milk Recording Scheme

Data were retrieved from the SOMRS, managed by VÄXA Sweden, for herds with at least 20 cows and at least 20% purebred SR cows and at least 20% SH cows in 2015/2016.

Individual cow data for these herds in the period 2012-2016 were retrieved. They contained: monthly test milking records from the first three test milking occasions after calving and the last one before drying off during previous lactation, 305-day lactation yield (kg) of milk, protein and fat, dates of calving, dates of drying off, artificial insemination records, records of disease and date at culling. Traits indicating fertility were represented by conception rate at first artificial insemination and PV30, which is the pregnancy rate within the first 30 days after the herd's predicted voluntary waiting period (defined as days in milk (DIM) when 10% of cows in the herd are inseminated). It is a measure of reproductive success that is adjusted for effects of management decisions.

Traits indicating health were represented by puerperal paresis, retained placenta, mastitis, SCC, overall culling and culling within 90 DIM.

3.2.2 Statistical Analysis

The associations between dry period length and the outcome variables were analysed using the SAS® software (2012; SAS Institute Inc., Cary, NC, USA). The significance level was set to $P<0.01$ because of the large number of observations. Milk recording data were analysed with a mixed regression model using the PROC MIXED procedure. The binominal variables and the time to event variables were analysed with generalised linear mixed models, with binomial and exponential distributions, respectively, using the SAS procedure PROC GLIMMIX. Modelled means and probabilities from these models are presented in Chapter 4 of this thesis. The fixed effects in the models were: DPL, breed, parity and season. Herd was considered as a random effect, but cow was not included in the models because a large proportion of cows occurred only once in the dataset. Interactions with dry period length were tested and included if significant ($P<0.01$).

4 Results and Discussion

4.1 Milk Yield

Cows with a dry period of 4W had 16% lower milk production and 14% lower ECM production (36.3 kg milk/d and 35 kg ECM/d, respectively) than cows subjected to a DP of 8W (43 kg milk/d and 40.8 kg ECM/d, respectively) during the first 12 weeks postpartum in the experimental study (Paper I). Likewise, a reduction in ECM production was found in the observational study for cows with DP<50 d, but it was not as marked as in the experimental study. In the observational study, the ECM production was, on average, 1.1 kg/d (2.8%) lower during the first three months in cows with a DP of 30-39 d, and 0.5 kg/d (1.3%) lower in cows with a DP of 40-49 d, than in cows with a 60-69 d DP (Paper III). An estimate of the milk production prepartum, based on the last test milking before dry-off, suggested that the extra milk produced more than compensated for the reduction in early lactation in the observational study. The milk yield reduction during the first 12 weeks in the experimental study was completely compensated for by the extra milk produced prepartum. A reduction in milk yield ranging from 1 to 32 % after a shortened or omitted dry period has been observed previously (Rastani *et al*., 2005; Kuhn *et al*., 2007; Watters *et al*., 2008; Steeneveld *et al*., 2013). To the best of my knowledge, only one previous study, that by Weber *et al*. (2015), has reported an increase in milk yield when shortening the DP. This wide range of reported responses to a short DP is probably mainly related to differences in experimental design. In some studies milk production was recorded for a limited period in the early lactation, while in other studies milk production was observed during the whole lactation. Furthermore, in some studies the extra milk produced prepartum was included in the calculations. The decreased milk yield is suggested to be because the mammary gland is not given enough time for involution and an increased amount of senescent cells with a reduced secretory capacity when omitting the DP (Capuco *et al*., 1997). Pezeskhi *et al*. (2010) suggested that a shortened DP could inhibit early involution by reduced accumulation of pro-apoptotic factors in the stored milk and less physical distention of the mammary epithelium (Figure 3). On the other hand, Gott *et al*. (2016) found that abrupt cessation of milking at dry-off, presumably causing high intramammary pressure, reduced milk production during the first 120 days of the following lactation in cows subjected to a short DP (25-44 days compared with 45-54 days), while gradually drying off at the same time did not result in any reduction in milk in the following lactation. Dry-off method did not influence milk production in the following lactation if the DP was between 55 and 79 days (Gott *et al*., 2016).

The ECM production in the 305-d lactation was only reduced for cows with a DP of 30-39 d, 70-79 d or 80-89 d, and did not differ between cows with a DP of 40-49 d or 60-69 d (Paper III). Daily milk yield data for the complete lactations were not available, and thus the shapes of the lactation curves are unknown. However, the results indicated that the influence of previous DPL on milk yield diminished as lactation proceeded. Atashi *et al*. (2013) studied the lactation curve in 65 971 lactations and found that primiparous cows with a DP of 0-35 d had the lowest milk production over 305 d, but also the most persistent lactation curve. The opposite was observed for multiparous cows, for which a DP of 110-160 d gave the most persistent lactation curve. However, the highest 305-d lactation milk yield was observed for cows with a DP of 61-85 d. A 0-d, 30-d or 60-d DP was found to have no effect on lactation persistency in the study by Chen *et al*. (2016a). Instead, the lack of difference in total production of fat- and protein-corrected milk when measured for two consecutive lactations following the assigned dry period length for both lactations was fully compensated for by the extra milk produced during the prolonged lactations (Chen *et al*., 2016a). Data were only available for 12 weeks, and not a full lactation, in the experimental study described in Paper I. However, of the cows kept in the herd after 305 d of lactation, the 4W cows (n=28) produced 9027 kg ECM and the 8W cows (n=29) produced 10 245 kg ECM. These values should be viewed with caution, since the cows could have been included in other studies beyond our control after the 12 weeks. Based on this knowledge and by scrutinising the data on milk production in Paper I, it can be hypothesised that most of the difference in milk production between DP groups still occurred in the early lactation.

In both Paper I and Paper III, the SR cows produced less milk than the SH cows, in line with previous experiences. Only a limited number of previous studies have examined the effects of adjusting the DP in different breeds. The results in this thesis show that both breeds responded to the different DPL in a similar way with regard to milk production.

It has been shown that the reduction in milk production also depends on the parity of the cow. Santschi *et al*. (2011b) reported a more pronounced decrease in early lactation when shortening the DP of cows delivering their second calf. The mammary gland of cows entering their second lactation is still developing and lack of, or too short DP may impair that development, causing an even greater reduction in milk production (Collier *et al*., 2012). However, in this thesis no interaction between DPL and parity regarding milk yield postpartum was observed (Papers I & III). These results are in line with those of Rastani *et al*. (2005), who reported no effect of parity from shortening the DP. The second parity cows with a 4W DP in the experimental study were as high-producing as the older cows both before and after parturition. In the observational study, cows in their first lactation had higher ECM kg/d in the last test milking before dry-off, *i.e.* closer to calving date, than cows approaching their second or more parturition (Paper III). It is reasonable to assume that these high-yielding young cows had a high lactation persistency in their first lactation, as seen in studies by Annen *et al*. (2004a) and van Knegsel *et al*. (2014). Interestingly, in the studies by van Knegsel *et al*. (2014) and Steeneveld *et al*. (2014), the decrease in milk production after calving was more pronounced in younger cows, but because these younger cows maintained their production prepartum, the total production was not less than for the multiparous cows when summarising the total fat- and protein-corrected milk production per cow.

Studies trying to identify cow characteristics associated with a short or omitted DP have not been able to prove that high milk yield in the previous lactation guarantees high production following a short or omitted dry period (Klusmeyer *et al*., 2009; Steeneveld *et al*., 2014). However, as for young cows, choosing high-producing cows with over 30 kg/d and less than 25% reduction in milk production 16-12 weeks prepartum ensures a great amount of milk prepartum. Adding that milk to the total milk yield per cow accounts for the losses postpartum. These two measurements, *i.e*. high milk yield and low reduction, have been shown to be correlated to total production of fat- and energy-corrected milk during the extended lactation and the following 305-d lactation (Klusmeyer *et al*., 2009; Steenveld *et al*., 2014). In the experimental study in Paper I, no relationship was found between daily milk yield during week 11 prepartum and week 2-12 postpartum, as can be seen in Figure 5. To avoid deep NEB in early lactation, it is then not possible to choose high-yielding cows because the amount of milk produced prepartum is not a prerequisite for being high yielding in the following lactation.

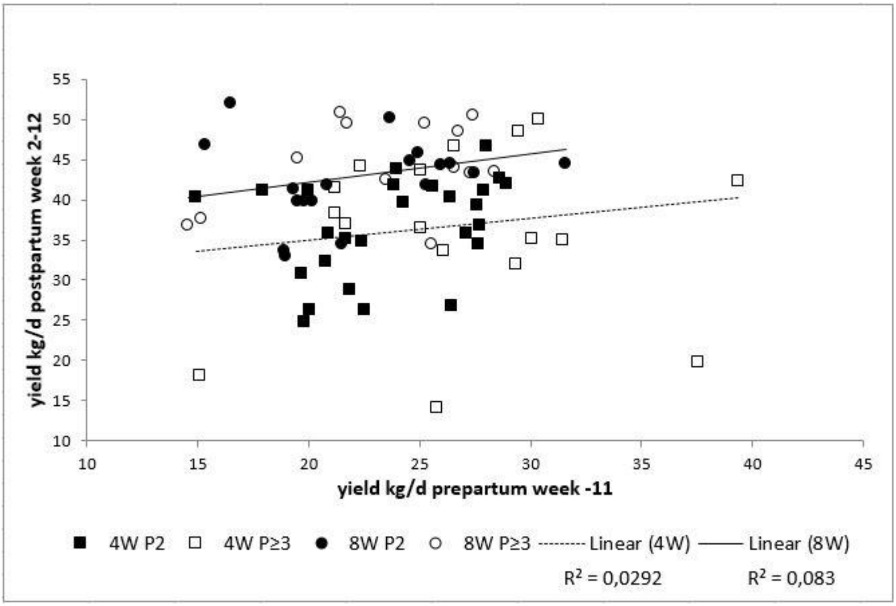

Figure 5. Average milk yield (kg/d) during week 11 prepartum and weeks 2-12 postpartum for cows with a 4-week (4W) or 8-week (8W) dry period length in: parity 2 and producing their second calf during the experiment (P2) or parity 3 and older (P≥3).

4.2 Milk Composition

In parallel with the reduction in milk yield among cows subjected to short DP the yield of fat, protein and lactose was reduced. However, the protein content was higher in the milk from the 4W cows (4W=3.42%, 8W=3.27%; $P<0.001$), which to some extent reduced the difference in ECM production between the groups (Paper I). This supports previous findings that a shortened DP causes an increase in protein content (Rastani *et al*., 2005; Watters *et al*., 2008; Bernier-Dodier *et al*., 2010). The lower milk yield in cows with a shortened DP could explain the increased protein content. It could either be a simple effect of dilution, but it has also been hypothesised that the improved EB would save amino acids and energy for protein synthesis (Annen *et al*., 2004b). It is noteworthy that in both Paper I and in the study by van Knegsel *et al*. (2014), protein content was increased and EB was improved in cows with a shortened DP, but no correlation between protein concentration in milk and energy balance was found (data not shown).

Fat content did not differ between the cows in the 4W and 8W groups (3.72% *vs*. 3.61%; P=0.250) (Paper I). This is in agreement with previous findings (van Knegsel *et al*., 2013). The SH cows had a higher fat content in milk after a 4W DP than after an 8W DP (3.63% *vs*. 3.30%), while the fat content in milk from SR cows was not influenced by the DP length. The regulation of fat content in milk is complex and influenced both by dietary and metabolic factors. In the work described in this thesis, both breeds were offered similar kinds of feeds and there were no interactions between energy balance or metabolites and breed or DPL. De Vries (2016) investigated the milk proteome from a subset of cows included in the present thesis and found, interestingly, that the milk proteome from SH cows in their early stage of lactation was less affected by the shorter DP than the milk proteome from corresponding SR cows. It is thus possible that difference in fat content response between breeds is genetic. There was a tendency for a higher lactose content in milk from cows subjected to an 8W DP (8W=4.81%, 4W=4.76%; P=0.05) in the experimental study (Paper I). These results suggest that mammary tight junctions were opened in 4W cows, allowing lactose to leak from milk into blood (Ben Chedly *et al*., 2010). However, mammary tight junctions were not affected by DPL in a study by Bernier-Dodier *et al*. (2010). In most studies examining shortening or omitting the DP, lactose content has been shown not to be affected (*e.g*. van Knegsel *et al*., 2014).

4.3 Energy Balance and Metabolic Status

4.3.1 Energy Balance and Body Condition

Dry matter intake was not affected by DPL (Paper I). In the experimental study, concentrate intake in the 8W and 4W group was 13.8 kg/d and 13.6 kg/d, respectively (P=0.35), and silage intake was 11.1 kg/d and 11.0 kg/d, respectively (P=0.85). This resulted in virtually equal net energy intake of 158.7 MJ NE/d and 158.5 MJ NE/d for 8W and 4W cows, respectively. As mentioned, cows with a 4W DP produced markedly less milk than the 8W cows. Consequently, while the 8W cows experienced NEB until week 11, the 4W cows were in a positive EB from the second week of lactation onwards. This is one of the benefits of shortening the DP because cows which reduce their milk yield while intake is maintained will improve their EB (van Knegsel *et al*., 2013). Cows subjected to a short DP maintained their energy intake in spite of the markedly lower requirement. In line with the results obtained in Paper I, it has been shown that cows which produce less milk in response to once a day milking have similar energy intake to cows that are milked twice a day, in spite of the lower energy requirement of the former cows (Rémond *et al*., 1999). On the other hand, fat cows in early lactation can reduce their energy intake without showing a reduction in milk yield (Rukkwamsuk *et al*., 1999). Taken together, the results indicate that energy intake and milk production are largely uncoupled in cows in their early lactation and that they have an extraordinary capacity to moderate energy intake and expenses by mobilisation and deposition of fat.

The 8W cows lost more in BCS postpartum than the cows in the 4W group, which was expected because of the higher milk yield of 8W cows and similar energy intake in both groups. The BCS was relatively high at the start of the study. Eight weeks prepartum, the LSM was 3.6 for both 4W and 8W cows, while during the first week of lactation it was 3.4 for both 4W and 8W cows (Paper I). In a review by Roche *et al*. (2009), an optimal BCS at calving was suggested to be between 3.0 and 3.25. Chen (2016b) found that milk yield was not affected by prepartum BCS in cows with a conventional DP of 60-d, but that cows with pre-calving BCS <3.25 and subjected to a 30-d DP produced less milk in terms of kg/d during the first 8 weeks of lactation than cows with pre-calving BCS ≥3.25. It should be noted, however, that in the study by Chen (2016b) the cows were subjected to a short DP for the second time in that study. In this thesis, BCS during the first week of lactation was not related to milk yield during lactation weeks 2 to 8 (Figure 6). Most of the SR cows were overconditioned, and thus it is not possible to draw any conclusions on how the body condition of these cows affected the milk production in relation to DPL. Overconditioned cows generally consume less feed, resulting in worsened NEB and increased risk of developing fatty liver and other metabolic diseases (Morrow, 1976; Rukkwamsuk *et al*., 1999). In this thesis, however, BCS was not related to DMI in any of the cows (data not shown).

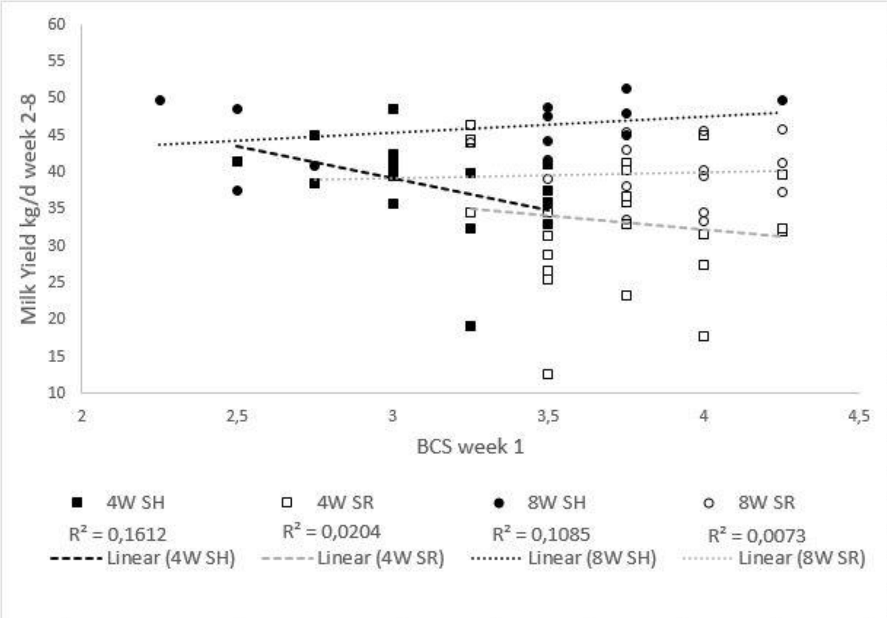

Figure 6. Body condition score (BCS) during the first week of lactation in relation to milk yield during lactation weeks 2 to 8 for cows of the Swedish Red breed (SR) and Swedish Holstein breed (SH) subjected to a dry period of 4 weeks (4W) or 8 weeks (8W).

4.3.2 Metabolic Status

Plasma metabolites and insulin concentrations were examined in Paper II. Postpartum NEFA was higher in the 8W cows, which is consistent with previous studies investigating NEFA or free fatty acids (FFA) in cows with a shortened DP (Pezeshki *et al*., 2007; Watters *et al*., 2008; Klusmeyer *et al*., 2009; Shoshani *et al*., 2014). It is well documented that elevated NEFA levels in plasma are associated with compromised metabolic health and reduced fertility (Ospina *et al*., 2013). However, in the experimental study in this thesis, only a few animals, regardless of DPL, reached the threshold plasma NEFA that indicates an increased risk of metabolic disease and compromised reproductive function (Ospina *et al*., 2013). The NEFA concentration in blood is also related to EB although the relationship is relatively weak (Bauman *et al*., 2000).

The lower NEFA concentration and the tendency for higher insulin and IGF-1 concentrations in 4W cows probably reflects their better metabolic status after calving, which is consistent with their lower milk yield and virtually the same DMI as in 8W cows. The SR cows had lower RQUICKI values both pre- and postpartum than the SH cows, although the differences were only significant prepartum. The SR cows generally had higher body condition score and it is reasonable to assume that the breed difference in RQIUCKI reflected body condition. This agrees with previous findings that lipolysis is pronounced in obese cows (Rukkwamsuk *et al.*, 1999). There was an interaction between breed and DPL in the prepartum phase, but not postpartum, for RQUICKI (Table 1). It is thus possible that the adipocytes of SR cows subjected to a short dry period were less responsive to insulin during the dry period than those of cows subjected to a conventional 8-week DP. The significance of this finding remains to be determined.

Table 1. *Least square means (LSM) of Revised Quantitative Insulin Sensitive Check Index (RQUICKI) pre- and postpartum in two different cow breeds (SH=Swedish Holstein, SR=Swedish Red) with two different dry period lengths (DPL) (4 weeks (4W) and 8 weeks (8W))*

		N	RQUICKI Prepartum	RQUICKI Postpartum
Dry period length	4W	43	0.53	0.54
	8W	34	0.55	0.53
	SEM[1]		0.01	0.03
Dry period length and Breed	4W SH	20	0.57[b]	0.57
	4W SR	23	0.50[a]	0.51
	8W SH	15	0.53[ab]	0.54
	8W SR	19	0.58[b]	0.52
	SEM[1]		0.02	0.03
Breed	SH	35	0.55	0.56
	SR	42	0.54	0.51
	SEM[1]		0.01	0.03
P Value[2]	DPL		0.24	0.75
	B		0.51	<0.01
	Parity[3]		0.49	<0.01
	W[4]		0.46	0.05
	DPL*B		<0.01	.

[a,b]Values within columns with different superscripts differ significantly (P<0.05). [1]Pooled standard error of least square mean (LSM). [2]Significance set at P<0.05) [3]Parity was divided into two classes; p2=parity 2, p≥3=parity 3 or older. [4]Samples were collected during weeks -8, -4, -2, and -1 prepartum and weeks 1, 2, 3, 4, 6, 9, and 12 postpartum.

4.4 Udder Health

In the experimental study, SCC was not affected by DPL, breed or parity (back-transformed LSM, 4W=120,000 cells/mL, 8W=80,000 cells/mL; P<0.1) (Paper II). In the observational study, a DPL of 70-79 d or 80-89 d was associated with a small but significant increase in SCC in the third monthly test milking (87,000 and 88,000 cells/mL, respectively) compared with cows with a DP of 50-59 d and 69 d (82,000 cells/mL) (Paper III). The predicted proportions of cows with high SCC during the three first monthly test milking's in the observational study were not affected by DPL (Paper III).

Previous results on the effect of dry period length on udder health are ambiguous, with SCC reported to be unaffected (Pezeskhi *et al*., 2007; Bernier-Dodier *et al*., 2010; van Knegsel *et al*., 2014), increased (Khazanehei *et al*., 2015) or decreased (Klusmeyer *et al*., 2009; Santschi *et al*., 2011b) when shortening the DP. It has been argued that there is also a dilution effect of the SCC in the milk of high-yielding cows (Green *et al*., 2006). Therefore in the studies by Steeneveld *et al*. (2013) and van Hoeij *et al*. (2018), milk yield was taken into account when studying SCC, to present more fair results for SCC in cows with different milk yield levels.

In the experimental study (Paper I), cases of mastitis tended to be more common among the cows in the 4W group than in the 8W group (26% vs. 9%, respectively; P=0.06). In the observational study (Paper III), mastitis incidence did not differ between cows with different DPL and around 11% of all cows were treated for mastitis postpartum. The lack of difference in the observational study could depend on *e.g*. a low degree of reporting mastitis treatments, which could obscure differences in mastitis incidence. The findings in this thesis confirm to some extent that the incidence of clinical mastitis is different in cows with different DPL (Pezeshki *et al*., 2007; Watters *et al*., 2008; Santschi *et al*., 2011a; van Hoeij *et al*., 2016). The use of blanket dry cow therapy is now strictly regulated in the European Union and in some countries is no longer permitted (EU 2019/6). To the best of my knowledge, apart from the studies reported in this thesis and that by van Hoeij *et al*. (2018), all existing studies examining the effect of dry period length on SCC in milk and mastitis have been performed with the use of blanket cow therapy, which makes comparisons more difficult. Omitting the DP does not allow use of any dry cow treatments and has been shown to be associated with higher SCC than when a DP is applied (Kuhn *et al*., 2006; Klusmeyer *et al*., 2009). One concern with shortening the DP and the use of antibiotics at drying off is the risk of antibiotic residues in milk in the subsequent lactation. Church *et al*. (2008) did not find any difference in antibiotic residues in milk at calving and at 7 DIM between cows subjected to a 30-d DP and treated with a commercial antibiotic intramammary therapy for lactating cows and cows subjected to a 60 d DP and treated with a standard dry cow therapy at drying off. In contrast, Bachmann *et al*. (2018) found residues exceeding the permitted threshold for up to 19 days postpartum in milk from cows treated with antibiotics during the DP.

High milk yield at dry-off increases the risk of IMI (Rajala-Schultz *et al*., 2005). Shortening the DP, and thus decreasing the milk yield at dry-off, has been suggested to decrease the risk of IMI and mastitis, both at dry-off and during the transition period. Henderson *et al.* (2016) studied SCC as an indicator of IMI, the rate of new IMI during the DP and the curing rate of existing IMI at dry-off. In agreement with Rajala-Schultz *et al.* (2005), they found that high milk yield at dry-off was associated with new infections during the DP and lower curing rate. However, they found that DPL was not associated with increased risk or lower curing rate (Henderson *et al.*, 2016). As mentioned earlier, high milk yield at dry-off may increase intramammary pressure, which could lead to milk leakage and delay keratin plug formations, in turn increasing the risk of new infections (Dingwell *et al*., 2004). The health and welfare benefits of lowering milk production at the time of dry-off are reviewed by Zobel *et al.* (2015).

4.5 Fertility

In Paper II, progesterone profiles were evaluated as a measurement of cyclicity. Among the 4W cows, 70% had a normal progesterone profile, while for 8W cows 53% had a normal profile (P=0.15). Among the disturbed profiles, profile D (prolonged luteal phase) was that most commonly observed for cows with a 4W DP (16%) and cows with an 8W DP (25%). Chen *et al.* (2015b) also studied progesterone profiles in relation to adjusted DPL and found a numerically higher proportion of normal profiles among cows with a 30-d DP than cows with a 60-d DP (47.7% and 26.0%, respectively). As found in Paper II, the most common disturbed profile in the study by Chen *et al.* (2015b) was that with a prolonged luteal phase (34.1% of cows with 30-d DP 50% of cows with 60-d DP). However, in the study by Petersson *et al.* (2006), who also compared the SR and SH breeds, the most common disturbed profile (16% of cows) was that with delayed first ovulation (profile B), while 7.3% of the cows had the profile with prolonged luteal phase (profile D). The proportion of normal profiles in the 4W cows (70%) was similar to that in the study by Nyman et al. (2014), where 63.3% of all Swedish cows in that study had a normal profile and 19.4% had a prolonged luteal phase (profile D). The proportion of disturbed profiles in the 8W cows (53%) corresponded more to that for cows described in other literature, *e.g.* 49% for Holsteins in Belgium (Opsomer *et al*., 2000) and 46% in a study in France by Cutullic *et al*. (2011).

A larger proportion of the SH cows (76.5%) had a normal progesterone profile than the SR cows (48.8%) (P<0.05). This was unexpected, as SH cows were found to have a 1.5-fold higher risk of a disturbed profile than SR cows in the study by Petersson *et al*. (2006). However, BCS over 3.5 is related to poorer cyclicity (Roche *et al*., 2007) and it might have affected the ability to return to normal cyclicity in the overconditioned SR cows in Paper II.

In Paper III, conception rate at first artificial insemination (AI) and at PV30 were studied. It was found that DPL had no effect on conception rate at first AI, while a longer DP (70-79 d and 80-89 d) was associated with poorer reproduction performance. In the experimental study, of the 14 cows conceiving within the 12-w trial period, 11 (25.6%) were in the 4W group and three (8.8%) in the 8W group, although this was not statistically evaluated. Days to CLA did not differ between the DPL groups or breeds (Paper II). Early onset of cyclicity has been shown in several studies to be advantageous for the subsequent ability of the cow to become pregnant (Galvão *et al*., 2010). Commencement of luteal activity is related to the severity of the NEB, as a deep NEB delays CLA (de Vries & Veerkamp, 2000). Negative energy balance is also reported to cause cyclicity disturbances and reduce conception rates (Wathes *et al*., 2003). Circulating IGF-I concentration decreases in early lactation and the magnitude of the drop influences both the interval to calving and the conception rate (Wathes *et al*., 2007). This thesis and several other studies (*e.g*. Gümen *et al*., 2005; van Knegsel *et al*., 2014) confirm a reduction in milk yield and NEFA, accompanied by increased concentrations of IGF-1 and improved EB in early lactation, when shortening the DP . However, few studies have been able to demonstrate any significant improvements in fertility. Table 2 presents the results from this and other studies that included milk yield, fertility measurements and, where applicable, DMI, EB and NEFA concentration. As can be seen, there are numerical differences in fertility measurements, in favour of a shortened DP, but very few significant differences. For example, Chen *et al.* (2015b) found no differences in cows subjected to a 30-d or 60-d DP on days to luteal activity and proportion of normal progesterone profiles during the first 8 weeks of lactation, although milk yield was decreased. Dry matter intake was unaffected and EB was improved in cows with a 30-d DP, but free fatty acids, IGF-I and insulin concentrations did not differ (Chen *et al.*, 2015b). In a follow-up study where the cows were again subjected to a 30-d or 60-d DP again, DPL had no effect on CLA, calving to first AI, first service conception rate, days open and services per pregnancy rate (Chen *et al*., 2017). Gümen *et al*. (2005) observed reduced milk yield and improved EB, in cows with 28-d compared with 56-d DP, but no difference in days to first ovulation and ovulation from first, second and third follicle wave. However, they did find a relationship between mean EB and days to first ovulation and between nadir EB and days to first ovulation (Gümen *et al*., 2005).

The magnitude of the NEB and the variation in metabolites is of course of relevance for how the cow will respond and for the impact on the fertility traits measured. In studies where the DP is omitted, it has been found that milk yield is further reduced, EB is improved and there are measurable improvements in fertility (Gümen *et al*., 2005; de Feu *et al*., 2009). Hence, severe cases of NEB related to decreased fertility performance were perhaps not an existing problem in this thesis, and therefore improvements in fertility were not detectable. In four of the studies in Table 2, milk yield was not decreased in cows with a shortened DP, and, although EB data are not presented, it can be hypothesised that improved fertility cannot be expected because of lack of difference in EB. However, in the study by Watters *et al*. (2009), all of the cows were treated with bovine somatotropin, which can enhance milk production.

Table 2. *Summary of findings on the effects of short or conventional dry period (DP) on milk yield (MY), dry matter intake (DMI), energy balance (EB), non-esterified fatty acids (NEFA) and fertility* measurements. Data is presented as short DP/conventional *DP*

Study	MY	DMI	EB	NEFA	CLA	CCI	CFI	CFO	PFI	DO	SP	CR	Normal cyclicity (%)
Papers I & II	36.3[a]/43[b]	24.6/24.9	10.9[a]/-8.8[b]	0.15[a]/0.20[b]	21.8/23.4								70/53
Chen *et al.*, 2015b	38.7[a]/43.3[b]	23.1/23.5	-59[a]/-132[b]		28.2/28.9								47.7/26
Chen *et al.*, 2017					28.8/27.8		88.9/86.2			147.3/142.	2.6/2.7		32.1/37.8
Gümen *et al.*, 2005	37.1[a]/42.3[b]	19.6/19.1	-6.3[a]/-9.6[b]	132/131			68/75	23.8/31.9	26/20	121.2/145.4	2.4/3.0		
Pinedo *et al.*, 2011	7224[a]/7291[b]					127.8/128.9	86.3/86.5		42/42		1.58[a]/1.65[b]		
Pezeshki *et al.*, 2007	35.4/35.2						56.9/55.6		53/39	91.9/85.2	2/2.4	71.2/67.1	
Pezeshki *et al.*, 2008	6932/7316								41.1/37	81.2/91.4	1.8/2.1	66.9/62.3	
Safa *et al.*, 2013	28.8[a]/36.2[b]			0.66/0.79			82/107	22.3/27.8		172/150	2.6/1.8		
Santschi *et al.*, 2011a	32.7/32.7						82.1/82		34.7/36.5	134.4/143.3	2.5/2.7		

Study	MY	DMI	EB	NEFA	CLA	CCI	CFI	CFO	PFI	DO	SP	CR	Normal cyclicity (%)
Shoshani *et al.*, 2014	39.6^{a}/41.2^{b}			762^{a}/1211^{b}		119/125	65.1/68		N.S				
Watters *et al.*, 2009	44/44.8			337.4^{a}/428.8^{b}			68/77	36^{a}/42^{b}	32/24.2	113/133			

CLA: Commencement of luteal activity (d). CCI: Interval from calving to conception (d). CFI: Interval from calving to first AI (d). CFO: Interval from calving to first ovulation (d). PFI: Pregnancy at first AI (%). DO: Days open (d). SP: Services per pregnancy. CR: Conception rate (%)

$^{a, b}$Different superscript letters within row and column indicate significant difference ($P<0.05$).

Papers I & II, primi- and multiparous cows 4W DP n=43, 8W DP n=34, MY kg/d, EB MJ NE/d, DMI kg/d, NEFA mmol/L 7-84 DIM

Chen *et al*. (2015b), primi- and multiparous cows 30-d DP n=55, 60-d DP n=56. Data on MY kg/d and EB kJ/kg$^{0.75}$.d for week 1-14 are taken from van Knegsel *et al*. (2014).

Chen *et al*. (2017), primi- and multiparous cows 30-d DP n=28-37, 60-d DP n=36-45

Gümen *et al*. (2005), primi- and multiparous cows 28-d DP n= 20, 56-d DP n=18. MY kg/d, EB Mcal/d 1-70 DIM. Data on DMI kg/d over 70 DIM and NEFA µEq/L 1-28 DIM are taken from Rastani *et al*. (2005).

Pinedo *et al*. (2011), primi- and multiparous cows, 31-52-d DP and 53-76 d DP, retrospective study with a total of 146 984 lactations. MY 305-d kg.

Pezeskhi *et al*. (2007), multiparous cows 30-d n=35, 56-d DP n=36, MY kg /d 1-210 DIM.

Pezeshki *et al*. 2008, multiparous cows 28-d DP n=34, 49-d DP n=27, MY kg 1-210 DIM.

Safa *et al*. (2013), primi- and multiparous cows 20-d DP n=12, 60-d DP n=1, MY kg/d, NEFA mmol/L 1-60 DIM.

Santschi *et al*. (2011a), multiparous cows 35-d DP n=224, 60-d DP n=190, Data on MY kg/d 1-305 DIM are taken from Santschi *et al*. (2011b).

Shoshani *et al*. (2014), multiparous cows 40-d DP n=200, 60-d DP n=200, MY kg/d 1-305 DIM. NEFA µEq/L, 2nd week of lactation.

Watters et al. (2009), multiparous cows 34-d DP n=174, 55-d DP n=181. Data on MY kg/d 1-100 DIM and NEFA µEq/L, 3rd week of lactation, are taken from Watters *et al*. (2008), all cows were treated with bovine somatropin.

4.6 Colostrum and Calf Health

The amount of colostrum was reduced in 4W cows in comparison with 8W cows (Paper II), but protein content was higher (16% *vs.* 12.5%; $P<0.01$). Protein content was still higher at the fifth milking occasion after calving. The high protein content reflects a higher IgG concentration, as shown by Fleenor and Stott (1980). Since the neonatal calf has limited capacity to drink large amounts of milk, high IgG concentration in colostrum has been shown to be important to provide the calf with sufficient amounts of IgG (McGuire *et al*., 2004). The IgG concentration in colostrum is strongly correlated to IgG and total protein in the plasma of the calves (Godden, 2008). The concentration of IgG and total protein in plasma was evaluated after 2-9 d and 56-64 d from birth and no differences were found between calves born to cows subjected to a 4W or 8W DP. The timing and amount of colostrum is also of importance for IgG uptake in the calf (McGuire *et al*., 2004). All calves in Paper II were fed within 6 h (except one, which were fed within 12 h) and received similar amounts of milk (~2.8 L).

Studies specifically evaluating DPL have not found complications with regard to colostrum quality (Rastani *et al*., 2005; Watters *et al*., 2008) or calf health when shortening the DP (Mayasari *et al*., 2015). However, studies investigating only colostrum quality sometimes include DPL in the model. This has, to some extent, resulted in a perception that a short DP is negatively related to colostrum quality (Pritchett *et al*., 1991; Gavin *et al*., 2018). However, those studies do not suggest any reason why the cow had a shorter DP. It is likely that all the cows included in these studies were assigned a conventional DP of 6-8 weeks, so cows with a shorter DP might have experienced pre-term parturition, which could have been the true cause of the poor colostrum quality.

5 Conclusions & Practical Implications

Shortening the DP in high-yielding dairy breeds from 60 to 30 days decreased the milk yield in the following lactation and improved the EB and metabolic status of the cow, as reflected by decreased levels of NEFA and tendencies for increased levels of insulin and IGF-I. The additional milk production in the preceding lactation in cows with a short DP was able to compensate for the reduction in milk production, and should be taken into account when evaluating the merits of short DPL. Dry period length did not significantly affect SCC, mastitis or fertility. However, protein content was higher in both colostrum and milk in cows with a shortened DP. Cows of different breeds and cows of different parities responded similarly to changes in DPL. Milk yield at 10 weeks prepartum was not a usable indicator of milk yield postpartum.

A DP of >70 days was not favourable, due to low milk production, increased risk of culling and decreased fertility.

From a practical perspective, shortening the DP could be used as a flexible management tool at dry-off. By delaying dry-off in healthy, high-yielding cows, the farmer will obtain more milk while the cow will experience a smoother dry-off. If the DP is shortened to less than 39 days, there is an increased risk of lower milk production in early lactation, but this will be compensated for by the additional milk production before dry-off and it will also enhance the EB of the cow. Dry periods longer than 70 days should be avoided.

6 Future Perspectives

This thesis involved one experimental study, performed on a research facility, and one observational study on a large dataset from commercial farms. It would be interesting to do a follow-up study on commercial farms and to study the outcome of a shortened DP from calving to calving in cows in a commercial set-up particularly chosen for short DPL. Since milk production, disease and fertility outcomes are already carefully recorded and since some farms have the technology to monitor body condition automatically, valuable information could quite easily be collected to evaluate the total milk yield, body condition, health and fertility on farm level. The economic consequences of shortening the DP need to be further evaluated and the practical consequences also need to be considered. For example, it would lead to a larger number of cows to be milked, but would provide more space in the drying-off pens. The cow types most suitable for a shortened DP remain to be determined, but in a study on commercial farms different scenarios could be investigated. However, the main focus should probably be on healthy, high-producing cows, to ease their burden at dry-off.

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Populärvetenskaplig sammanfattning

Svensk mjölkproduktion och studiernas målsättning

Svenska kor producerar i genomsnitt över 10 000 kg mjölk per år och det är få andra länder där korna har så hög avkastning. Avkastningen har mer än fördubblats sedan 1970-talet. Samtidigt har mjölknäringen genomgått en omfattande strukturell förändring, då mjölkgårdarna har blivit färre men betydligt större. Dagens mjölkproducenter får betydligt sämre betalt för mjölken än tidigare, i nominellt värde får dagens mjölkproducenter bara 70 % av vad de fick 1989 men kostnaderna för foder och drivmedel har ökat. I ett internationellt perspektiv har svenska kor en mycket god hälsa och välfärd och användningen av antibiotika och hormoner är låg. Trots det goda läget finns det starka incitament för att ytterligare förbättra kornas hälsa.

De flesta svenska mjölkproducenterna strävar efter att kon ska få en kalv om året, oavsett hur mycket mjölk hon producerar, men i praktiken är intervallet mellan kalvningar drygt 13 månader. Den generella rekommendationen har varit att kon ska ha omkring 8 veckors sintid innan hon kalvar. Högavkastande kor producerar fortfarande mycket mjölk när det är dags för sinläggning innan kalvning. Det är inte komplikationsfritt att sinlägga kor med högavkastning. Själva sinläggningsproceduren medför stress hos kor med hög avkastning och risken för juverinflammation ökar betydligt. Därför skulle det kunna vara fördelaktigt att vänta med sinläggningen tills kon själv har minskat sin mjölkproduktion, vilket hon gör naturligt ju närmare kalvningen hon kommer. Det finns utländska studier som visar att kor som haft en kortare sintid än 8 veckor har lägre mjölkavkastning under nästa laktation vilket bidrar till en minskad belastning på ämnesomsättningen men resultaten är delvis motsägande. Det finns en oro för att kor med kort sintid bildar råmjölk av sämre kvalitet. Råmjölkens kvalitet är avgörande för kalvens hälsa.

Målsättningen med studierna som presenteras i avhandlingen var att undersöka hur sintidens längd påverkar kons mjölkavkastning, ämnesomsättning, juverhälsa och fruktsamhet. Ytterligare en målsättning var att undersöka kalvarnas immunförsvar, om blodets halt av immunoglobuliner hos kalvar som fått råmjölk från kor som hade haft kort sintid, påverkades. I avhandlingen har både kor som kalvat för andra gången och äldre kor undersökts och de två dominerande raserna i Sverige har ingått. Resultaten från studierna kan utnyttjas av rådgivare, mjölkproducenter och veterinärer.

Studiernas genomförande

Avhandlingen består av tre vetenskapliga artiklar baserade på två studier, en experimentell studie, utförd på Lövsta, Centrum för forskning på lantbrukets djur utanför Uppsala, och en observationsstudie baserad på uppgifter från kokontrollen. Kokontrollen är en frivillig svensk mjölkkodatabas som samlar in en stor mängd information från mjölkproducenterna, ca 80 % av alla svenska mjölkkor är anslutna. I den experimentella studien ingick totalt 77 kor i olika åldrar av de två dominerande mjölkraserna svensk röd och vit boskap (SR) och svensk holstein (SH), varav 43 var SR och 34 SH. Korna delades in i två grupper, en kontrollgrupp med traditionell sintid om 8 veckor (34 st) och med kort sintid om 4 veckor (43 st). Korna följdes från 10 veckor innan kalvning till 12 veckor efter kalvning. I observationsstudien valdes lämpliga besättningar ut i kokontrollen, utifrån förutbestämda kriterier, så att de representerade kor i olika åldrar och av raserna SR och SH med en sintidslängd om 30-89 dagar. Detta resulterade i ett dataset med ca 78 000 laktationer.

Avkastning

Korna med kort sintid i den experimentella studien mjölkade mindre efter kalvning, de hade ca 15 % lägre avkastning än korna med traditionell sintid. När den extra mjölk som producerades innan kalvning räknades med så hade de två grupperna dock producerat lika mycket mjölk under försökstiden. Det fanns inte något samband mellan hur stor avkastning korna hade innan sinläggning och hur mycket de mjölkade i den efterföljande laktationen.

I observationsstudien var det störst skillnad under den första månaden efter kalvning och skillnaderna i mjölkavkastning (ECM) minskade senare i laktationen för att nästan försvinna när avkastningen efter 305 dagars laktation jämfördes. Då hade kor med en sintid om 30-39 dagar bara en något lägre avkastning än kor med en sintid om 60-69 dagar. I observationsstudien räknades inte mjölken med som producerades innan kalvning, men en grov uppskattning av den mjölkmängden resulterade i att kor med kort sintid över ett år skulle ha producerat lika mycket mjölk som kor med traditionell sintid.

Råmjölk

Korna med kort sintid producerade mindre råmjölk, dock tillräckligt mycket för att det skulle räcka till kalven, och halten av protein var högre. Sintidslängden hos mödrarna påverkade inte kalvarnas immunförsvar, mätt som koncentrationen av immunoglobulin G eller protein i blodplasma.

Ämnesomsättning

Foderintaget skiljde sig inte mellan korna i den experimentella studien, men eftersom korna med 4 veckors sintid mjölkade mindre drabbades de inte en negativ näringsbalans. Kor med 8 veckors sintid hade högre halter av fria fettsyror i blodet efter kalvning än kor med kort sintid. Det tyder på att kor med den längre sintiden i högre grad mjölkade på sina kroppsreserver. Båda raserna påverkades på samma sätt av sintidslängderna.

Fruktsamhet och juverhälsa

Det var ingen skillnad i kornas förmåga att komma igång med sin sexuella cyklicitet igen efter kalvning och inga andra hälso- eller fertilitetskillnader kunde ses i den experimentella studien mellan de två sintidsgrupperna, men det fanns en tendens till ökad risk för juverinflammation hos korna med kort sintid. I observationsstudien visade det sig att kor med lång sintid (70-79 och 89-89 dagar) hade något högre celltal vid den tredje månadens provmjölkning och hade sämre förmåga att bli dräktiga inom en månad efter den frivilliga väntetiden. De slaktades även ut i högre grad än kor med traditionell sintidslängd. Kor med kort sintid (30-39, 40-49 och 50-59 dagar) slogs däremot ut i lägre grad än kor med traditionell sintidslängd.

Slutsatser

När sintiden kortades ner minskade avkastningen i tidig laktation, men näringsbalansen förbättrades och koncentrationen av fria fettsyror blev lägre. Den extra mjölk som producerades innan kalvning motsvarade ungefär minskningen i avkastning efter kalvning och bör alltid räknas med i den totala avkastningen. Kort sintid gav inte några tydliga hälso- eller fertilitetsfördelar, mindre mängd råmjölk men med högre proteinhalt. Risken för utslagning minskade för kor med kort sintid. Lång sintid (70-79 och 80-89 dagar) ökade istället risken för utslagning, gav sämre mjölkavkastning och sämre fertilitet. Kor av både SR och SH och kor i olika ålder svarade likadant på sintidens längd. Det fanns inte något samband mellan hur stor avkastning korna hade innan sinläggning och hur mycket de mjölkade i den efterföljande laktationen.

Det skulle vara intressant att i framtida studier följa kor på konventionella gårdar över ett år och med olika sinlängdsstrategier, men fokus bör ligga på kor som fortfarande har hög avkastning vid sinläggning.

Popular science summary

Swedish milk production and the objectives of this thesis

Swedish cows produce on average over 10 000 kg of milk per year and there are few other countries where the cows have such a high yield. Milk yield in Sweden has more than doubled since the 1970s. At the same time, the dairy industry has undergone a major structural change, as dairy farms have become fewer but significantly larger. Today's milk producers are paid significantly less for their milk than before, in nominal values receiving only about 70% of what they received in 1989, while the costs of feed and fuel have increased. In an international perspective, Swedish cows have very good health and welfare and the use of antibiotics and hormones is low. Despite this good situation, there are strong incentives to further improve the health of the cows.

Most Swedish milk producers strive to have their cows produce one calf per year, regardless of how much milk they produce, but in practice the interval between calvings is just over 13 months. The general recommendation in the past has been that the cow should have about an 8-week dry period before calving. High-yielding cows are still producing a lot of milk when it is time for drying off before calving, and drying off cows with high yield is not free of complications. The drying-off procedure itself causes stress in cows with high yields and the risk of mastitis increases significantly. Therefore, it could be advantageous to delay drying off until the cow itself has reduced its milk production, which occurs naturally the closer the cow comes to calving. International studies show that cows with a dry period shorter than 8 weeks have lower milk yield during the next lactation, which contributes to a reduced metabolic load, but the results are partly contradictory. There are concerns that cows with a short dry period produce lower quality colostrum. The quality of the colostrum is crucial for the calf's health.

The aim of the studies presented in this thesis was to investigate how the length of dry period affects milk yield, metabolism, udder health and fertility in cows. A specific objective was to investigate the immune system of the calves, to determine whether the blood content of immunoglobulins in calves that received milk from cows with a short dry period was affected. Cows calving for the second time and older cows were studied, and the two dominant breeds in Sweden, Swedish Red and Swedish Holstein, were compared. The results of the studies can be useful to advisors, dairy farmers and veterinarians.

The studies

An experimental study was carried out at Lövsta, the Swedish Livestock Research Centre outside Uppsala, and an observational study was performed based on data from the Swedish Official Milk Recording Scheme. The scheme is a voluntary Swedish dairy cow database that collects a large amount of information from dairy producers, with about 80% of all Swedish dairy cows enrolled. The experimental study included a total of 77 cows of different ages of the two dominant milk breeds Swedish Red (SH) and Swedish Holstein (SH), of which 43 were SR and 34 SH. The cows were divided into two groups, a control group with a conventional dry period of 8 weeks (34 cows) and a group with a short dry period of 4 weeks (43 cows). The cows were followed from 10 weeks before calving to 12 weeks after calving. In the observational study, suitable herds were selected in the Swedish Official Milk Recording Scheme, based on predetermined criteria, so that they represented cows of different ages and of the breeds SR and SH with a dry period of 30-89 days. This resulted in a dataset of about 78 000 lactations.

Milk yield

Cows with a short dry period in the experimental study produced less milk after calving, with about 15% lower milk yield than the cows with a conventional dry period. However, when the extra milk produced before calving was added, the two groups produced the same amount of milk during the trial period. There was no relationship between how much milk the cows produced before drying off and how much milk they produced in the subsequent lactation.

In the observational study, the largest difference was in the first month after calving and the milk yield (energy-corrected milk) differences later decreased in lactation to almost disappear when the yield after 305 days of lactation was compared. Then cows with a dry period of 30-39 days only had a slightly lower total yield than cows with a dry period of 60-69 days. The observational study did not include milk produced before calving, but a rough estimate of the amount of milk showed that, over the space of a year, cows with a short dry period produced as much milk as cows with a conventional 8-week dry period.

Colostrum

The cows with a short dry period produced less colostrum, but the amount was still sufficient for the calf and the protein content was higher. The dry period length of the mothers did not affect the immune system of the calves, measured as the concentration of immunoglobulin G or protein in blood plasma.

Metabolism

Feed intake did not differ between the cows in the experimental study. Thus, as the cows with a 4-week dry period produced less milk, they did not suffer from a negative energy balance, unlike the cows with a conventional dry period. Cows with an 8-week dry period had higher levels of free fatty acids in the blood after calving than cows with a 4-week dry period. This indicates that cows with a longer dry period used their body reserves to produce milk to a greater extent.

Fertility and udder health

There was no difference in the ability of the cows to resume sexual cyclicity after calving and no other health or fertility differences were seen between the two dry period groups in the experimental study, but there was a tendency for increased risk of mastitis in the cows with a short dry period. In the observational study, cows with a long dry period (70-79 and 89-89 days) were found to have slightly higher somatic cell counts at the third month of test milking and had lower ability to become pregnant within one month of the voluntary waiting period. They were also culled to a greater extent than cows with a conventional 60-69 days dry period. In contrast, cows with shorter dry periods (30-39, 40-49 and 50-59 days) were culled to a lesser extent than cows with a conventional dry period length.

Conclusions

When the dry period was reduced, milk yield in early lactation decreased, but the nutritional balance of the cow improved and the concentration of free fatty acids in milk decreased. The extra milk produced before calving corresponded to approximately the decrease in yield after calving, and should therefore be included in the total yield. A short dry period did not result in any clear health or fertility benefits. It resulted in a smaller quantity of colostrum, but with a higher protein content. The risk of culling was reduced for cows with a short dry period. A long dry period (70-79 and 80-89 days) increased the risk of culling, reduced milk yield and was associated with poorer fertility.

Cows of different breeds and cows of different parities responded equally to changes in dry period length. There was no relationship between how much milk the cows produced before drying off and how much milk they produced in the subsequent lactation.

In future studies, it would be interesting to monitor cows on commercial farms over a year and examine different dry period length strategies, but the main focus should probably be on healthy, high-producing cows.

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