Effects of Restricted and Free Suckling

- In Cattle used in Milk Production Systems

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Cover: A cow of Zebu crossbred (in the front) and Swedish Red (in the background), suckled by their calves.
(Sofie Fröberg)

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Abstract

The aim of this thesis was to study the effects of restricted and free suckling in comparison with non-suckling on production and behaviour of cow and calf in dairy production systems. In the first and second study cows of Zebu × Holstein (n=24) and Holstein breed (n=27) and their calves were allocated to two treatments, restricted suckling (RS) and artificial rearing (AR) and studied during eight weeks. In the first study calves were present during milking and RS calves suckled after milking and in the afternoon. Behaviour and weight gain of calves and milk yield, milk composition and udder health (California Mastitis Test, CMT) of cows were measured. In the second study calves suckled two h after milking. Behaviour, feed intake and weight gain of calves and CMT and milk let-down of cows were registered. In the third study 65 calves of Swedish Red breed were allocated to three treatments: Free suckling (FS), low milk (LM) or high milk (HM) substitute allowance from an automatic feeder. Behaviours of FS and HM during the milk feeding period and of FS, LM and HM during weaning were observed. Weight gain and feed intake of calves were recorded until week 10. Milk yield and composition of FS dams and 15 contemporary herd-mates were measured until week 12. The result indicated an attachment between RS and FS cow-calf pairs. RS calves displayed less cross-sucking compared to AR, whereas it did not occur at all in FS during the suckling period. During the first 24 h after weaning FS showed more behavioural signs of stress than LM and HM calves. Suckling calves in all studies ate less solid feed than non-suckling calves. Weight gain was similar in RS and AR calves. Weight gain of FS calves was higher before weaning, but not after weaning compared to LM and HM. Saleable and total milk yield was higher of suckled cows in RS but not in FS compared to non-suckled cows. There were indications of improved udder health of RS compared to AR cows in extensive system. In FS system there was no effect on milk somatic cell count. In conclusion, RS resulted in beneficial effects on both production and behaviour in an extensive system. In intensive systems, RS and FS indicated benefits for calf behaviour and weight gain of FS calves; however, weight gain of FS was reduced after weaning.

Keywords: Artificial rearing, Behaviour, Calf weight gain, Holstein cattle, Milk production, Suckling calves, Zebu crossbred cattle, Udder health

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Det lönar sig inte att springa ikapp med en tokig kalv.
(Ordspråk av Stina-Greta Berggård)

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 Fröberg, S., Aspegren-Güldorff, A., Olsson, I., Marin, B., Berg, C., Hernández, C., Galina, C. S., Lidfors, L. and Svennersten-Sjaunja, K. (2007). Effect of restricted suckling on milk yield, milk composition and udder health in cows and behaviour and weight gain in calves, in dual-purpose cattle in the tropics. Tropical Animal Health and Production 39 (1), 71-81.

II Fröberg, S., Gratte, E., Svennersten-Sjaunja, K., Olsson, I., Berg, C., Orihuela, A., Galina, C.S., García, B. and Lidfors, L. (2008). Effect of suckling ('restricted suckling') on dairy cows' udder health and milk let-down and their calves' weight gain, feed intake and behaviour. *Applied Animal Behaviour Science,* 113, 1-14.

III Fröberg, S. and Lidfors, L. (2008). Behaviour of dairy calves suckling the dam in a barn with automatic milking or being fed milk substitute from an automatic feeder in a group pen. *Resubmitted to Applied Animal Behaviour Science.*

IV Fröberg, S., Lidfors, L., Svennersten-Sjaunja, K. and Olsson, I. (2008). Weight gain and weaning behaviour of dairy calves suckling the dam in an automatic milking system. *Submitted to Journal of Dairy Science.*

V Fröberg, S., Olsson, I., Pettersson, G., and Svennersten-Sjaunja, K. (2008). Dairy cows suckled by their calves in an automatic milking system. (manuscript of short communication).

Abbreviations

AM	Automatic milking
ADG	Average daily gain
AR	Artificial rearing
CMT	California mastitis test
DM	Dry matter
ECM	Energy corrected milk
FS	Free suckling
HM	High milk substitute allowance
LM	Low milk substitute allowance
ME	Metabolisable energy
NS	Non-suckling
RS	Restricted suckling
SCC	Somatic cell count

Introduction

The dairy calf is one of few farm animals that, as common practice, is separated from its mother at birth. Since the focus in dairy production is on selling milk, there has been no economic justification for allowing dairy calves to suckle their mothers. However, there are dairy production systems in developing countries in which the calf is allowed at least some access to the dam in the form of restricted suckling. It is not excluded that this type of system could both increase productivity and provide behavioural benefits; perhaps also in high technology systems with pure dairy breed cattle. In industrialized parts of the world, there is a rising consumer demand for production systems that comply with the animals' natural behaviour. At the same time, herd sizes are increasing, mainly as a consequence of decreasing milk prices and increasing costs of labour, forcing milk producers to increase production per invested working hour. If cows were allowed to care for their calves for shorter daily periods or continuously, a more natural and animal-friendly form of calf rearing would be achieved which might signify labour saving and perhaps contribute to an improved and more sustainable dairy production.

The Calf as a Factor in Milk Production

In a global perspective, due to environmental conditions and traditional practice, different dairy production systems exist in which various breeds are used. *Bos indicus* (Zebu) cattle are common in tropical countries. These cattle are heat tolerant and resistant to tropical diseases, but are not highly selected for milk and beef traits as are breeds of *Bos taurus* cattle. Therefore, *Bos taurus* cattle are often kept where climate and feeding conditions allow, such as in temperate and industrialized countries.

Calf Rearing in Tropical and Developing Countries

To improve milk production under tropical conditions, it is common practice to cross the local Zebu breeds with *Bos taurus* dairy cattle, primarily Brown Swiss and Holstein. According to Preston and Vaccaro (1989), these crosses are generally used in dual purpose cattle production systems in the tropics. These systems often employ restricted suckling, and the calf is commonly tethered next to the cow to stimulate milk let-down (Orihuela, 1990). After milking the calf is allowed to suckle the dam for a limited period. Restricted suckling has been regarded as labour intensive and has subsequently been replaced by artificial rearing, especially where milk is an expensive part of the diet and cheap substitutes are available (Galina *et al.*, 2001). On the other hand, it has been found that the additional time needed to milk with the calf next to the dam was similar to the time spent on feeding calves (Junqueira *et al.*, 2005). Studies have shown that there may be several beneficial effects if restricted suckling is applied instead of artificial non-suckling systems (Knowles and Edwards, 1983; Mejia *et al.*, 1998). Few studies have covered both production and behavioural aspects like Margersion et al (2002; 2003). The influence of restricted suckling from a holistic point of view could be further evaluated.

Calf Rearing in Industrialized Countries

In industrialized countries, the conventional calf rearing is by artificial rearing in single pens. However, herd sizes have increased substantially in recent years (Statistics Sweden, 2008), and there is a movement towards more technological management such as systems with loose-housing provided with automatic milking (AM). Large farms often raise calves in groups. Although group pens are beneficial for calves as they are allowed social contact, locomotion and play (Chua *et al.*, 2002), large groups have been indentified as a health hazard (Svensson *et al.*, 2003). For various reasons, *e.g.* welfare concerns, a number of farms have introduced different types of suckling systems, mainly utilizing foster cows which may each nurse several calves (Norrbom, 2001). A system in which calves suckle freely during the first 6-8 weeks of life in a loose-housing system with parlour milking has been successfully tested (Grøndahl *et al.*, 2007). Weight gain and health reports were very satisfying, but there was no record of feed intake or systematic behavioural studies. Further improvement could be achieved if free suckling is practised in an AM barn due to facilities such as quarter milking, which means that the teat cups are removed according to the milk flow of the individual udder quarter. Moreover, if the care of the calves is handed over to the cows, this could benefit the performance of both cow

and calf at the same time as the possibility to perform their natural behaviour is increased. A free suckling system of this kind may also offer a less labour intensive alternative to traditional calf management.

Effects of Suckling on Cow and Calf Performance

Weight Gain and Performance of the Calf

The calf rearing method may influence the physiology of calves, which in turn may affect their growth. Release of the hormones insulin and oxytocin was found to be higher during suckling than bucket drinking, and after suckling there was a marked decrease of the hormone cortisol compared to bucket drinking (Lupoli *et al.*, 2000). Oxytocin has been found to have a growth promoting effect in mongastric animals (Björkstrand and Uvnäs-Moberg, 1996). Several studies have reported a higher growth rate in Zebu crossbred calves raised with restricted suckling than with artificial rearing (Knowles and Edwards, 1983; Little *et al.*, 1991; Mejia *et al.*, 1998). Higher growth rate is often related to higher milk fat content (Sahn *et al.*, 1997; Mejia *et al.*, 1998) and amount of suckled milk (Jonasen and Krohn, 1991). In a review (Krohn, 2001) of suckling systems in industrialized countries it was reported that calves were usually healthy with a high growth rate. The incidence of diarrhoea was found to be lower in suckling Zebu crossbred calves compared to bucket fed calves (Preston and Vaccaro, 1989). The frequency of diarrhoea in dairy calves during the first three weeks of life tended to decline with age of separation *i.e.* 6 h, 24 h or four days (Weary and Chua, 2000).

Nutrition and weight gain during the rearing period may influence the future milk-producing capacity of the mammary gland (Sejrsen *et al.*, 2000). High weight at calving may be positively associated with production - if high growth rate does not occur during a critical pre-pubertal period that occurs after two to three months of age (Sejrsen *et al.*, 2000). In the young calf, a high growth rate does not seem to have this negative impact (Sejrsen *et al.*, 2000; Foldager and Krohn, 1991). Instead, a tendency to higher milk production during their first lactation was found in cows that were allowed to suckle as calves, as opposed to being bucket fed (Foldager and Krohn, 1991; Bar-Peled e*t al.*, 1997).

Milk Production of the Cow

Several studies have reported that restricted suckling increases milk production in *Bos indicus* cattle and their crosses (Knowles and Edwards,

1983; Mejia *et al.*, 1998) and in pure Holstein cattle (Everitt and Philips, 1971; Bar-Peeled *et al.*, 1995). Milk production is believed to be enhanced by the teat stimulation of the calf (Bar-Peled *et al.*, 1995), a more efficient udder emptying when the calf suckles after milking (Sandoval-Castro *et al.*, 2000), and improved udder health when cows are suckled (Preston, 1984; Mejia *et al.*, 1998). Moreover, it has been shown that more frequent udder emptying in early lactation is beneficial for the development of the milk secreting cells (Hale *et al.*, 2003).

It is a well known fact that milk fat content increases during milking (Johansson *et al.*, 1952). If the calf is allowed to suckle after milking it will ingest the residual milk which is higher in fat content than the machine-milked milk, and as a carry-over effect the milk fat content at next milking, usually the saleable milk, will be reduced (Boden and Leaver, 1994; Tesorero *et al.*, 2001).

Although *Bos taurus* cattle do not normally need the presence of the calf during milking, it has been reported that milk ejection at milking can be disturbed when cows are milked during the suckling period (Boden and Leaver, 1994; Bar-Peled *et al.*, 1995; Sandoval-Castro *et al.*, 1999; Tancin *et al.*, 2001).

Udder Health of the Cow

Mastitis is an inflammation of the mammary gland, and is one of the most common and costly diseases in dairy cattle. Mastitis is, in most cases, caused by bacterial infection and presents either clinically or sub-clinically. In clinical mastitis there are one or more visible inflammatory signs from the udder and milk. The milk may be abnormal, a little watery including dots and the milk somatic cell count (SCC) is increased (Sandholm, 1995). In sub-clinical mastitis there are no visible signs of inflammation, but milk composition may be altered. In particular, lactose content is decreased during mastitis when SCC is increased (Claesson, 1965; Linzell and Peaker, 1972; Korhonen and Kaartinen, 1995). An indirect measurement of milk SCC is the California Mastitis Test (CMT).

Suckling seems to be advantageous for udder health regardless of the length of the suckling period (for a review see Krohn, 2001) or whether the cows are of Zebu or dairy breeds (Knowles and Edwards, 1983; Sanh *et al.*, 1997; Mejia *et al.*, 1998; Everitt and Phillips, 1971; Rigby *et al.*, 1976). The beneficial effects on udder health have been attributed to mechanical factors in the suckling (Rigby *et al.*, 1976), a better udder emptying and antibacterial substances in the calf's saliva (Rigby *et al.*, 1976; Mejia *et al.*, 1998). However, it has been proposed that high-producing cows are suckled

mostly on front teats (Jung, 2001), hence, this may increase the risk of wear on udder tissue, if machine-milking empty udder quarters. In systems in which the teat cups are removed according to each udder quarters' individual milk flow, as in many AM barns, this risk may be diminished.

Effects of Suckling on Behaviour

An important aspect of animal production is to develop systems in which the animals can perform their natural behaviour. If calves are kept with their mothers, their suckling behaviour can be expressed. Suckling behaviour is probably influenced by factors such as breed and whether the cow is milked during the suckling period. If cow and calf develop an attachment to each other, a behavioural response at weaning is to be expected. If, as in most dairy production systems, the milk diet is simultaneously withdrawn, this would be a contributing stress factor.

Attachment between Cow and Calf

Attachment is found in group-living species with precocial young, it ensures that resources are provided for the mother's own young and not others (Gubernick, 1981). Criterions for attachment to be fulfilled have been presented by Gubernick (1981): seeking and maintaining closeness to a preferred individual, using the preferred individual as a secure base, and response to separation from and reunion with the preferred individual.

In Chillingham cattle (Hall, 1979) and in most African wild ungulates, the mother gives birth in isolation that is believed to reduce the risk of predation and to facilitate the development of attachment between mother and young (Leuthold, 1977). Studies have shown that only some cows of dairy (Edwards, 1983) and beef cattle (Kiley-Worthington and de la Plain, 1983; Lidfors *et al.*, 1994) seek isolation at calving, which Lidfors *et al.* (1994) suggested was dependent mainly on habitat and the availability of hiding places. Lidfors (1994) found indications of a better development of the cow-calf attachment when calves of dairy and beef cattle were born in isolation, in comparison with close to the herd.

The licking of the calf, as suggested by Lidfors (1994), firstly serves the function of stimulating the calf after birth, and secondly of strengthening the attachment between cow and calf. Hudson and Mullord (1977) reported that 5 min of contact with a calf was enough for the formation of a strong bond to the calf. It has also been observed that mother-reared Friesian cows licked and nursed their calves for longer than cows that had been reared in isolation (Le Neindre, 1989). Maternal behaviour can also be expected to vary between breeds. In general, beef cattle production takes advantage of strong

maternal behaviour, whereas there may be relaxation of natural selection (Price, 1984) in dairy production related to the practice of separating cow and calf soon after birth.

Suckling Behaviour of Calves

Apart from selection and breeding, the suckling behaviour of calves may be affected by factors such as the cow's lactation number, whether the cow is milked during the suckling period, whether the calf has free or restricted access to suckle, and the age of the calf. Das (2000) observed a longer suckling time in Zebu calves in comparison with Zebu crossbred calves during the restricted suckling sessions after milking. The author interpreted this as an attempt by the Zebu calves to obtain more milk from their dams which were low-yielding compared to Zebu crossbreds. It has also been reported that free-ranging beef calves of low-producing dams suckled for longer and more times per day in early lactation than calves of high-producing dams (Day *et al.*, 1987). The behaviour of calves with continuous access to the dam has been observed in several studies *e.g.* of semi-wild Maremma cattle (*Bos primigenius taurus*, Vitale *et al.*, 1986), pure beef cattle or beef and dairy crosses (Nicol and Sharafeldin, 1975; Lidfors *et al.*, 1994; Waltl *et al.*, 1995; Víchová and Bartoš, 2005), and Zebu cattle and their crosses (Reinhardt and Reinhardt, 1981b). There are few studies of free suckling dairy calves and most of them focus on the first days of life, with a few exceptions *e.g.* Ylipekkala (1990).

Non-nutritive Oral and Abnormal Calf Behaviour

Calves perform non-nutritive sucking both under natural and artificial rearing conditions. When calves are reared by the dam, the non-nutritive sucking is a part of the suckling bout (Lidfors *et al.*, 1994). Artificially reared calves kept in single pens have been found to engage in excessive licking of objects (Stephens, 1982) and the own body (Fraser, 1983; Wood-Gush *et al.*, 1984). These behaviours have been considered to be a need for exploration (Van Putten and Elshof, 1982). Sucking on objects in connection with milk ingestion may serve as an outlet for sucking motivation (Jung and Lidfors, 2001). Calves kept in groups may direct their sucking towards body parts of other calves, *i.e.* cross-sucking (Stephens, 1982; Lidfors, 1993). Calves allowed to suckle the dam or another cow have rarely been observed to display cross-sucking (Krohn *et al.*, 1999; Margerison *et al.*, 2003). Cross-sucking may cause disease transmission (de Passillé, 2001) and is also believed to be related to teat-sucking in heifers (inter-sucking) and milk-stealing in cows (Keil *et al.*, 2000; Lidfors and Isberg, 2003).

Insufficiently stimulated or suppressed feeding behaviour is regarded a cause of sterotypies (Sambraus, 1985; Sato *et al.*, 1994), which are described as repetitive, invariant behaviour patterns without obvious function (for a review see Mason, 1991). An example is tongue-rolling, where the tongue is moved in a circulating way inside or outside the mouth. Tongue-rolling was found to disappear when tethered dairy calves, heifers and cows were let out to pasture in the summer, and diminish when moved to a loose-housing system (Redbo, 1992). Furthermore, calves weaned at six weeks in comparison with 13 weeks of age displayed more tongue-rolling (Bøe and Andersen, 2007). Obviously, stereotypies are often observed in environments that seem barren and sub-optimal; however, the connection to animal welfare is still unclear, according to Mason (1991). It is not fully evaluated whether the incidence of non-nutritive oral and abnormal behaviour is different in free in comparison to restricted suckling systems.

Weaning

Natural weaning has been defined as the stage when the parental investment ceases most sharply (Martin, 1984; Babbit and Packard, 1990). In free-ranging Chillingham cattle the calf has been reported to suckle the dam until her next calf is born (Hall, 1982). In beef breeds, natural weaning occurs at 6-14 months of age according to Kiley-Worthington and de la Plain (1983). Natural weaning, in contrast with many commercial production systems, is a gradual process in which the access to milk is reduced and the young's solid feed intake increases (Martin, 1984). The social bond between cow and calf has been found to remain after weaning (Reinhardt and Reinhardt, 1981a; Veissier and Le Neindre, 1989).

Signs of stress after separation have been reported to last for three to four days and may include behavioural reactions such as an increase in vocal and locomotory activity and reduced weight gain. Weaning has been studied predominately in beef cattle (Lefcourt and Elsasser, 1995; Stookey *et al.*, 1997; Price *et al.*, 2003), which usually are weaned closer to the natural weaning age compared to most dairy production systems. In dairy cattle, studies have been carried out on calves a few days old (Lidfors, 1996; Stehulova *et al.*, 2008) and a couple of weeks old (Flower and Weary, 2001) and the calves were not weaned from milk simultaneously. Similarly dairy foster calves have also been studied (Loberg *et al.*, 2008). In many studies the cow and calf were at visible, audible and olfactory distance to each other after abrupt weaning which, according to Stehulova *et al.* (2008), resulted in a greater response. The effects of abrupt weaning of free suckling dairy calves have not been studied.

Aims of the Thesis

The purpose of this thesis was to evaluate the influence of restricted and free suckling in comparison with non-suckling on production and behaviour of cow and calf used in dairy production systems. The specific questions to be answered when comparing suckling to non-suckling systems were:

- Do cow and calf develop a strong attachment, and when allowed to suckle freely, does the calf suckle the dam only?
- Do suckling calves rest more and display less non-nutritive oral behaviours and abnormal behaviours?
- Do behavioural signs of stress in free suckling calves disappear a few days after abrupt weaning?
- Is the weight gain increased and solid feed intake lower of calves during the suckling period?
- Is the weight gain of free suckling calves affected during the first few weeks after abrupt weaning?
- Is the total daily milk production of suckled cows higher than that of non-suckled cows, and is their udder health improved?

Materials and Methods

Farms

Two of the studies were conducted in Mexico, at El Clarin Research Centre of the National University of Mexico in the tropics (study A; paper I), and at a private farm in a semi-arid zone (study B; paper II). The third study (study C; paper III-V) was carried out Kungsängen Research Centre, the Swedish University of Agricultural Sciences, Uppsala, Sweden.

Experimental Design and Animals

In each study groups of cow-calf pairs or calves were allocated into suckling versus non-suckling treatments. In study A and B, the cow-calf pairs were alternately allocated to two treatments, restricted suckling (RS) and artificial rearing (AR), in order of calving. In study C, calves were allocated to one of three treatments, free suckling (FS), low milk (LM) substitute allowance or high milk (HM) substitute allowance, the last two fed from an automatic feeder. Twenty-four F1 cows (Holstein × Zebu) and their calves (F1 × Simmental) was used in study A (Fig. 1). In study B, 27 Holstein cows and their calves (Holstein and Holstein × Jersey) were included (Fig. 1). The cows and calves in both experiments were studied from calving and eight weeks onwards. In study C, 65 calves and 33 cows of the Swedish Red breed were included (Fig. 1). The group of cows consisted of the 18 dams of the FS calves and 15 of their contemporary herd-mates (NS). The calves were studied from birth to 10 weeks of age and the cows from calving and 12 weeks onwards.

The approximate average annual milk production of the herds was 2,400 kg/cow for crossbred cattle, 8,000 kg/cow for Holstein and 9,000 kg/cow for Swedish Red.

Due to various reasons that are described in the papers, a number of cows and calves were excluded from part or all of the analysis. The remaining cow-calf pairs were 12 RS and 11 AR in study A, and 10 RS and 12 AR in study B. In study C, data from 16 calves in FS and 18 in HM was included in paper III, from 13 calves in FS, 23 in LM and 22 in HM in paper IV and from 12 cows in FS and 14 in NS in paper V.

Figure 1. Cows and their calves. From the left: Zebu crossbred (Photo: Carlos Hernández), Holstein (Photo: Emma Gratte) and Swedish Red (Photo: Sofie Fröberg).

Management

In study A, the cows grazed together. Sugar-cane molasses and concentrate were given at milking. Cows and calves were separated five days after parturition. In the morning, all cows were milked with their calves tethered next to their heads. After milking, the RS calves had access to suckle the residual milk and an un-milked udder quarter. They were allowed to suckle for another 30 min in the afternoon. AR calves were fed 3.6 litres of whole milk from a nipple bottle twice daily, which, however, due to a decision by the manager was changed to milk substitute five weeks after the start of the study. All calves were kept together (Fig. 2a). Concentrate was provided *ad lib*. Calves were weaned at four months of age.

In study B, cows in RS and AR were kept in the same pen together with other cows, fed a total mixed ration and milked three times per day. All calves were separated from the cow within 12 h after birth and moved to group pens, one for each treatment (Fig. 2b). The RS calves were allowed to suckle their dams for 30 min two h after morning and afternoon milking, whereas the AR calves were fed whole milk from a bucket with a floating nipple. The daily allowance for AR calves was 4 litres during week

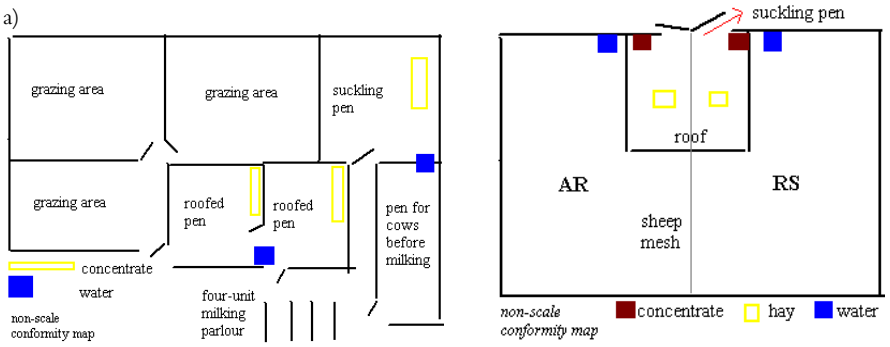

Figure 2a) Illustration of the pen with grazing areas for calves in restricted suckling and artificial rearing treatments as well as the milking parlour in study A. b) Illustration of the pens for restricted suckling (RS) and artificial rearing (AR) in study B.

1 and 2, 6 litres during weeks 3 to 7 and 4 litres during week 8. During week 8, suckling or milk feeding occurred in the morning only. Alfalfa hay and concentrate were provided *ad lib*. The calves were weaned at 8 weeks of age.

In study C, the experimental cows were kept together with other cows in a barn with an AM system (DeLaval) utilizing selective traffic with controlling gates which allowed cows to enter the milking unit when eight h had elapsed since last milking. The cows were fed forage and concentrate. All calves were born in separate calving pens. Cows and calves in FS were moved to the AM barn (Fig. 3a) approximately six days after calving. Calves in LM and HM were separated from the dam within 24 h after birth. After three days they were moved from a single to a group pen (Fig. 3b). The LM and HM calves were given 5 and 9.0 litres/day, respectively, of milk substitute from an automatic milk feeder. The allowance was offered in 0.5 litre portions, and three portions could be served in one meal. Calves in all treatments were offered concentrate and hay *ad lib*. Calves in LM and HM were kept in different pens. The calves were abruptly weaned at 8 weeks of age and were removed from the group pen after 10 weeks of age.

Recordings and Analyses

Behavioural Observations

The behaviour of focal animals was recorded with 0-1 sampling once weekly in study A, and on two separate days during weeks 1, 3, 5 and 7 in

study B. The social behaviour of cows and calves and the non-nutritive oral behaviour of calves during milking (study A) and during morning milk feeding (study A and B) were recorded. In addition, the teat preference of RS calves was recorded during morning feeding (study B). Calf behaviour was observed two h after afternoon milk feeding.

In study C, the suckling behaviour of FS calves was observed once weekly during a continuous 24 h period (paper III). The behaviour of FS and HM calves was studied at 8:00 on one day at the end of week 2, 4 and 8 (paper III). Three calves were observed during the two h observation period (40 min/calf). In the same manner, the behaviour at weaning of FS, LM and HM calves was observed during two h periods 24 h before weaning and 0, 10, 24 and 72 h after weaning (paper IV).

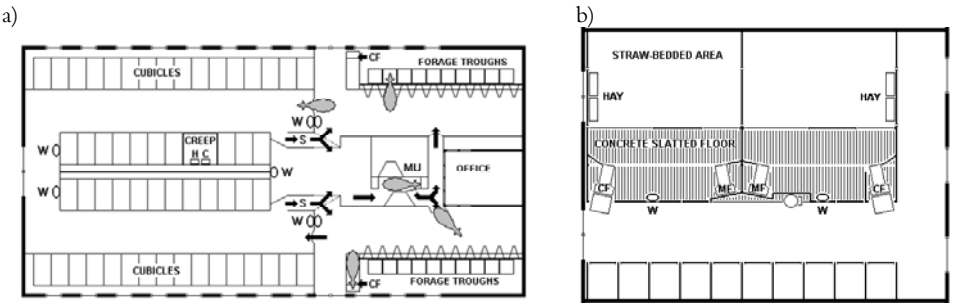

Figure 3. General layout of: a) the barn (34 m × 16 m) with AM system. MU=milking unit, S=controlling gate, W=water bowl, CF=concentrate feeder for cows. H=hay and C=concentrate, available for calves only, b) the calf barn with single pens and two group pens (each 5.9 m × 5 m) with transponder-controlled automatic milk (MF) and concentrate (CF) feeder.

Weight Gain, Milk- and Feed Intake of Calves

The weight of RS and AR calves was recorded at birth and once (study A) or twice weekly (study B) before morning milk feeding. In study B, the weigh-suckle-weigh procedure was practiced on RS calves once weekly in the morning and afternoon. Milk samples were taken once a week from RS cows before and after suckling and from the milk fed to the AR calves. The concentrate intake of the RS and AR calf groups was recorded daily.

In study C, calf weight was recorded on day 1 after birth, and thereafter once weekly. The hay intake of all groups of calves and the pre-weaning concentrate intake of the FS calf group were recorded twice weekly. The intake of milk substitute and concentrate of the LM and HM calves, and the FS calves' post-weaning concentrate intake were recorded by the automatic feeders.

Udder Health and Milk Production of Cows

The CMT-test (Klastrup and Schmidt Madsen, 1974) was used once weekly in study A and B. In study A, milk yield was recorded and milk samples were taken for analysis of milk composition once weekly. In addition, "fore-milk" was collected from each udder quarter weeks 3, 6 and 9. In study B, the time to milk let-down was recorded once weekly during milking. In study C, milk samples from each milking during a 24 h period were collected twice weekly until week 12 for analysis of milk composition and somatic cell count (SCC). Milk yield was recorded at each milking.

Milk Analyses

Milk samples taken in study A and B were analysed for fat, protein and lactose with mid-infrared spectroscopy (FMA2001, Miris AB, Uppsala, Sweden). The ME content of milk ingested by calves in study B was calculated from the DM and fat content. In study C, milk samples were analysed for fat, protein and lactose with mid-infrared spectroscopy (MilcoScan FT 120 Foss Electric, Hilleröd Denmark) and SCC was analysed using electronic fluorescence-based cell counting (Fossomatic 5000, A/SN. Foss Electric, Hilleröd Denmark) at Kungsängen laboratory, SLU.

Statistical Analyses

Statistical analysis in all papers was conducted with SAS version 8.1 or 9.1 (Statistical Analysis System Inc., Cary, USA, 1999 or 2002-2003) if not otherwise stated. In study A and B (paper I and II), behavioural data was tested with analysis of variance using the mixed linear models procedure (PROC MIXED). Data that was not normally distributed was transformed and tested again, and if normality was not achieved tested with Wilcoxon rank sum test, Chi-square test, and in study B, Wilcoxon signed rank test (Lowry, 1999-2005).

In study C, the behaviour of FS and HM calves (paper III) and the weaning behaviour of FS, LM and HM calves (paper IV) were Poisson distributed with the exception of 'lying'. The generalized linear models procedure (PROC GENMOD) was used with model specifications including repeated measurement models with repeated measurements on individual calves supposed to follow an autoregressive correlation structure. The suckling behaviour of FS calves (paper III) was normally distributed and analysed with the MIXED procedure. Model specifications included a random calf effect and a repeated statement concerning weeks, where weeks followed an unstructured covariance structure. The initiator of a suckling

bout (paper III) and the number of calves that displayed cross-sucking (paper III, IV), the number of sucking bouts lasting two min or more (FS and HM) and recordings on front and rear teats (paper III) were analysed with a Chi-square test.

In study B (paper II), the variance in weight gain of calves was analysed with an F-test. In study C (paper IV), weight gain of calves, milk substitute and concentrate intake of LM and HM calves as well as post-weaning concentrate intake in FS calves were analysed with the general linear models procedure (PROC GLM).

In study A and B, milk yield and fat, protein and lactose content of the machine-milk and the fore-milk (paper I), and teat preference and time to milk let-down (paper II) were evaluated with analysis of variance using the GLM procedure. The CMT scores of cows (paper II) were analysed using a Chi-square test. In study C, the daily milk yield and its composition, the ^{10}log values of SCC and the daily yield of ECM, during three periods of the study (week 3-4, 5-8, 9-12) were evaluated with analysis of variance in a factorial model using the GLM procedure. The GLM procedure was also used to estimate the treatment LSM of daily milk yield for each lactation week.

Results

Behaviour

Cow and Calf Relation

In study A (the extensive system, paper I), the RS cows tended to be more social with their calves during milking than did the AR cows. In study B (the intensive system, paper II), the RS cow-calf pairs exhibited more sniffing than licking or rubbing. The RS calves spent more time suckling on the front teats than on the rear teats (paper II).

In study C (free suckling system, paper III), there were more observations of FS calves suckling on the front teats than the rear teats. 80% of all suckling attempts and suckling bouts were on the dam. Most calves were observed suckling on another cow at least once. Two calves stood for 66% of the suckling bouts on cows other than the dam; however, one was excluded after four weeks of age because the dam's milk let-down at milking was inhibited, leading to a swollen udder and concern for the cow's welfare. The dam was most often the initiator of a suckling bout (63%). The dams licked their calves during or after a suckling bout or suckling attempt in 39% of the observations, and rarely interrupted their suckling calves. A calf suckling a cow other than its dam was never licked by this cow which instead most often acted as the terminator of the suckling bout. The reverse parallel position was most common when suckling the dam, whereas the anti-parallel position or from behind was more common when suckling on other cows. When calves suckled on cows with a calf of their own, half of these bouts occurred at the same time as the cow's own calf suckled. The suckling time and number of suckling attempts or bouts on all cows tended to decrease with increasing calf age. The number of suckling attempts or bouts

on the dam decreased with increasing calf age, but not the total suckling time. Calves born to multiparous cows suckled for longer time and had a greater number of suckling attempts or bouts than those with primiparous dams.

During the morning observations, the FS and HM calves were recorded to suck teat the same number of times; however, a greater number of the FS calves' suckling bouts lasted for two min or longer (paper III).

Non-nutritive Oral and Abnormal Behaviours

In study A, the AR calves licked and sniffed objects to a greater extent than did the RS calves during milking and milk feeding (paper I). In study B, the AR calves licked objects to a greater extent than did the RS calves during milk feeding and in the afternoon (paper II). Calves in the non-suckling treatments displayed more cross-sucking than calves in the suckling treatments (Table 1). Some of the AR calves exhibited cross-sucking during milking in study A (paper I). During milk feeding and in the afternoon, cross-sucking was displayed more often by AR than by RS calves in study A (paper I) and study B (paper II). In study C, about 50% of the cross-sucking events performed by HM calves were recorded within 20 min after a milk meal (paper III). Cross-sucking seemed to decrease with increasing calf age in study A and B (paper I-II), but not in study C (paper III). After weaning in study C (paper IV), cross-sucking was displayed by a greater number of HM calves than FS and LM calves (Table 1). At 72 h after weaning, numerically fewer LM calves displayed cross-sucking compared to FS and HM calves, in particular compared to the latter treatment. Tongue-rolling was observed in two calves in HM, but not in FS before weaning (paper III) or in calves in study A or B (paper I-II). In study C, tongue-rolling was observed both before weaning (1 LM, 3 HM calves) and after weaning (1 FS, 4 LM, 9 HM calves).

General- and Feeding Behaviour

Calves in the non-suckling treatments performed feeding behaviours to a greater extent in each study than did those in the suckling treatments (Table 2). In study A (paper I), the RS calves walked more than the AR calves, whereas in study C (paper III), the HM calves moved more than the FS calves (Table 2). Calves in study A and B (paper I-II) became more active with increasing age; they ate and moved more, whereas they lay down less. In study C, the calves ruminated more and tended to eat more concentrate, but they did not eat hay or move more, or lie down less, with increasing age (paper III).

Table 1. *Percentage of suckling calves versus non-suckling calves that displayed cross-sucking at least once during the given observation period (FS= free suckling, RS= restricted suckling, AR= artificial rearing, LM= low milk substitute allowance, HM= high milk substitute allowance)*

		Suckling		Non-suckling		
Study	Observation period	FS	RS	AR	LM	HM
A	Milking		0	27		
A	Milk feeding		8	91		
B	Milk feeding		20	83		
A	Afternoon		33	73		
B	Afternoon		20	83		
C	8:00-10:00 week 2, 4, 8	0				61
C	24 h before weaning	0			6	29
C	After weaning; 0, 10, 24, 72 h	31			36	65

Weaning Behaviour of Free Suckling Calves

In paper IV, most of the behaviours of the FS, LM and HM calves were similar before weaning, with the exception of LM and HM calves eating concentrate and hay considerably more often than the FS calves. At 24 h after weaning, the FS calves lay down, licked objects and ruminated less, but moved and vocalized more in comparison with the LM and HM calves. The FS calves also performed more sniffing of objects after their change to a new environment, in contrast to the LM and HM calves which remained in their original pen. At 72 h after weaning, almost all of these behaviours were similar to the LM and HM calves, and to the pre-weaning values, with the exception of FS calves tending to lie down less compared to before weaning. Although the FS calves ate less concentrate and hay compared to the LM and HM calves, they increase their number of feeding observations after weaning. Both the LM and HM calves continued to visit the milk-feeder, but compared to 24 h before weaning, the number of visits was reduced at 72 h after weaning.

Weight Gain, Milk- and Feed Intake of Calves

Restricted Suckling

In study A (paper I), the average daily gain (ADG) of RS and AR calves was similar (Table 3), but the ADG was not tested for significance due to problems such as diarrhoea encountered upon the abrupt change of milk diet.

Table 2. *Mean number of behaviours per calf, every min (0-1 sampling) during one h in the afternoon, for restricted suckling (RS) and non-suckling calves in study A and B, and every third min during two h in the morning for free suckling (FS) and non-suckling calves in study C. Level of significance (P) for difference between treatments*

		Suckling		Non-suckling	
Study	Behaviour	FS	RS		P
A	Lie		30.75	27.57	NS
B			34.07	32.22	NS
C		29.50		22.31	< 0.001
A	Walk		9.55	6.92	< 0.01
B	Move		10.56	9.73	NS
C	Move[1]	14.36		21.53	< 0.05
A	Graze		7.78	6.55	NS
B	Eat hay		3.97	7.06	< 0.05
C	Eat hay[2]	0.28		3.14	< 0.001
A	Eat concentrate		1.49	2.21	< 0.05
B			1.08	2.49	< 0.05
C		0.06		1.00	< 0.001
A	Ruminate		2.36	1.93	NS
B			1.20	3.95	< 0.01
C		4.77		3.20	< 0.05

1) Move: Every time at least one leg was moved.

2) Eat hay: Every occasion when hay was taken into the mouth.

In study B (paper II), the average total milk consumption was equal in RS and AR (Table 3). The AR calves consumed all milk that was given to them, whereas milk intake varied greatly among the RS calves. Due to the higher estimated fat content and DM content in suckled milk, the average intake of ME from milk was higher for the RS calves, but the AR calves consumed much more concentrate (Table 3). This resulted in a similar total intake of ME for the RS and the AR calves during the study. The average weight at birth and the ADG before weaning were similar in RS and AR calves (Table 3), but the individual variation in ADG was greater among the RS calves than the AR calves.

Table *3. The ADG of suckling (FS=free suckling, RS=restricted suckling) and non-suckling calves (AR=artificial rearing, LM and HM=low and high milk substitute allowance) in each study, and feed intake in study B and C. Means in the same row with different superscripts are significantly different (P < 0.05). Significance (P) for difference between treatments*

		Suckling		Non-suckling			
Study		FS	RS	AR	LM	HM	P
A	ADG, kg/day		0.28	0.24			-
B	ADG, kg/day		0.48	0.47			NS
	Milk, kg/day		5.2	5.2			NS
	Concentrate, kg DM/day		0.07	0.34			-
C	ADG kg/day						
	Week 1-8[1]	1.43			0.66^{a}	0.83^{b}	<0.001
	Week 9-10	0.03^{a}			1.12^{b}	1.12^{b}	<0.001
	Milk subst., l/day	-			4.88^{a}	7.95^{b}	<0.001
	Concentrate, kg DM/day						
	Week 1-8	0.01^{a}			0.41^{b}	0.18^{c}	<0.001
	Week 9-10	0.78^{a}			1.82^{b}	1.42^{c}	<0.001
	Hay, kg DM/day						
	Week 1-8	0.01			0.18	0.09	-
	Week 9-10	0.53			0.73	0.72	-

1*) Analysis of variance only including LM and HM treatments*

Free Suckling

In paper IV, the LM and HM calves consumed almost their entire allowances of milk substitute (Table *3*). The average concentrate intake of LM calves was double that of HM calves, whereas FS calves consumed traces of solid feed (Table *3*). Also after weaning, the concentrate intake of LM calves was higher than that of HM calves, and lower in the FS than the HM calves. The daily DM intake of hay followed a similar pattern to the concentrate intake (Table *3*). Before weaning, the ADG of FS calves was much higher compared to that of the LM and HM calves (Table *3*). The ADG of the HM calves was higher than that of the LM calves for the first four weeks only. Despite a very low post-weaning ADG in the FS calves, they still had an advantage in weight over the LM and HM calves at 10 weeks.

Restricted Suckling

In paper I, the RS cows produced more (14%) machine-milked milk than the AR cows. However, the milk fat content of the saleable milk was lower in the RS than AR cows (2.29 vs. 3.06%). When the amount of energy corrected milk (ECM, Sjaunja *et al.*, 1990) was calculated, the saleable daily yield was similar for the RS and AR cows (5.8 vs. 5.5 kg). The protein content of the saleable milk was similar (2.91 vs. 2.83%). The CMT scores indicated improved udder health in the RS cows compared to the AR cows. In the RS cows, 84% of the udder quarter samples had a CMT score of 1, and 7% a score of 5. In the AR cows, 68% of the quarters had a CMT score of 1, and 14% had a score of 5. A further indication of improved udder health in the RS cows was the higher lactose content of both machine-milked milk (4.72 vs. 4.51%) and fore-milk compared to the AR cows.

In study B (paper II), there was a tendency to improved udder health of the RS in comparison with the AR cows as indicated by the lower CMT scores. However, there was a deterioration of the CMT scores over time; in week 2, 13% of the udder quarters in both groups had CMT scores of 3-5, which increased to 22% in week 5. Several cows were treated for mastitis (6 RS, 5 AR). In the RS cows, the CMT scores of front and rear quarters were similar; in the AR cows, however, the majority of the scores of 3-5 were found in the rear udder quarters. The time to milk let-down during milking was similar in the RS and AR cows (68 vs. 61 sec), but increased with increasing time after calving, with the exception of week 8.

Free Suckling

In study C, the average amount of machine-milked milk was much lower in the FS in comparison to the NS cows during the suckling period, whereas there was no difference during the weeks after the calf removal. The total milk production, *i.e.* when a calculated amount of suckled milk was added to the amount of machine-milked milk, differed slightly less, but was not tested for statistical differences. There was no clear difference in the protein content, whereas the fat and lactose content was lower in FS than NS cows during the week 3-4 (fat: 3.62 vs. 4.26, lactose: 4.55 vs. 4.78) and during 5-8 (fat: 3.41 vs. 3.89, lactose: 4.63 vs. 4.82), but similar week 9-12 (fat: 4.23 vs. 4.01, lactose: 4.74 vs. 4.83). The milk SCC was similar in the FS and NS cows during the experimental period of 12 weeks.

General Discussion

The major findings in this thesis were that restricted suckling had positive effects on different aspects of cow productivity and calf behaviour both in the extensive and intensive dairy production systems. There were also beneficial effects when free suckling was applied in an AM barn.

Attachment and Suckling Behaviour

When the occurrence of social licking is high, which it seemed to be in our studies (paper I-III), it has been considered an indication of strong social bonds (Sato *et al.*, 1993). The ease with which the RS cows and calves were reunited at the daily suckling sessions suggested that they were attached to each other (paper I, II).

Despite indications of an attachment, several of the FS calves were observed to suckle cows other than the dam, and did so more than occasionally. Although not included in the systematical recordings, a few RS calves were noted to suckle other cows during study B; this occurred more rarely during study A. The event of calves suckling cows other than the dam has previously been observed both in dairy calves studied at a few days of age (Špinka and Illman 1992; Illman and Špinka 1993), and in older calves of beef bred and dairy-beef crosses (Waltl *et al.*, 1995; Víchová and Bartoš, 2005). Further, studies report that few calves suckled other cows, but this event occurred more often in dairy breeds than in beef breeds (Le Neindre, 1989), and in Zebu × Holstein crossbred than in Zebu cattle (Das *et al.*, 2000). Several studies, mainly on beef cattle, have found that other calves were usually refused to suckle (Nicol and Sharafeldin, 1975; Price *et al.*, 1981; Lidfors, 1994). Easy milking of the cow (Le Neindre, 1989) and the practise of removing the dairy calf after birth may have resulted in a higher proportion of cows exhibiting weaker maternal behaviour. Hence, in the

high producing dairy breeds in study B and C, there could be more dams with a weak attachment to the calf, as compared to less selected dairy breeds.

Víchová and Bartoš (2005) suggested that calves of beef and beef crosses suckled on other cows due to factors such as insufficient milk supply from the dam. In our study on FS (paper III), the calves most likely did not lack milk, as they suckled high producing dairy cows. It has also been suggested that in herds in which the females are related, a combination of attachment and cooperative care of the young may have evolved (Gubernick, 1981). The FS dams did not seem eager to let other calves suckle, nevertheless, some calves obtained access to other dams by suckling at the same time as the dams' own calves. Furthermore, in contrast to beef cattle, the herd in the study C also included milk producing cows without a bond to a calf.

In accordance with our study on FS, Örtendahl (1996) found, in a small study on young dairy calves in a loose housing system with parlour milking, that the dam was most often the initiator of a suckling bout. Beef calves older than one week were more often the initiator than their dams (Lidfors *et al.*, 1994), and in semi-wild Maremma cattle the cows rarely moved towards their calves (Vitale *et al.*, 1986). The calf's motivation to initiate suckling is probably higher in lower than higher-yielding breeds.

Previous studies have found a negative relationship between milk yield of the dam and suckling frequency (Zebu cattle: Hutchison *et al.*, 1962; Beef cattle: Walker, 1962; Day *et al.*, 1987) and suckling time (Beef cattle: Somerville and Lowman, 1979; Day *et al.*, 1987). Despite higher milk yield of multi- compared to primiparous dams, the calves of the former group suckled more often and for longer total time than the latter, for which no explanation was found (paper III). The decrease in suckling frequency with age of the FS calves is consistent with the findings of earlier studies (Somerville and Lowman, 1979; Walker, 1962). The total suckling time has been found to decrease in Zebu cattle and in beef and dairy breed crosses (Walker, 1962; Reinhardt and Reinhardt, 1981b; Day *et al.*, 1987), but also to remain relatively constant with age (Nicol and Sharafeldin, 1975; Lidfors and Jensen, 1988). A suckling time similar to the one found in study B (paper II), and a lack of age effect has also been found in previous studies on twice daily suckling two h after milking during weeks 1-5 (Hepola *et al.*, 2007) and weeks 1-9 (de Passillé and Rushen, 2006).

According to our observations, the calves suckled more on front teats than on rear teats in both the RS and FS groups in the intensive systems. In high-yielding cows, the front teats are easier to reach than the rear teats and these quarters contain enough milk to satisfy the calves (Jung, 1994). In study B, the suckling time on front teats seemed to decrease with increasing

calf age; this effect was not seen in study C. Jung (1994) proposed that the suckling time on the rear teats is increased when the age of the calf or time since last suckling is increased or when the dam's milk yield seems to be low.

Feeding- and Resting Behaviour

Calves in the non-suckling treatments performed feeding behaviour to a greater extent (paper I-IV), and had a higher solid feed intake (paper II, IV) than those in the suckling treatments. Margerison *et al.* (2003) suggested that food ingestion could serve as a replacement stimulus for suckling. It is also probable that the non-suckling calves were more motivated to consume solid feed due to their lower ME intake from milk in comparison with the suckling calves. Surprisingly, in study C (paper III) the FS calves were found to ruminate more than the HM calves during the first weeks. The rumination time of the FS calves did not seem to reflect their solid feed intake, in contrast to Swansson and Harris (1958) who found a positive correlation between rumination time and feed consumption of calves. The lack of significant increase of performing eating concentrate in study C was probably due to the low consumption of the FS calves (paper III). The increase in foraging behaviour with increasing age in study A and B (paper I-II) is in accordance with the findings of Margerison *et al.* (2003) regarding restricted suckling and artificial rearing of calves.

The lying time was found to decrease with increasing age in study A (paper I) and B (paper II) which is in accordance with previous studies (Wood-Gush *et al.*, 1984; Ylipekkala, 1990). However, the lying time did not change with age in study C (paper III). There could have been an effect of the different rearing systems, and due to that less time was spent on eating solid feed in study C related to high milk intake (paper III). The calves were kept on pasture in study A, and in the studies by Ylipekkala (1990) and Wood-Gush *et al.* (1984). Jensen (2004) reported that calves kept in group pens with automatic milk-feeding spent as much as 16-19 h per day lying down at 21-70 days of age. Some of these differences could also have been related to that the calves in study A and B compared to C were observed at different times of the day. The longer resting time found for FS calves compared to HM calves in study C, may have reflected an anti-stress effect of oxytocin, expressed *e.g.* as calmness (Uvnäs-Moberg, 1997). The release of feeding related oxytocin in calves has been found to be higher during suckling compared to bucket-drinking (Lupoli *et al.* 2000).

In study B (paper II), the RS calves and the AR calves consumed similar amounts of milk, and in study C (paper III), the HM calves were fed a high milk allowance. However, in both studies, ingesting milk by suckling the dam took much longer than ingesting milk by artificial methods. The performance of sucking, and the time taken to ingest milk are both important to reduce non-nutritive sucking (Loberg and Lidfors, 2001). In similarity with our studies (paper I-IV), Nielsen *et al.* (2008) also found occurrences of cross-sucking at other times than after a milk meal. Sucking has been found to be elicited by the taste of milk (de Passillé, 2001), but when cross-sucking is established it may be triggered by other circumstances. In study C (paper III), the HM calves were offered many small portions of milk with the intention of allowing calves to choose when to drink (they could consume 1.5 L/meal) in a similar manner to the FS calves. Nielsen *et al.* (2008) reported that large portions (1.5-2.0 L) and high daily allowances of milk may provide an outlet for the sucking motivation of calves fed from automatic milk-feeders. In a study by De Paula Vieira *et al.* (2008), there were almost no occurrences of cross-sucking in calves fed less than five litres of milk twice daily from automatic milk-feeders. As an effect of slow milk flow, milk intake lasted an average of 7.3 min/meal (De Paula Vieira *et al.*, 2008), which probably quenched the motivation to suck. The many small portions offered to the HM calves may have triggered cross-sucking; however, the number of rewarded visits per day was similar to the LM calves (Fröberg *et al.*, 2008, unpublished data). Less cross-sucking in the LM calves could relate to their higher solid feed intake as compared to the HM calves (paper IV); solid feed ingestion may provide a replacement stimulus for suckling (Margersion *et al.*, 2003). It is also likely that hungry calves are highly motivated to perform sucking (de Passillé, 2001), particularly calves recently weaned from high milk allowances. Since the post-weaning consumption of hay and concentrate increased rapidly, it is probable that the occurrences of cross-sucking would cease, although later in the HM and FS calves than in the LM calves. Nielsen *et al.* (2008) reported that gradual weaning of calves fed from automatic milk-feeders stimulated their concentrate intake, and reduced the occurrence of cross-sucking compared to abrupt weaning of calves.

In study A (paper I) and B (paper II) we found, as did Das (1999), that AR calves performed more licking and nibbling of objects than RS calves. Wiepkema *et al.* (1987) proposed that deprivation of sucking can constitute a conflict, and that this stress could result in abnormal biting and licking. Nibbling of objects has also been suggested to be a step in the development

of feeding behaviour in young calves; at older ages, only edible objects should be nibbled (Veissier *et al.*, 1998). These reports, together with our findings, indicate that licking of objects is also performed by suckling calves, and it appears that it is not necessarily an abnormal behaviour.

In study C (paper IV), tongue-rolling was predominantly displayed after weaning. The frequency of tongue-rolling has previously been found to be higher in calves weaned at the early age of six weeks compared to those weaned at 13 weeks (Bøe and Andersen, 2007). Stress or conflicts may cause stereotypies according to Wiepkema *et al.* (1987), and weaning may be such a stress factor. Redbo (1992) observed low levels of tongue-rolling in the second month of nipple or bucket-fed calves, and suggested that the short duration of milk intake could be a causal factor for the development of abnormal oral behaviours.

Weight Gain and Energy Intake of Calves

The Milk Feeding Period

The ADG in study A (paper I) was relatively low in comparison with previous studies of restricted suckling of Zebu crossbred calves (Knowles and Edwards, 1983; Sanh *et al.*, 1995; Mejia *et al.*, 1998). However, most previous studies covered a longer time period than study A did. Some studies (Sanh *et al.*, 1995; Mejia *et al.*, 1998) found an approximately similar weight gain at a similar age as study A, but the amount of milk consumed for this age period was not reported. In study A, the ADG was low in relation to the amount of milk fed to the AR calves, which could be an effect of the sudden change of milk diet.

In contrast to our findings (paper I, II), several previous studies have found a higher ADG from restricted suckling compared to artificial rearing for both Zebu crossbred calves (Little *et al.*, 1991; Mejia *et al.*, 1998) and dairy calves (Jonasen and Krohn, 1991; Fallon and Harte, 1980; Bar-Peled *et al.*, 1997). Variations in ADG are highly correlated to the consumption of milk and solid feed, and their energy content. Nevertheless, information on feed intake is lacking in many reports. In study B (paper II), the ADG was less than expected according to NRC (2001), given the ME calculated from milk ingested by RS and AR calves. The low ADG may partly be explained by the high incidence of diarrhoea; other factors such as extreme weather changes and large pen areas could also have resulted in energy being spent on maintenance and movement. The average amount of milk suckled by the RS calves was at similar level as that of dairy calves suckling twice daily during week 1-5, as reported by Hepola *et al.* (2007). A study by de Passillé

and Rushen (1997) reported a similar milk intake to study B during week 1, but no further milk intake levels were reported until week 9. In a study by Jonasen and Krohn (1991), the intervals between milking and suckling were longer than the two h in study B, which may explain the higher milk intake reported in their study.

In study B (paper II), the milk consumption of the RS calves differed considerably between calves (2-13 kg/d), and the variation in ADG was much larger than that of the AR calves. To facilitate that a satisfactory nutrient supply is ensured for the individual calf, a more uniform weight gain is desirable. When calves are allowed to suckle more frequently, they may be able to ingest sufficient amounts of milk. In study C (paper IV), the variation in growth among FS calves was small, and similar to the non-suckling calves.

In study C (paper IV), the ADG of the FS calves became much higher than that of the HM calves. The intention, however, was to achieve comparable ADG for HM and FS calves as a basis for calculating the amount of milk that was suckled. Nine litres of milk substitute, with a content of ME/kg similar to that of whole milk containing 4% fat, seemed a reasonable choice of "high milk" allowance. This value was based on previous studies (Fröberg *et al.,* 2005; Appelby *et al.*, 2001; Jasper and Weary, 2002), and on the condition that the FS dams would be milked during the suckling period. In a pilot study of calves suckling three times daily prior to the milking of their dams (Fröberg *et al.,* 2005), four Holstein calves ingested 7.9 kg/day of milk during the first four weeks and 8.8 kg/day during the following four weeks. Studies on Holstein calves with free access to whole milk from nipples have reported a similar consumption (about 9 kg/day) of whole milk during the first four weeks of life (Appelby *et al.*, 2001; Jasper and Weary, 2002; De Paula Vieira *et al.*, 2008). When NRC (2001) was applied in study C, the recorded total intake of ME was 9 and 15% higher for the LM and HM calves, respectively, than the predicted requirements. For the FS calves, the predicted daily amount of ME for the recorded ADG corresponded to an average of 10.9 (7.0-15.2) kg/d of milk during the first four weeks, and 14.5 (10.9-18.2) kg/d for the following four weeks. The high weight gain found in study C and by Grøndahl *et al.* (2007) in a loose housing system, shows that calves are able to consume great amounts of milk when allowed to suckle freely. Very high milk intake has also been recorded for Holstein calves that suckled three times daily some hours after milking (Bar-Peled *et al.*, 1997).

It is a well known fact that large amounts of milk (or high ME from milk) limit the consumption of solid feed (*e.g.* Bar-Peled *et al.*, 1997; Davies

and Drackley, 1998), and this was also found in the suckling calves in study B and C (paper II, IV). In spite of their lower energy intake, the LM calves had a similar ADG to the HM calves during the last four weeks prior to weaning, this could, at least partly, have reflected a process of gut fill at the start of consumption of considerable amounts of solid feed.

Effects of Abrupt Weaning on Behaviour and Weight Gain

The intention of study C was to apply a suckling system that would require limited rebuilding of the barn. Hence, an abrupt weaning procedure was practised, upon which the FS calves were removed from their dams (paper IV). The behavioural response of the FS calves peaked at 24 h after weaning. A peak in vocalization at 18-24 h after weaning has been found previously (Thomas *et al.*, 2001; Flower and Weary, 2001). This peak has been proposed to be a response to hunger, whereas the earlier calls may be an effect of social separation (Thomas *et al.*, 2001). Lidfors (1994) suggested that the function of vocalization for the cow and calf is to reunite. This theory is strengthened by Loberg *et al.* (2008), who found that calves prevented from suckling by a plastic device in the muzzle but remaining with the foster cow, did not vocalize. Calves separated and moved to a pen 4-10 m from the foster cow, peaked in their vocalization at 8.5-9.5 and 24-26 h after weaning (Loberg *et al.*, 2008). The proximity to the foster cow may explain the early response as compared to our findings. Stehulova *et al.* (2008) found a greater response to separation if cow and calf were kept in visual and auditory contact with each other.

The FS calves seemed to become accustomed to the new system after a few days, according to their behaviour. The FS calves tended to lie down less after weaning, which might reflect that a greater amount of time was spent eating solid feed. There was no behavioural effect of weaning in the LM and HM calves, with the exception of twice as many HM calves displaying cross-sucking compared to before weaning.

The reduction of growth rate for the FS calves lasted for a longer time period than the changes in behaviour. Previous studies have shown that negative effects of weaning may be reduced if physical contact with the dam is allowed (beef cattle: Stookey *et al.*, 1997; Haley *et al.*, 2001, 2005; Price *et al.*, 2003; dairy calves: Loberg *et al.*, 2008). However, in beef cattle weaning usually occurs at usually six months of age. The foster calves in Loberg *et al.* (2008) were kept in groups of four together with one cow which limited their access to milk. Therefore, in these studies the calves were probably adapted to eating solid feed at the time of weaning. To avoid reduced post-

weaning growth in calves with high access to milk, the intake of solid feed must be stimulated during the milk feeding period. Phillips (1993) reported that young cattle probably learn to recognize suitable feed through mimicking others, particularly the dam. In an AM barn with suckling calves, a controlled system of recording solid feed for calves ought to be introduced in the same feeding area as that of the cows. Nevertheless, it seems necessary to restrict access to milk prior to weaning, to make the process less abrupt. In comparison with FS, there was slightly higher solid feed intake in the RS calves in study B (paper II) and in Fröberg et al (2005). When twice daily suckling was reduced to once daily suckling in week 6-8, the concentrate intake was increased (Hepola *et al.*, 2007) to levels above that of the calves in study B. Moreover, there was no severe decline in energy intake and growth the two weeks after weaning (Hepola *et al.*, 2007).

The lack of post-weaning weight difference between the LM and HM calves, in spite of lower energy intake of the latter, might partly be an effect of the evolution of gut fill in the HM calves. The advantage in weight of FS calves over HM calves and of HM calves over LM calves persisted throughout the experiment. Metz (1987) reported that the higher weight achieved by calves suckling freely during the first 10 days, compared to that of calves separated from the dam after birth, remained until at least until 60 days of age. Weight differences that arise early in life have been reported to persist until 500 days of age (Smith *et al.*, 1973). High body weight at calving may be positively associated with milk production later in life (Sejrsen *et al.*, 2000). Calves allowed to suckle, in comparison with those that were bucket-fed, tended to have a higher milk production during the first lactation (Foldager and Krohn, 1991; Bar-Peled e*t al.*, 1997).

Our findings emphasize that from the point of view of both animal welfare and productivity, the intake of solid feed must be stimulated before weaning. This may be achieved if twice daily or once daily suckling is applied towards the end of the suckling period of free suckling calves, by separating cow and calf during parts of the day.

Milk Yield and Milk Quality

The RS cows in the extensive system produced 14% more machine-milked milk than did the AR cows; when the milk fed to the AR calves was deducted, the difference in saleable milk was even greater (paper I). In previous studies, the amount of saleable milk has been reported to be 34-37% higher for RS compared to AR cows of Zebu crossbred cattle (Sanh *et al.*, 1995; Mejia *et al.*, 1998). As mentioned in the introduction, there are

several explanations for increased milk yield of suckled cows. One major reason was probably the more frequent udder emptying of RS cows (paper I). The biological explanation is mostly due to the more frequent removal of a milk protein, FIL (feed back inhibition of lactation), that exerts a negative feedback control over milk synthesis (Wilde *et al.*, 1995). The cows in study C (paper V) did not produce more milk than the non-suckled cows similarly to the study by Bar-Peled *et al.* (1995). However, two calves allowed to suckle three times daily (Bar-Peled *et al.*, 1995) consumed considerably more milk than a single calf could do in study C. The authors reported that relatively little milk was removed during milking and suckling seemed superior to milking.

The lower fat content of saleable milk from RS cows (paper II) is interpreted as an effect of the calves suckling the residual milk after milking, as described in previous studies (Boden and Leaver, 1994; Tesorero *et al.*, 2001). Lower fat content was also observed for the FS cows in study C (paper V) and also by Bar-Peled *et al.* (1995). The processing industry considers reduced fat content to be undesirable. However, the composition of saleable milk from suckled cows can be manipulated by employing different regimes of restricted suckling (Sandoval-Castro *et al.*, 2000). If calves suckle before milking, the fat content of saleable milk can be elevated (Tesorero *et al.*, 2001) since the calves will ingest the milk portion with the lowest fat content.

Different forms of milking management were employed in the three studies included in this thesis. In the intensives systems, pure bred dairy cattle were used which do not normally need the calf stimulation for milk ejection in contrast to cattle types like those used in study A. Fröberg *et al.* (2005) found that milk let-down of cows suckled one h before milking was seriously impaired compared to cows, which were suckled two h after milking. Therefore, in study B, it was decided that the calves would suckle two h after milking (paper II). The time to milk let-down was similar for the RS and AR cows, which may indicate that the RS cows did not withhold the milk during machine milking. Milk let-down occurs approximately 30 sec to 2 min after stimulation, depending on the degree of udder fill, measured from the start of teat stimulation until udder pressure increases (for a review see Bruckmaier and Blum, 1998). In study B, the time to milk let-down was found to be within this interval (64.5 s). In a number of previous studies of dairy cattle, it has been observed that milk ejection can be disturbed when cows are machine-milked during the suckling period (Sandoval-Castro *et al.*, 1999; Krohn, 2001; Hepola *et al.*, 2007).

Udder Health

In agreement with our findings in study A, there are a number of studies on improved udder health in suckled compared to non-suckled Zebu crossbred cattle (Rigby *et al.*, 1976; Knowles & Edwards, 1983; Sanh *et al.*, 1997; Mejia *et al.*, 1998). In study A and B, it must to be noted that the milk samples were not analysed for milk SCC and bacteriology, whereby the results could only be taken as indications of udder health status (paper I, II). In study B and C, the udder health was similar in both treatments (paper II, V). Other studies have also found no difference in udder health between RS and un-suckled dairy cows (Fulkerson *et al.*, 1978; Thomas *et al.*, 1981; Bar-Peled *et al.*, 1995). It has also been observed that teat skin condition deteriorates more after suckling compared to machine milking (Rasmussen and Larsen, 1998), which may increase the risk of bacterial colonisation in skin cracks. In study B, the hygiene in the pen was poor, particularly after the heavy rainfalls that started in the middle of the study; this might be a possible explanation for the deterioration of udder health (paper II).

Similar to the findings in study B and C (paper II-III), Jung (1994) found that calves of high-yielding cattle mostly suckled on the front teats. Consequently the udder health may be at risk due to uneven udder emptying according to Jung (2001). However, in study B, the CMT scores indicated no difference in udder health between front and rear quarters, which could be explained by the fact that RS calves suckled the rear teats for a substantial time as well.

General Conclusions

Based on the result from the three studies in this thesis the following conclusions are made:

- Cow and calf seemed to develop a strong attachment in both suckling systems, and free suckling calves suckled mainly on the dam
- In restricted suckling calves there was less cross-sucking and licking of objects, whereas there was no cross-sucking in free suckling calves during the milk feeding period, compared to non-suckling calves.
- Restricted suckling calves did not rest more, whereas free suckling calves rested more than non-suckling calves.
- Behavioural signs of stress of calves that had been free suckling disappeared at 72 h after abrupt weaning, and fewer of these calves displayed cross-sucking after weaning than calves given high amounts of milk substitute.
- The weight gain was similar in restricted and non-suckling calves both in extensive and intensive systems, whereas free suckling calves had considerable higher weight gain than non-suckling calves during the milk feeding period. Solid feed intake was lower in restricted and free suckling calves in intensive systems in comparison to non-suckling calves.
- Weight gain of free suckling calves was severely reduced during the two weeks after abrupt weaning due to low feed intake.
- Total daily milk production was increased in restricted suckled cows in extensive system.
- In restricted suckled cows, there were indications of an improved udder health in extensive system and tendecies for improved udder health in intensive system. There was no significant difference in udder health between suckled and non-suckled cows in free suckling system.

Svensk Sammanfattning

Inom mjölkproduktionen i många i-länder är det brukligt, till skillnad från annan husdjursproduktion, att separera kalven från kon strax efter födelsen. Syftet med mjölkproduktion är att sälja mjölk, därför har det ansetts ekonomiskt oförsvarbart att låta kalven dia kon. På senare tid har intresset för djurens välmående ökat, där möjligheten att uttrycka naturliga beteenden står i fokus. I vissa tropiska u-länder förekommer kalvskötselsystem där kalven tillåts viss daglig kontakt med modern. Detta system skulle kunna erbjuda positiva effekter både ur produktions- och beteendesynpunkt, kanske även i högteknologiska system med mjölkkor. En del mjölkproducenter har infört olika typer av digivningssystem, vanligen med amkor, där tre till fyra kalvar får dia en ko. Samtidigt ökar storleken på besättningarna runt om i världen, huvudsakligen till följd av sjunkande mjölkpriser och högre arbetskostnad, vilket driver producenter till ökad produktion per investerad arbetstimme. Utvecklingen går även mot högteknologiska system såsom lösdriftstall försedda med automatiskt mjölkningssystem (AMS) och grupphållningssystem för kalvar med automatisk mjölkutfodring. Grupphållning främjar lek- och sociala beteenden, men kan även medföra problem i form av sugande på andra kalvar och ökad sjukdomsförekomst. Om däremot kon skulle få ta hand om kalven, ökar det deras möjlighet att uttrycka naturliga beteenden. Den här typen skötselsystem skulle kunna vara arbetsbesparande, och dessutom leda till ökad produktion både för ko och kalv.

Syftet med denna avhandling var att ur ett holistiskt perspektiv undersöka effekterna av restriktiv och fri digivning. De frågor som skulle besvaras var om de två digivningssystemen i jämförelse med artificiell uppfödning skulle medföra att kalvarna vilade mer, hade färre onormala beteenden och ökad tillväxt, och om kornas juverhälsa och produktion förbättrades. I den första studien ingick kor av Zebukorsningsras, som är vanliga i extensiva mjölk-

och köttproduktionssystem i tropikerna. Den andra studien baserades på mjölkkor av Holsteinras i ett intensivt system. I båda experimenten studerades korna och kalvarna de första åtta veckorna efter kalvningen. Korna mjölkades en gång per dag i första studien medan de mjölkades två gånger dagligen i andra studien. Kalvarna diade antingen två gånger per dag eller fick mjölk ur nappflaska eller nappförsedd hink. I den tredje studien fick mjölkraskalvar av Svensk Röd Boskap dia fritt i ett AMS-stall, eller dricka låg eller hög giva mjölkersättning från en automatisk kalvamma. Kalvarna studerades under mjölkperioden och två veckor efter den abrupta avvänjningen. Mödrarna till de fritt diande kalvarna och kontrollkorna utan kalv, hade tillträde till mjölkningsenheten var åttonde timme. Korna studerades också i 12 veckor. Resultaten visade att om kalvarna fick dia restriktivt var förekomsten av sugande på andra kalvar lägre, medan det inte förekom alls hos de fritt diande kalvarna, jämfört med kalvar som inte diade. De fritt diande kalvarna diade ibland andra kor än modern, och vilade mer än de som utfodrades i kalvamma. De första 24 timmarna efter avvänjningen visade de kalvar som hade diat fritt fler beteenden som tydde på stress än de kalvar som hade fått två olika mjölkgivor. En annan effekt av digivning var en lägre kraftfoderkonsumtion, i synnerhet hos de fritt diande kalvarna. I studierna med restriktiv digivning var det ingen skillnad i tillväxt. I den tredje studien utfodrades en kalvgrupp med hög mjölkgiva i syfte att uppnå en liknande tillväxt som de fritt diande kalvarna, för att skatta mängden diad mjölk. Tillväxten hos de fritt diande kalvarna blev avsevärt högre, dock sjönk den betydligt de två veckorna efter avvänjningen, jämfört med kalvarna som fick två olika mjölkgivor. Den totala mjölkproduktionen var högre hos de restriktivt diade korna i det extensiva systemet, dessutom fanns det indikationer på förbättrad juverhälsa jämfört med kor som inte diades. Restriktiv digivning av korna i det intensiva systemet visade en tendens till bättre juverhälsa, dessutom försämrades inte mjölknedsläppet jämfört med de kor som inte diades. De kor som diades fritt hade lägre mjölkproduktion under digivningsperioden, medan de veckorna efter avvänjningen hamnade på samma nivå som de kor som inte diats. Juverhälsan var lika hos de diade och de kor som inte diats. Slutsatsen är att restriktiv digivning i extensivt system ökar den totala och säljbara mjölkmängden, dessutom minskar sugandet på andra kalvar. Restriktiv digivning kan även tillföra positiva effekter i intensiva system med mjölkraskor. När kalvar har möjlighet att dia fritt får de en mycket hög tillväxt och utför inget sugande på andra kalvar, dock behöver deras kraftfoderintag stimuleras innan de avvänjs för att undvika en kraftigt minskad tillväxt efter avvänjningen.

References

Appleby, M. C., D. M. Weary & Chua. B. (2001). Performance and behaviour of calves on ad libitum milk from artificial teats. *Applied Animal Behaviour Science 74*, 191-201.

Babbit, K. J. & Packard, J. M. (1990). Parent-offspring conflict relative to phase of lactation. *Animal Behaviour 40*, 765-773.

Bar-Peled, U., Maltz, E., Bruckental, I., Folman, Y., Kali, Y., Gacitua, H. & Lehrer, A. R. (1995). Relationship between frequent milking or suckling in early lactation and milk production of high producing dairy cows. *Journal of Dairy Science 78*, 2726–2736.

Bar-Peled, U., Robinzon, B., Maltz, E., Tagari, Y., Folman, Y., Bruckental, I., Voet, H., Gacitua, H. & Lehrer, A. R. (1997). Increased weight gain and effects on production parameters of Holstein heifer calves that were allowed to suckle from birth to six weeks of age. *Journal of Dairy Science 80*, 2523–2528.

Björkstrand, E. & Uvnäs-Moberg, K. (1996). Central oxytocin increases food intake and daily weight gain in rats. *Physiology and Behaviour 59*, 947-952.

Boden, R. F. & Leaver, J. D. (1994). A dual purpose cattle system combining milk and beef production. *Animal Production 58*, 463-464 (Abstract).

Bøe, K. E. & Andersen, I. L. (2007). Early weaning of calves – a behavioural problem? In: *Proceedings from the conference on calf management*, Nord-Trøndelag University College, Steinkjer, Jun 20-22, 2007. 126-131.

Bruckmaier, R. M. & Blum, J. W. (1998). Oxytocin release and milk removal in ruminants. *Journal of Dairy Science 81*, 939–949.

Chua, B., Coenen, J., van Delen, J. & Weary, D. M. (2002). Effects of pair versus individual housing on the behaviour and performance of dairy calves. *Journal of Dairy Science 85*, 360-364.

Claesson, O. (1965). Studies on the variation of the rennin coagulation time of milk. *Annals of the Agricultural College of Sweden 31*, 237-332.

Das, S. M. (1999). *Performance and behaviour of the cow and the calf in restricted suckling and artificial rearing systems*. Diss. Uppsala: Swedish University of Agricultural Sciences, ISBN 91-576-5451-4

Das, S. M., Redbo, I. & Wiktorsson, H. (2000). Effect of age of calf on suckling behaviour and other behavioural activities of Zebu and crossbred calves during restricted suckling periods. *Applied Animal Behaviour Science 67*, 47-57.

Davis, C. L. & Drackley. J. K. (1998). *The development, nutrition, and management of the young calf*. Iowa State University Press, Ames.

Day, M. L., Imakawa, K., Clutter, A. C., Wolfe, P. L., Zalesky, D. D., Nielsen, M. K., & Kinder, J. E. (1987). Suckling behaviour of calves with dams varying in milk production. *Journal of Animal Science 65*, 1207-1212.

de Passillé, A. M. & Rushen, J. (1997). Effects of nursing on milk ejection an milk yield during milking. *Journal of Dairy Science 80 (Supplement 1)*, 203.

de Passillé, A. M. (2001). Sucking motivation and related problems in calves. *Applied Animal Behaviour Science 72*, 175–187.

de Passillé, A. M. B. & Rushen, J. (2006). Calves' behaviour during nursing is affected by feeding motivation and milk availability. *Applied Animal Behaviour Science 101*, 264-275.

De Paula Vieira, A., Guesdon, V., de Passillé, A. M., von Keyserlingk, M. A. G. & Weary, D. M. (2008). Behavioural indicators of hunger in dairy calves. *Applied Animal Behaviour Science 109*, 180–189.

Edwards, S. A. (1983). Factors affecting the time to first suckling in dairy calves. *Animal Production 34*, 339-346.

Everitt, G. C. & Phillips, D. S. M. (1971). Calf rearing by multiple suckling and the effects on lactation performance of the cow. *Proceedings of the New Zealand Society of Animal Production 31*, 22-40.

Fallon, R. J. & Harte, F. J. (1980). Methods of feeding milk to young calves. *Irish Journal of Agricultural Research 19*, 67–74.

Flower, F. C. & Weary, D. M. (2001). Effects of early separation on the dairy cow and calf: 2. Separation at 1 day and 2 weeks after birth. *Applied Animal Behaviour Science 70*, 275-284.

Foldager, J. & Krohn., C. C. (1991). Kviekalve opdrættet på meget høj eller normal fodringsintensitet fra fødsel til 6-10 ugers alderen og deres senere mælkeproduktion. *Statens Husdyrbrugsforsøg*, Meddelelse No. 794. (In Danish).

Fröberg, S., L. Lidfors, I. Olsson, & Svennersten-Sjaunja., K. (2005). Early interaction between the high producing dairy cow and calf – effects of restricted suckling versus artificial rearing in group or individual pen on the growth, feed intake behaviour of the calf and the milk production of the cow. *Swedish University of Agricultural Sciences*, Report 263. ISSN 0347-9838. FOOD21 No. 3/2005. ISSN 1650-5611.

Fulkerson, W. J., Hooley, R. D. & Findlay, J. K. (1978). Improvement in milk production of first calf heifers by multiple suckling. *Australian Journal of Agricultural Research 29*, 351-357.

Galina, C. S., Rubio, I., Basurto, H. & Orihuela, A. (2001). Consequences of different suckling systems for reproductive activity and productivity of cattle in tropical conditions. *Applied Animal Behaviour Science 72*, 255-262.

Grøndahl, A. M., Skancke, E. M., Mejdell, C. M. & Jansen, J. H. (2007). Growth rate, health and welfare in a dairy herd with natural suckling until 6–8 weeks of age: a case report. *Acta Veterinaria Scandinavica 49*. Avaiable from: http://www.actavetscand.com/content/49/1/16 (5 March 2008).

Gubernick, D. J. & Klopfer, P. H. (Eds.) (1981). Parent and infant attachment in mammals. In: Gubernick, D. J. (Ed.) *Parental care in mammals*. 243-305. Plenum press, New York.

Hale, S. A., Capuco, A. V. & Erdman, R. A. (2003). Milk yield and mammary growth effects due to increased milking frequency during early lactation. *Journal of Dairy Science 86*, 2061-2071.

Haley, D. B., Bailey, D. W. & Stookey. J. M. (2005). The effects of weaning beef calves in two stages on their behavior and growth rate. *Journal of Animal Science 83*, 2205-2214.

Haley, D. B., Stookey, J. M., Clavelle, J. L. & Watts, J. M. (2001). The simultaneous loss of milk and maternal contact distress at weaning in beef calves. In: *Proceedings of the 35th Congress of International Society of Applied Ethology*. University of California-Davis. August 4-9, 2001. 41.

Hall, S. J. G. (1979). Studying the Chillingham wild cattle. *The Ark 6*, 72-79.

Hall, S. J. G. (1982). The Chillingham herd of wild white cattle. *Applied Animal Ethology* 9, 96-97.

Hepola, H., Raussi, S., Veissier, I., Pursiainen, P., Ikkeläjärvi, K., Saloniemi, H. & Surjälä-Qvist, L. (2007). Five or eight weeks of restricted suckling: influence on dairy calves' feed intake, growth and suckling behaviour. *Acta Agriculturae Scandinavica Section A 57*, 121-128.

Hudson, S. J. & Mullord, M. M. (1977). Investigations of maternal bonding in dairy cattle. *Applied Animal Ethology 3*, 271-276.

Hutchison, H. G., Woof, R., Mabon, R. M., Salehe, I. & Robb, J. M. (1962). A study of the habits of zebu cattle in Tanganyika. *Journal of Agricultural Science* 59, 301-315.

Illmann, G. & Špinka, M. (1993). Maternal behaviour of dairy heifers and suckling of their newborn calves in group housing. *Applied Animal Behaviour Science 36*, 91-98.

Jasper, J. & Weary, D. M. (2002). Effects of ad libitum milk intake on dairy calves. *Journal of Dairy Science 85*, 3054-3058.

Johansson, I., Korkman, N. & Nelson, N. J. (1952). Studies on udder evacuation in dairy cows. I. The rise in fat percentage during milking. *Acta Agriculturae Scandinavica 2*, 43-81.

Jonasen, B. & Krohn, C. C. (1991). Undersøgelser vedrørande ko-kalv samspil, 4. Adfærd, produktion og sundhed hos pattekalve (SDM). *Beretning fra Statens Husdyrbrugforsøg 689*. (In Danish).

Jensen, M. B. (2004). Computer-controlled milk feeding of dairy calves: The effects of calves per feeder and number of milk portions on use of feeder and social behaviour. *Journal of Dairy Research 87*, 3428-3438.

Junqueira, F.S., Madalena, F.E. & Reis, G.L. (2005). Production and economic comparison of milking F1 Holstein × Gir cows with and without the stimulus of the calf. *Livestock Production Science 97*, 241-252.

Jung, J. (1994). *Temporal patterning of natural suckling behaviour of dairy calves*. Skara: *Swedish University of Agricultural Sciences, Faculty of Veterinary Medicine, Department of Animal Hygiene*. Specialarbete 21. ISSN 0283-0701.

Jung, L. (2001). *Foraging behaviour in cattle. Suckling, begging and grazing in tropical and European cattle*. Diss. Skara: Swedish University of Agricultural Science. ISSN 1401-6257.

Jung, J. & Lidfors, L. (2001). Effects of amount of milk, milk flow and access to a rubber teat on cross-sucking and non-nutritive sucking in dairy calves. *Applied Animal Behaviour Science 72*, 201-213.

Keil, N. M., Audigé, L. & Langhans, W. (2000). Factors associated with intersucking in Swiss dairy heifers. *Preventive Veterinary Medicine 45*, 305-323.

Kiley-Worthington, M. & de la Plain, S. (1983). The behaviour of beef suckler cattle (*Bos taurus*). Tierhaltung 14. Birkhäuser Verlag, Basel.

Klastrup, O. & Schmidt Madsen, P. (1974). Nordiske rekommendationer vedrørende mastitundersøgelser af kirtelprøver. *Nordisk veterinär-medicinsk tidskrift 26*, 197-204. (In Norwegian).

Knowles, R. T. & Edwards, M. D. (1983). A comparison of the effects of restricted suckling and artificial calf rearing systems on dam and calf performance. *The Malaysian Agricultural Journal 54*, 1–9.

Korhonen, H. & Kaartinen, L. (1995). Changes in the composition of milk induced by mastitis. In: Sandholm, M., Honkanen-Buzalski, Kaartinen, Pyörälä, S. (Eds) *The Bovine Udder and Mastitis*. 76-82. Gummerus Kirjapaino, Oy, Jyväskylä.

Krohn, C. C. (2001). Effects of different suckling systems on milk production, udder health, reproduction, calf growth and some behavioural aspects in high producing dairy cows - a review. *Applied Animal Behaviour Science* 72, 271–280.

Krohn, C. C., Foldager, J. & Mogensen, L. (1999). Long-term effect of colostrum feeding methods on behaviour in female dairy calves. *Acta Agriculturae Scandinavica Section A Animal Science 49*, 57-64.

Lefcourt, A. M. & Elsasser, T. H. (1995). Adrenal responses of Angus × Hereford cattle to the stress of weaning. *Journal of Dairy Science 73*, 2669-2676.

Le Neindre, P. (1989). Influence of cattle-rearing conditions and breed on social relationships of mother and young. *Applied Animal Behaviour Science 23*, 117-127.

Leuthold, W. (1977). *African ungulates. A comparative review of their ethology and behavioural ecology*. 158-183. Springer-Verlag, Berlin.

Lidfors, L. M. (1993). Cross-sucking in group-housed dairy calves before and after weaning off milk. *Applied Animal Behaviour Science 38*, 15–24.

Lidfors, L., 1994. *Mother-young behaviour in cattle. Parturition, development of cow-calf attachment, suckling and effects of separation*. Diss. Skara: Swedish University of Agricultural. ISBN 91-576-4830-1.

Lidfors, L. (1996). Behavioural effects of separating the dairy calf immedeately or 4 days post-partum. *Applied Animal Behaviour Science 49*, 269-283.

Lidfors, L. & Isberg, L. (2003). Intersucking in dairy cattle - review and questionnaire. Behaviour and welfare of cattle housed in big groups. *Applied Animal Behaviour Science 80*, 173.

Lidfors, L. & Jensen, P. (1988). Behaviour of free-ranging beef cows and calves. *Applied Animal Behaviour Science 20*, 237-247.

Lidfors, L. M., Jensen, P. & Algers, B. (1994). Suckling in free-ranging beef cattle – temporal patterning of suckling bouts and effects of age and sex. *Ethology 98*, 321-332.

Linzell, J. L. & Peaker, M. (1972). Day-to-day variation in milk composition in the goat and cow as a guide to the detection of subclinical mastitis. *British Veterinary Journal 128*, 284-295.

Little, D. A., Anderson, F. M. & Curkin, J. W. (1991). Influence of partial suckling of crossbred dairy cows on milk yield off-take and calf growth in the Ethiopian highlands. *Tropical Animal Health and Production 23*, 109-114.

Loberg, J. & Lidfors, L. (2001). Effect of milkflow rate and presence of a floating nipple on abnormal sucking between dairy calves. *Applied Animal Behaviour Science 80,* 207-231.

Loberg, J. M., Hernandez, C. E., Thierfelder, T., Jensen, M. B., Berg, C. & Lidfors, L. (2008). Weaning and separation in two steps – a way do decrease stress in dairy calves suckled by foster cows. *Applied Animal Behaviour Science 111*, 223-234.

Lowry, R. (1999–2005). Concepts and Applications of Inferential Statistics. Vassar College Poughkeepsie, NY, USA. http://faculty.vassar.edu/lowry/webtext.html (accessed 15-Jun-2005).

Lupoli, B., Johansson, B., Uvnäs-Moberg, K. & Svennersten-Sjaunja, K. (2000). Effect of suckling on the release of oxytocin, prolactin, cortisol, gastrin, cholecystokinin, somatostatin and insulin in dairy cows and their calves. *Journal of Dairy Research 68*, 175-187.

Margerison, J. K., Preston, T. R. & Phillips, C J. C. (2002). Restricted suckling of tropical dairy cows by their own calf or other cows' calves. *Journal of Animal Science 80*, 1663-1670.

Margerison, J. K., Preston, T. R., Berry, N. & Phillips, C. J. C. (2003). Cross-sucking and other oral behaviours in calves, and their relation to cow suckling and food provision. *Applied Animal Behaviour Science 80*, 277-286.

Martin, P. (1984). The meaning of weaning. *Animal Behaviour 32*, 1257-1259.

Mason, G. J. (1991). Stereotypies: a critical review. *Animal Behaviour 41*, 1015-1037.

Mejia, C. E., Preston, T. R. & Fajersson, P. (1998). Effects of restricted suckling versus artificial rearing on milk production, calf performance and reproductive efficiency of dual purpose Mpwapwa cattle in a semi-arid climate. *Livestock Research for Rural Development 10*. Available from: http://www.cipav.org.co/lrrd/lrrd10/1/meji101.htm (6 November 2008).

Metz, J. (1987). Productivity aspects of keeping dairy cow and calf together in the post-partum period. *Livestock Production Science 16*, 385-394.

Nicol, A. M. & Sharafeldin, M. A. (1975). Observations on the behaviour of single-suckled calves from birth to 120 days. *Proceedings of the New Zealand Society of Animal Production* 35, 221-230.

Nielsen, P. P., Jensen, M. B. & Lidfors, L. (2008). Milk allowance and weaning method affect the use of a computer controlled milk feeder and the development of cross-sucking in dairy calves. *Applied Animal Behaviour Science 109*, 223-237.

Norrbom, S. (2001). *Suckling system in dairy production – experiences and solutions for building design*. Alnarp: Swedish University of Agricultural Sciences. Department of Agricultural Biosystems Technology. Thesis, 6. (In Swedish, English abstract).

NRC. (2001). National Research Council. Nutrient requirements of dairy cattle. 7th rev. ed. National. Academy of Science, Washington, DC.

Orihuela, A. (1990). Effect of calf stimulus on the milk yield of Zebu-type cattle. *Applied Animal Behaviour Science 26*, 187-190.

Örtendahl, M. (1996). *Milk production combined with suckling calves – a case study on Ekenäs estate of behaviour, calf growth, milk production and udder health*. Uppsala: Swedish University of Agricultural Sciences, Department of Agricultural Engineering, Building Design Section, Report 212. (In Swedish, abstract in English). ISSN 0283-0086.

Phillips, C. (1993). *Cattle behaviour*. Farming Press Books, Ipswich, UK.

Preston, T.R. (1984). Restricted suckling: effects on cow and calf performance. Maximum livestock from minimum land. In: *Proceedings of 4th seminar*, Bangladesh Agricultural University, Mymensingh, May, 2-4, 1983. 54-66. James Cook University of North Queensland, Townsville.

Preston, T. R. & Vaccaro, L. (1989). Dual purpose cattle production systems. In: C.J.C. Phillips (Ed.) *New Techniques in Cattle Production*. 20–32. Butterworths, London.

Price, E. O. (1984). Behavioral aspects of animal domestication. *The Quarterly Review of Biology 59,* 1-32.

Price, E. O., Harris, J. E., Borgward, R. E., Sween, M. L. & Connor, J. M. (2003). Fenceline contact of beef calves with their dams at weaning reduces the negative effects of separation on behaviour and growth rate. *Journal of Animal Science 81*, 116-121.

Price, E. O., Thos, J. & Anderson, G. B. (1981). Maternal responses of confined beef cattle to single versus twin calves. *Journal of Animal Science 53*, 934-939.

Rasmussen, M. D. & Larsen, H. D. (1998). The effect of post milking teat dip and sucklingon teat skin condition, bacterial colonisation, and udder health. *Acta Veterinaria Scandinavica 39*. 443–452.

Redbo, I. (1992*). Sterotypies in dairy cattle – and their relation to confinement, production-related factors, physiological reactions, and adjoining behaviours*. Diss. Skara: Swedish University of Agricultural Science. ISSN 0347-9838.

Reinhardt, V. & Reinhardt, A. (1981a). Cohesive relationship in a cattle herd (*Bos indicus*). *Behaviour* 77, 121-150.

Reinhardt, V. & Reinhardt, A. (1981b). Natural sucking performance and age of weaning in zebu cattle (*Bos indicus*). *Journal of Agricultural Science, Cambridge 96*, 309-312.

Rigby, C., Ugarte, J. & Boucourt, R. (1976). Rearing dairy calves by restricted suckling. VII. Effect on mastitis development caused by Staphylococcus aureus. *Cuban Journal of Agricultural Science 10*, 35-40.

Sambraus, H. H. (1985). Mouth-based anomalous syndromes. In: Fraser, A.F. (Ed.), *Ethology of farm animals*. 391-422. Elsevier, Amsterdam.

Sandholm, M. (1995). Inflammation in Mastitis. In: Sandholm, M., Honkanen-Buzalski, Kaartinen, Pyörälä, S. (Eds). *The Bovine Udder and Mastitis*. 59-75. Gummerus Kirjapaino, Oy, Jyväskylä.

Sandoval-Castro, C. A., Anderson, S. & Leaver, J. D. (1999). Influence of milking and restricted suckling regimes on milk production and calf growth in temperate and tropical environments. *Animal Science 69*, 287-296.

Sandoval-Castro, C. A., Anderson, S. & Leaver, J. D. (2000). Production responses of tropical crossbred cattle to supplementary feeding and to different milking and restricted suckling regimes. *Livestock Production Science 66*, 13-23.

Sanh, M. V., Preston, T. R. & Fajersson, P. (1995). Effects of restricted suckling versus artificial rearing on performance and fertility of Bos Taurus and Bos indicus cows and calves in Tanzania. *Livestock Research for Rural Development 6*. Available from: http://www.cipav.org.co/lrrd/lrrd6/3/10.htm (1 March 1998).

Sanh, M. V., Preston, T. R. & Le Viet, L. (1997). Effects of restricted suckling versus artificial rearing on performance and fertility of crossbred F1 (Holstein × Local) cows and calves in Vietnam. *Livestock Research for Rural Development 9*. Available from: http://www.cipav.org.co/lrrd/lrrd94/sahn941.htm; pp. 1-9 (1 March 1998).

Sato, S., Tarumizu, K. & Hatae, K. (1993). The influence of social factors on allogroming in cows. *Applied Animal Behaviour Science 38*, 235-244.

Sato, S., Nagamine, R. & Kubo, T. (1994). Tongue-playing in tethered Japanese Black cattle: diurnal patterns, analysis of variance and behaviour sequences. *Applied Animal Behaviour Science 39*, 39-47.

Sejrsen, K., S. Purup, M. Vestergaard, & J. Foldager. (2000). High body weight gain and reduced bovine mammary growth: physiological basis and implications for milk yield potential. *Domestic Animal Endocrinology 19*, 93-104.

Sjaunja, L.O., Baevre, L., Junkarinen, L., Pedersen, J. & Setälä, J. (1990). A Nordic proposal for an energy corrected milk (ECM) formula. ICAR, 27th session. 156-157. July 2-6, Paris. EAAP Publication No 50, 1991.

Smith, M. E., Callow, C. & McSweeny, B. J. (1973). Ten and eighteen-week suckling of Friesian steers. In: *Proceedings of the New Zealand Society of Animal Production 33*, Wellington, Vol 11. 161-175.

Somerville, S. H. & Lowman, B. G. (1979). Observations on the nursing behaviour of beef cows suckling Charolais cross calves. *Applied Animal Ethology 5*, 369-373.

Špinka, M. & Illmann, G. (1992). Suckling behaviour of young dairy calves with their own and alien mothers. *Applied Animal Behaviour Science 33*, 165-173.

Statistics Sweden. 2008. Yearbook of Agricultural Statistics 2008 including Food Statistics. Official Statistics of Sweden. Available from: http://www.scb.se/statistik/_ Publikationer/JO1901_2007A01_BR_00_JO01BR0801.pdf (accessed 10-Oct-2008.

Stephens, D. B. (1982). A review of some behavioural and physiological studies which are relevant to the welfare of young calves. In: Signoret, J. P. (Ed.). *Welfare and Husbandry of Calves*. 47–69. Martinus Nijhoff, The Hague.

Stěhulova, I., Lidfors, L. & Špinka, M. (2008). Response of dairy cows and calves to early separation: Effect of calf age and visual and auditory contact after separation. *Applied Animal Behaviour Science 110*, 144-165.

Stookey, J. M., Schwartzkopf-Fenswein, K. S., Waltz, C. S. & Watts, J. M. (1997). Effects of remote and contact weaning on behaviour and weight gain of beef calves. *Journal of Animal Science 75 (Supplement 1)*, 157 (Abstract).

Svensson, C., Lundborg, K., Emanuelson, U. & Olsson., S-O. (2003). Morbidity in Swedish dairy calves from birth to 90 days of age and individual calf-level risk factors for infectious diseases. *Preventive Veterinary Medicine 58*, 179-197.

Swansson, E. W. & Harris., J. E. (1958). Development of rumination in young calf. *Journal of Dairy Science 41*, 1768-1776.

Tancin, V., Kraetzl, W-D., Schams, D. & Bruckmaier, R. M. (2001). The effects of conditioning to suckling, milking and of calf presence on the release of oxytocin in dairy cows. *Applied Animal Behaviour Science 72*, 235-246.

Tesorero, M., Combellas, J., Uzcátegui, W. & Gabaldón, L. (2001). Influence of suckling before milking on yield and composition of milk from dual purpose cattle with restricted suckling. *Livestock Research for Rural Development 13*. Avaiable from: http://www.cipav.org.co/lrrd/lrrd13/1/teso131.htm. (20 February 2002).

Thomas, T. J., D. M. Weary, & Appleby, M. C. (2001). Newborn and 5-week-old calves vocalize in response to milk deprivation. *Applied Animal Behaviour Science* 74, 165-173.

Thomas, G. W., Spiker, S. A. & Mickan, F. J. (1981). Influence of suckling by Friesian cows on milk production and anoestrus. *Australian Journal of Experimental Agriculture 21*, 5–11.

Uvnäs-Moberg, K. (1997). Physiological and endocrine effects of social contact; role of oxytocin. *Annales of the New York Academy of Sciences (New York NY) 807*, 146-163.

Van Putten, G. & Elshof, W. J. (1982). Inharmonious behaviour in veal calves. *Hohenheimer Arbeiten 121*, 61-71.

Veissier, I. & Le Neindre, P. (1989). Weaning in calves: Its effects on social organization. *Applied Animal Behaviour Science 24*, 43-54.

Veissier, I., Ramirez de la Feb, A. R. & Pradel, P. (1998). Non-nutritive oral activities and stress responses of veal calves in relation to feeding and housing conditions. *Applied Animal Behaviour Science 57*, 35-49.

Vitale, A. F., Tenucci, M., Papini, M. & Lovari, S. (1986). Social behaviour of the calves of semi-wild Maremma cattle, *Bos primigenius taurus*. *Applied Animal Behaviour Science 16*, 217-231.

Víchová, J. & Bartoš, L. (2005). Allosuckling in cattle: Gain or compensation? *Applied Animal Behaviour Science 94*, 223-235.

Waltl, B., Appleby, M. C. & Sölkner, J. (1995). Effects of relatedness on the suckling behaviour of calves in a herd of beef cattle rearing twins. *Applied Animal Behaviour Science 45*, 1-9.

Walker, D. E. K. (1962). Suckling and grazing behaviour of beef heifers and calves. *New Zealand Journal of Agricultural Research 5*, 331-338.

Weary, D. M. & Chua, B. (2000). Effects of early separation on the dairy cow and calf. 1. Separation at 6 h, 1 day and 4 days after birth. *Applied Animal Behaviour Science 69*, 177-188.

Wiepkema, P. R., van Hellemond, K. K., Roessingh, P. & Romberg, H. (1987). Behavioural and abomasal damage in individual veal calves. *Applied Animal Behaviour Science 18*, 257–268.

Wilde, C. J., Addey, C. V. P., Boddy, L. M. & Peaker, M. (1995). Autocrine regulation of milk secretion by a protein in milk. *Biochemical Journal 305*, 51-58.

Woivalin, A. (1990). Beteende hos frigående mjölkkokalvar – socialt beteende. *Veterinärmedicinska högskolan, Institutionen för husdjurshygien*, Helsingfors. (Abstract in English).

Wood-Gush, D. G. M., Hunt, K., Carson, K., Dennison, S. G. C. (1984). The early behaviour of suckler calves in the field. *Biology of Behaviour 9*, 295–306.

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