Applied Animal Behaviour Science 181 (2016) 1–11

Contents lists available at ScienceDirect

Applied Animal Behaviour Science

journal homepage: www.elsevier.com/locate/applanim

Is rearing calves with the dam a feasible option for dairy farms?—Current and future research

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ARTICLE INFO

Article history:
Received 8 May 2015
Received in revised form 6 November 2015
Accepted 15 November 2015
Available online 27 November 2015

Keywords:
Dairy calves
Alternative calf rearing
Suckling
Welfare

ABSTRACT

In the dairy industry it is common practice to separate cow and calf shortly after birth but this practice is disputed because of animal welfare concerns. Some producers, in many countries, milk cows that also nurse dairy calves. These cow–calf systems allow nursing as well as affiliative and other natural behaviours. In this review paper we describe cow–calf systems used in practice and/or in research, discuss the benefits and challenges documented by research, and identify areas where more research is needed. Four cow–calf systems are described: (1) free contact systems where cow and calf have unrestricted access to each other; (2) restricted suckling systems allowing short daily contact only to nurse; (3) half day contact where cow and calf are housed together during the day or night; and (4) foster cow systems where one cow nurses 2–4 calves usually without milking. In free and half day cow–calf contact systems the calf drinks large amounts of milk and has high daily weight gains. High pre-weaning calf weight gains have been shown to lead to higher milk yield during that animal's first lactation. One issue with cow–calf systems is the depressed weight gain of calves at weaning. The premature separation of cow and calf, compared to the natural situation, may cause stress especially in free contact systems. Weaning and separation should therefore occur in two steps. Half day contact seems particularly promising because animals get used to being separated, they experience positive human handling, and calves can learn to use a milk feeder which will prevent the growth check following weaning. Nursing cows yield less saleable milk during the suckling period, can have problems with milk ejection during machine milking and have a lower fat content of the milk, compared to non-nursing cows. Udder health of the cow may be positively affected by nursing. A rich social rearing environment has recently been shown to improve cognitive skills of calves. Still, studies on long term effects of dam rearing on behaviour, health, production and farm economics are few. There is also a need to address ways to control transmissible diseases when dairy cattle are kept in mixed age groups. Increased knowledge will help us design functional high tech dairy management systems that respect the natural behaviour of cows and calves during the calf rearing period.

1. Introduction

On most dairy farms, the calf is routinely separated from the dam shortly after birth. This practice deprives dairy cows and calves of forming bonds and profiting from natural interactions, and is criticized from an animal welfare point of view (e.g., von Keyserlingk and Weary, 2007). However, calves are hiders and this may be why the practice of separating calves and cows at birth has been successful. The cow seeks isolation from the herd before parturition, and the calf is left alone and hides while the dam is foraging (Kilgour and Dalton, 1984; Vitale et al., 1986; Langbein and Raasch, 2000). When the cow returns to the herd with her calf, the calf seeks the company of other calves, and from approximately the age of two weeks calves spend much time in "kinder-garden" groups (e.g., Reinhardt et al., 1977; Kiley-Worthington and de la Plain, 1983; Vitale et al., 1986).

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http://dx.doi.org/10.1016/j.applanim.2015.11.011
0168-1591/

Over the past decade, a number of studies have explored different ways of keeping cows and calves together and examined possible benefits of this more natural rearing system, including the expression of natural behaviours. In many cow–calf systems, calves can choose the frequency of meals and meal sizes that fit their physiological needs. Studies looking at calf growth highlight the large discrepancy between the low amount of milk usually fed to calves on farms and the large amount the calves will drink when allowed to suckle freely from their dam (Grøndahl et al., 2007; Khan et al., 2011). There is a growing body of evidence that early high milk intake leads to higher milk production in the heifers' first lactation (Shamay et al., 2005). All these results support the view that leaving cow and calf together before weaning can improve calf welfare and also give some production benefits. However, high milk intakes by calves can be achieved without dam rearing, and there are challenges with dam rearing systems which need to be addressed.

This review and discussion paper is inspired by the satellite workshop "Dam rearing in dairy production" during the annual meeting of the International Society for Applied Ethology (ISAE) 2014. Workshop participants described and discussed cow–calf systems, production traits of the suckled cow and effects on calf development as well as productivity when becoming a dairy cow.

In the current paper we present and discuss the advantages and disadvantages of the different cow–calf systems as well as further research opportunities in this area. We examine welfare and productivity aspects (milk yield, milk composition and growth), including long-term effects for the cow and calf, as well as practical challenges such as labour inputs and problems with milk let down at milking. We also explore novel advantages, recently demonstrated, such as the flexible learning capacity of calves when raised in complex social environments as compared to calves raised in a conventional individual housing system (Costa et al., 2014; Gaillard et al., 2014; Meagher et al., 2014). We describe ways of managing cow–calf rearing that may be attractive to producers as well as the public. Finally we discuss how studies of dam rearing of dairy calves have permitted scientists to study and better understand the physiology, behaviour and performance of calves and cows from a different angle. These findings and approaches are clearly opening the way to a different look at how to improve cow and calf welfare on dairy farms.

There are differences between dam rearing in *Bos taurus* and *Bos indicus* which at some points are mentioned but the focus of this paper is high yielding *B. taurus* dairy cows.

2. Dairy cow–calf systems

The design elements of the different dairy cow–calf systems originate to a large extent from practical developments and the experience of farmers who keep cows and calves together. In Norway and Sweden, respectively, 18% and 22% of the organic dairy farmers let the calves suckle beyond the mandatory 3 days (now 1 day for Sweden), mostly for one week, but some for an extended period up to the age of 13 weeks (Ellingsen et al., 2015). In this section, we will review and describe the effects of the different suckling systems on cow–calf bonding, on responses of cows and calves to separation and weaning as well as on calf growth. Advantages and disadvantages of the different systems regarding behaviour and calf performance, as compared to conventional rearing, are given in Table 1.

2.1. Free cow–calf contact

Free contact systems imply that the cow and her calf are kept together 24 h/d for an extended period of time (mostly 6 to 12 weeks) during which the cow is milked, usually twice daily. Consequently cow and calf are free to interact and can nurse at any time. This system has been implemented in different cow management systems: cubicle housing with an automatic milking system (Fröberg and Lidfors, 2009); cubicle housing with milking parlour where a selection gate permits calves' exclusive access to a separate calf creep area (Roth et al., 2009; Fröberg et al., 2011; Wagner et al., 2013), and lastly deep litter straw yard system with a concrete loafing area and a separate calf creep area (Johnsen et al., 2015c; Zipp et al., 2015).

Benefits of the free contact system for the calf include high weight gains and contact with the dam as well as other cows and calves (Table 1). The weight gain of free suckling calves is higher than that of calves reared without the dam in the conventional limit milk feeding system (usually a milk allowance of 10–13% of body weight per day). In fact, average daily weight gains of 0.9 kg to 1.4 kg during the first months are reported for calves suckling their dam (Grøndahl et al., 2007; Roth et al., 2009).

Care-taking behaviours by the dam, nursing, and cow–calf bonding which include affiliative behaviours such as licking, rubbing and staying close are important natural behaviours of cattle (Wagenaar and Langhout, 2007) and are all performed in a free contact system. Calves in free-contact systems show less abnormal behaviours such as tongue-rolling and cross-sucking during the pre-weaning period compared to calves reared without the dam and fed conventional restricted amounts of milk (Table 1). Cross-sucking refers to the behaviour of a calf sucking ears, navel or scrotum of other calves in a group. It is stimulated by the intake of milk and linked to an unsatisfied motivation to suck (de Passillé, 2001), insufficient oral stimulation (Vaughan et al., 2012) or hunger (Herskin et al., 2010). Cows and calves also have a better chance to self-regulate the frequency and timing of suckling bouts which are reported to vary between 4 and 9 depending on calf age (Fröberg and Lidfors, 2009; Jensen, 2011) and is similar to that of cattle kept under semi-natural conditions (Reinhardt and Reinhardt, 1981).

Due to the calves' high milk intake and therefore loss of saleable milk for the farmer, separation is done prematurely, for instance at 8–12 weeks, which is long before natural weaning takes place, i.e., 8–12 months of age (Reinhardt and Reinhardt, 1981). One main disadvantage of the free contact system is the frequent, high pitched vocalizations by cows and calves which occur during the first days after separation and indicate severe distress (Johnsen et al., 2015c). Many farmers find this distressing, too. Following early weaning, calves often perform abnormal oral behaviours, partly because they are hungry (Jung and Lidfors, 2001). Suckling calves usually have low intakes of solid feed before weaning (Roth et al., 2009; Fröberg et al., 2011). The sudden shift of reliance on milk to solid feed results in a period of low weight gains post-weaning accompanied by behavioural signs of stress (Fröberg and Lidfors, 2009; Johnsen et al., 2015c). These findings clearly indicate that ways to increase solid feed intake of nursed calves pre-weaning as well as the development of weaning management systems that mitigate the growth check following weaning are needed before the free contact system can be recommended.

2.2. Restricted suckling contact

Restricted suckling systems imply that the calf is allowed to suckle its own dam during 1–2 short periods daily, often around milking hours. Cow and calf may for instance stay together for 2×15 min (de Passillé et al., 2008; Roth et al., 2009), or 2×30 min (Fröberg et al., 2007). For the rest of the day cow and calf are separated. Restricted suckling systems are commonly practiced in milk producing herds in tropical areas (Das et al., 2001; Fröberg et al., 2008). Restricted suckling contact occurs in tie stall systems in Norway, Sweden (Johnsen, personal communication) and

Table 1
Advantages (+) and disadvantages (−) of different dairy cow–calf rearing systems compared to conventional rearing with respect to measures of dairy calf performance and cow and calf behaviour. The studies are sorted by the number of weeks of suckling since birth.

	Aspect		Free cow-calf contact	weeks		Restricted suckling contact	weeks		Half day contact	weeks		Foster mother	weeks
Calf productivity	Pre-weaning milk intake from the dam[a]				=	Lupoli et al. (2001)	1				+	Mendoza et al. (2010)	8
					+	Mendoza et al. (2010)	8				-	Margerison et al. (2002)	26
					=	Fröberg et al. (2008)	8						
					+	de Passillé et al. (2008)	9						
					-	Margerison et al. (2003)	26						
					+	Boden and Leaver (1994)	31						
	Growth pre-weaning[a]	+	Metz (1987)	0.5	+	Jonasen and Krohn (1991) cited in Krohn (2001)	8	+	Johnsen et al. (2015b)	6	+	Loberg et al. (2008)	10
		+	Grøndahl et al. (2007)	6-8	=	Fröberg et al. (2008)	8	+	Veissier et al. (2013)	10	-	Margerison et al. (2002)	26
		+	Fröberg et al. (2011)	8	+	de Passillé et al. (2008)	9						
		+	Veissier et al. (2013)	10	+	Roth et al. (2009)	12						
		+	Roth et al. (2009)	12	-	Margerison et al. (2002)	26						
		+	Wagenaar and Langhout (2007)	12									
	Growth post-weaning	+	Metz (1987)	0.5	-	Jonasen and Krohn (1991) cited by Krohn (2001)	8	+	Johnsen et al. (2015b)	6	+	Loberg et al. (2008)	10
		+	Grøndahl et al. (2007)	6-8	-	Hepola et al. (2007)[b]	5	+	Veissier et al. (2013)	10	=	Margerison et al. (2002)	26
		-	Fröberg et al. (2011)	8	+	Roth et al. (2009)	12						
		-	Veissier et al. (2013)	10	+	Margerison et al. (2002)	26						
		-	Roth et al. (2009)	12									
Behaviour	Cross-sucking pre-weaning	+	Fröberg and Lidfors (2009)	8	+	Fröberg et al. (2008)	8	=	Veissier et al. (2013)	10			
		=	Fröberg et al. (2011)	8	+	Roth et al. (2009)	12						
		=	Veissier et al. (2013)	10	+	Fröberg et al. (2007)	16						
		+	Roth et al. (2009)	12	+	Margerison et al. (2003)	26						
	Cross-sucking post-weaning	=	Fröberg et al. (2011)	8	+	Fröberg et al. (2008)	8	=	Veissier et al. (2013)	10			
		-	Veissier et al. (2013)	10	+	Roth et al. (2009)	12						
		+	Roth et al. (2009)	12									
	Affiliative behaviour between cow and calf	+	Lidfors (1996)	0.5	+	Fröberg et al. (2008)	8	+	Johnsen et al. (2015b)	6			
					+	Roth et al. (2009)	12						
					+	Schneider et al. (2007)	12						
					+	Fröberg et al. (2007)	16						
	Post-separation stress response	-	Fröberg et al. (2009)	8				-	Veissier et al. (2013)	10	-	Loberg et al. (2008)	10
		-	Johnsen et al. (2015a)	8									
		-	Veissier et al. (2013)	10									

[a] In conventional rearing control the milk allowance may be reduced compared to the cow–calf system investigated.
[b] Improved post-weaning growth by using a gradual step-down in daily suckling bouts from 5th to 8th week.

in Germany and Switzerland where it also occurs in cubicle or deep litter housing systems (Zumbrunnen, 2012).

Even in the restricted suckling system the cow–calf pairs show behaviours indicative of recognition and bonding (Table 1): upon reunion during the daily nursings, cows and calves rapidly approach, sniff, rub and lick each other. Also, cross-sucking is rare according to several authors (See Table 1). However, more research is needed to clarify how cow and calf perceive this limited contact and how this management affects the development of social and cognitive abilities of the calf. There is little published information about the responses of calves and their dams to separation and weaning in restricted suckling systems. Newberry and Swanson (2008) suggested that periods of forced separation between cow and calf may encourage the development of social independence from the dam and in this way the repeated daily separation of calf and cow may be beneficial. Roth et al. (2008) showed that the heart rate was higher in the nursed calves during an isolation test compared to calves reared at the automatic feeder. According to anecdotal reports from German farmers using restricted suckling (often 2 × 60 min per day), separation stress is evident. To reduce the stress, they often wean the calves gradually by decreasing contact frequencies and duration before complete separation.

Weight gains reported for calves in restricted suckling systems are highly variable, both pre- and post-weaning. This variation is likely related to the variation in time spent together and the timing of the nursing relative to the milking of the cow, the breeds used as well as the milk production level of the cows in the different studies. In fact, some studies have reported relatively low daily gains (i.e., less than 0.5 kg) (Das et al., 1999; Margerison et al., 2002; Fröberg et al., 2007). Daily milk intake of calves in a restricted suckling system varies between 1.1 kg/d for tropical breeds (Margerison et al., 2002; Fröberg et al., 2008) and 8–10 kg/d for Holstein calves (de Passillé et al., 2008), the latter being comparable to the ad libitum amounts calves drink from an artificial teat (Appleby et al., 2001; de Passillé et al., 2008). This indicates that calves are able to ingest large amounts of milk in a short time when suckling high yielding cows.

Disadvantages of the restricted suckling system are (1) calves have a lower intake of concentrates than calves reared without the dam on a restricted milk allowance and show low growth rates after separation and weaning (Table 1); (2) the possibilities for the calf to learn from the dam or other cows are limited; and (3) leading the calves to and from the dams for nursing can be labour intensive depending on how it is managed.

2.3. Half day calf–cow contact

This system, which is less studied than the free contact and the restricted suckling contact systems, lies in between the two and implies that cow and calf are kept together for around 12 h/d. It was first studied by Veissier et al. (2013) who compared two contact systems; free contact and part time contact during daytime only, hereafter referred to as half day contact. The authors showed that the calves in a half day contact system had high weight gains not only pre-weaning, but also post-weaning (0.95 kg/d). The positive effects on growth during and after weaning were attributed to the fact that calves in the half day contact system were accustomed to being separated from the dam and were less dependent on the dam. When integrating a milk feeder into a half day contact system, calves that were trained to use the feeder during the suckling period continued to use it once they were separated from the dam (Johnsen et al., 2015a). As a result, these calves were nutritionally more independent from the dam at separation such that the calves maintained very good weight gains during separation and weaning.

Fig. 1. An automated gate controls the access of calves to the cows.

Cow–calf pairs kept in a half day contact system also performed bonding behaviours (Johnsen et al., 2015b). Interestingly, a strong bond was formed even when suckling was prevented by equipping the cow with an udder net (Johnsen et al., 2015b). By showing that the cow–calf bond is more than a nutritional one, the authors demonstrate that the mother-young relationship is complex in cattle. The udder net may be a viable way of allowing cow–calf contact without suckling, but the effects on milking management and the resulting labour load have not been investigated yet.

The daily separating and reuniting of cow and calf in the half day contact systems is considered labour intensive. However, studies have shown that calves' access to the dams can be automated (Fig. 1; Roth et al., 2009; Wagner et al., 2012).

2.4. Foster cow system

The foster cow system implies that 2–4 calves are kept together and suckle one cow. The cow's own calf may or may not be among the calves. In the traditional system the cow is not milked, but this may vary depending on stage of lactation and number of calves per cow. A foster cow system can follow a dam rearing system when calves are dam reared for the first week(s) after birth and then transferred to a foster cow (Ellingsen et al., 2015).

Advantages of the foster cow system include calves living in groups, having contact with adult cows and performing natural suckling behaviour (Loberg and Lidfors, 2001). Difficulties with this system occur when a foster cow does not accept, or does not form a bond with the calves. Although most foster cows accept alien calves (Loberg and Lidfors, 2001), fostered calves often receive less affiliative behaviours from the foster cow compared to the cow's own calf, and the foster cow may often show preference for 1–2 specific calves (Loberg, 2007).

The weight gains of calves suckling foster cows are highly variable, especially when the cow has a low milk production. There is little published information on the solid feed intake and post-weaning performance of fostered calves. Foster cow and calves show behavioural reactions to separation indicative of considerable stress (Loberg et al., 2007, 2008) and this research also showed that a two-step weaning system using nose-flaps (Haley et al., 2005) on the foster calves alleviates post-separation stress for both cow and calf, as it does in beef cattle.

3. Influence of suckling on milking performance in dairy cows

Zebu cattle (*B. indicus*) and crossbreeds of Zebu nursing their calves shortly before and after each milking, are reported to yield

a similar (Little et al., 1991; Negrão and Marnet, 2002; Junqueira et al., 2005) or higher (Kaskous et al., 2006) amount of saleable milk compared to that of non-suckled cows. However, in European dairy cows (*B. taurus*) the situation is reversed. By allowing suckling, the amount of saleable milk is reduced by 7–12 kg in restricted suckling and up to 20 kg per day in free contact systems (Barth et al., 2007; Schneider et al., 2007; de Passillé et al., 2008; Mendoza et al., 2010; Zipp et al., 2013). There are two reasons for this decrease in collected milk: first, the calves drink a lot of milk, more than given to calves in conventional dairy calf rearing (e.g., Sandoval-Castro et al., 1999; de Passillé et al., 2008; Fröberg et al., 2008), and second, the alveolar milk ejection response can be impaired.

The indicators of an impaired alveolar milk ejection reflex when compared to the expected alveolar milk ejection in a non-nursing cow, are (1) a slower milk flow during machine milking (Barth et al., 2010; Mendoza et al., 2010; Zipp et al., 2013); (2) a bimodal rather than a unimodal milk flow pattern with one plateau, unless the cisternal milk was sucked by the calf before milking, in which case a unimodal pattern is seen (Barth et al., 2007); (3) a higher amount of residual milk after milking: 8.7 kg (25% of total milk yield) in cows nursing a calf 2 h after milking vs. 3.2 kg (8% of total milk yield) in non-nursing cows (de Passillé et al., 2008); and (4) a reduced milk fat content by 1.0–1.5% (Table 2) as explained physiologically by Ontsouka et al. (2003).

In the following sections, possible implications of the reduced milk ejection and approaches to overcome it are discussed.

3.1. Cow welfare during milking

Nursing cows release less oxytocin during machine milking compared to non-nursing cows (Akers and Lefcourt, 1984; de Passillé et al., 2008) and compared to dams during nursing (Akers and Lefcourt, 1982; Lupoli et al., 2001). This reduced oxytocin release might be caused by an aversion to being milked or because the cow is keeping milk for the calf (de Passillé et al., 2008).

Schneider et al. (2007) and Zipp et al. (2014) compared behavioural and physiological responses to milking in nursing cows in a free and restricted (only Schneider et al., 2007) contact system to a control group of non-nursing cows. They found moderate indications of stress in the nursing cows in terms of vocalisation, tense postures, wide open eyes, absence of rumination (Schneider et al., 2007) or more elimination behaviour (Zipp et al., 2014). However, there were no differences in kicking (Schneider et al., 2007; Zipp et al., 2014) and stepping behaviour or in heart rate during milking (Zipp et al., 2014).

3.2. Udder health

Concerns have been raised with respect to udder health in nursing cows. It is suggested that the increased residual milk in the udder after milking may serve as a substrate for pathogens and increase the risks of mastitis (Bruckmaier and Wellnitz, 2008). However, studies with non-nursing dairy cows in the USA, New Zealand and Australia on earlier automatic cluster removal in order to shorten milking duration with consequently higher amounts of residual milk do not support this. At least for herds with initially low somatic cell count (SCC), no or minor increases in somatic cell counts were found (Jago et al., 2010; Edwards et al., 2013) and no differences in incidences of mastitis were reported (Clarke et al., 2004). In herds with *Streptococcus agalactiae* problems, the situation could be different and suckling is suspected to increase the risk for mastitis (Blowey and Edmondson, 2010; Jago et al., 2010). Nevertheless, the udder health of nursing and non-nursing cows is reported to be similar or better in nursing cows in a number of studies (Table 2). This may result from the residual milk being consumed by the calf soon after milking (de Passillé et al., 2008) which would also reduce the risk of a lower milk production due to high residual milk (Blowey and Edmondson, 2010).

3.3. Effects on milk yield

Evidence that suckling can increase total milk yield (harvested and suckled milk combined) has been reported (Ryle and Orskov, 1990). During the suckling period, the high milk intake by the calf reduces the harvested milk yield as compared to non-nursing cows (Table 2). A lower milk yield can continue during the first week after weaning (Metz, 1987), but disappears in the post-weaning period (reviewed by Krohn, 2001; de Passillé et al., 2008). Interestingly, several studies have reported that over the whole lactation there is not a significant difference in milk yield between nursing and non-nursing cows (Table 2). However, some of these studies have limitations. Metz (1987) investigated a nursing period of only 10 days. Margerison et al. (2002) reported on a special breed (Lucerna breed) under tropical conditions. The non-significant result of Kišac et al. (2011) who compared suckling during one vs. two and three weeks reported a difference of 700 kg between groups. In contrast to these results, other authors report a lower overall milk production in cows that have nursed calves (Table 2). Thus, further studies are needed to evaluate the influence of suckling on lactation yield and the conditions that ensure better milk yield at milking.

3.4. Influence on the fat content and composition of milk

While milk composition is mainly influenced by genetics (breed and individual), nutrition, stage of lactation, disease and age of the cow (Oldham and Sutton, 1979), a reduced fat content of milk at milking is repeatedly reported for nursing cows. Although the fat content of the produced milk is not reduced, the fat content of the milk harvested at milking is, due to milk ejection problems as explained above. This may cause a problem for the producer when the fat content of the bulk tank must attain a certain level. In fact, if herds are small or routinely have low fat levels or if calving is seasonal, any extra decrease in fat content can affect the price the producer obtains for the milk. The impact of milk fat content on milk prices differs between dairies and countries.

Another issue is the quality of the fat composition. Recent studies report a lower amount of polyunsaturated fatty acids (PUFA) in the milk during the suckling period (Cozma et al., 2013: dairy cows; Tzamaloukas et al., 2015: ewes). These fatty acids are beneficial for human health (reviewed by Haug et al., 2007) and therefore desirable. Higher PUFA-content in the milk is a result of feeding fresh green fodder, mainly by extended grazing which is more common in organic or low-input farm-systems (e.g., Butler et al., 2011; Kusche et al., 2015). As dam rearing is often adopted on such farms, more research is needed to examine effects of nursing on the milk PUFA-content and on effects of combining dam rearing and grazing.

In general, the protein content of milk is relatively stable and mainly influenced by genetics and feed energy and protein content (Oldham and Sutton, 1979). Studies on the influence of dam rearing on the protein content in milk are rare and report conflicting results. Some found a weak increase (Boden and Leaver, 1994; Lidfors and Johansson, 2005; Schneider et al., 2007), others a decrease (Cozma et al., 2013) in the protein content of dams' milk. Mendoza et al. (2010) did not find any differences. Neither reasons for these different results nor which milk proteins are possibly influenced are known so far.

3.5. Attempts to overcome milk ejection problems

One method to overcome severe milk ejection problems during milking is the injection of exogenous oxytocin (Wellnitz and Bruckmaier, 2001). Injection of exogenous oxytocin can lead to

Table 2
Advantages (+) and disadvantages (−) of different suckling systems as compared to conventional rearing with respect to measures on dairy cow productivity, health and fertility. The studies are sorted by the number of weeks of suckling since birth.

	Aspect		Free cow-calf contact	weeks		Restricted suckling	weeks		Half day contact	weeks		Foster mother	weeks
Cow productivity	Machine gained milk yield pre-weaning	-	Metz (1987)	1.5	-	Krohn et al. (1990) cited by Krohn (2001)	6-8	-	Johnsen et al. (2015b)	6			
		-	Zipp et al. (2015)	9	-	Mendoza et al. (2010)	8	-	Zipp et al. (2015)	9			
		-	Krohn (1999) cited by Krohn (2001)	12	-	de Passillé et al. (2008)	9						
		-	Schneider et al. (2007)	12	-	Barth et al. (2007)	12						
		-	Barth et al. (2009)	12	-	Schneider et al. (2007)	12						
		-	Barth et al. (2010)	12	-	Barth et al. (2009)	12						
		-	Zipp et al. (2013)	12	=	Cozma et al. (2013)[a]	30						
					-	Boden and Leaver (1994)	31						
	Machine gained milk yield of lactation	=	Metz (1987)	1.5	=	Kišac et al. (2011)	3	=	Johnsen (2015)	6	+/-	Brouček et al. (1995)[b]	3 or 4
		-	Zipp et al. (2015)	9	=	Krohn et al. (1990) cited by Krohn (2001)	6-8	=	Zipp et al. (2015)	9	=/-	Everitt and Phillipps (1971)[b]	7-10
					=	Margerison et al. (2002)[c]	26				=	Margerison et al. (2002)	26
	Milk fat content pre-weaning	-	Zipp et al. (2015)	9	-	Mendoza et al. (2010)	8	-	Zipp et al. (2015)	9	=/-	Bar-Peled et al. (1995)[c]	6
		-	Schneider et al. (2007)	12	-	Barth et al. (2007)	12				=	Margerison et al. (2002)[c]	26
		-	Barth et al. (2009)	12	-	Schneider et al. (2007)	12						
		-	Barth et al. (2010)	12	-	Barth et al. (2009)	12						
		-	Zipp et al. (2013)	12	-	Margerison et al. (2002)[c]	26						
					=/-	Cozma et al. (2013)[a]	30						
					-	Boden and Leaver (1994)	31						
Cow health	Udder health pre-weaning	=	Zipp et al. (2015)	9	=/+	Krohn et al. 1990, cited by Krohn (2001)	6-8	=	Zipp et al. (2015)	9	+	Walsh (1974)[b]	14
		=	Zipp et al. (2013)	12	=/+	Fröberg et al. (2008)	8				+	Margerison et al. (2002)[c]	26
					=	Barth et al. (2007)	12						
					=	Barth et al. (2009)	12						
					=	Margerison et al. (2002)	26						
					=/+	Cozma et al. (2013)[a]	30						
					+	Boden and Leaver (1994)	31						
Fertility	Interval calving-conception	+	Metz (1987)	1.5	=	Krohn et al. (1990) cited by Krohn (2001)	6-8	=	Zipp et al. unpublished results	9	=/+	Brouček et al. (1995)[b]	3 or 4
		=	Zipp et al. unpublished results	9	=/-	Margerison et al. (2002)	26				=	Margerison et al. (2002)[c]	26

[a] 1 min suckling before milking, calf presence during milking, suckling after milking until udder was empty.
[b] Multiple suckling without milking in early lactation, after weaning: milking.
[c] Restricted suckling by alien calves and milking.

desensitization of the cow's response such that the oxytocin threshold at the alveolar level rises (Mačuhová et al., 2004; Belo and Bruckmaier, 2010). Clearly this is not a sustainable solution. Furthermore, consumers question the use of hormones especially when they have chosen to buy a "natural" product.

A non-invasive alternative to oxytocin injections is to use a stimulus that induces endogenous oxytocin release. Two methods used by producers have been investigated and found to improve milk let down especially with heifers: (1) the calf suckles one teat while the three other teats are machine milked (Lucht, 2009: only 3 cows); or (2) a short nursing is allowed just before milking (Tournadre et al., 2008; Cozma et al., 2013). Possible drawbacks of these methods include concerns about hygiene during milking, high labour inputs (Tournadre et al., 2008), and low milk intakes (4.5 kg per day) of calves when they only have access to milk at milking time (Lucht, 2009).

Oxytocin plays an important role in maternal bonding and maternal behaviour (reviewed by Kendrick, 2000; Uvnäs-Moberg et al., 2001). The presence of the calf (without nursing) at milking has been reported to improve milk let-down at milking in some studies (Peeters et al., 1973; Williams et al., 1993; Tournadre et al., 2008) but not in another (Tančin and Bruckmaier, 2001). In many milking parlours it would not be feasible to have the calf present routinely. However, according to our own observations, some farmers have solved this by allowing cow–calf contact by putting the calves in a pen in front of the parallel parlour during milking (Zipp, Mejdell and Johnsen, personal communications).

Some original research using training or calf-associated stimuli to improve milk ejection have been reported. Classical conditioning to associate the calf-suckling with a blue disk, that is then used as the stimulus, has been shown to improve milk let-down, but this was only tested in three animals and would require further investigation (Willis and Mein, 1983). Olfactory stimulation during milking, presenting calf odours in different ways was not successful in improving milk let-down (Barth et al., 2010; Zipp et al., 2013) nor was an acoustic stimulus (played back calls of hungry alien calves) or an extended manual teat massage (Zipp et al., 2013). Vaginal stimulation can induce milk let-down especially during the first milkings of a heifer (Bruckmaier et al., 1992; Kraetzl et al., 2001) but on-farm feasibility; public opinion and welfare implications may limit its application

Another approach is to limit suckling opportunities for the calves and thereby increase udder filling. Zipp et al. (2015) compared free contact with half-day contact and found that cows gave more milk at the morning milking after the overnight separation from the calf. In less intensive systems it might even be possible to milk nursing cows only once a day, right after the separation period. Milking once a day during early lactation in non-nursing animals was found to result in a shorter interval to first oestrus (Patton et al., 2006), better maintenance of body weight and body condition score (BCS), and a positive effect on energy balance and metabolic status in early lactation but had a negative impact on later milk yield (McNamara et al., 2008). Losses in body weight and low BCS during early lactation as well as long interval to first oestrus are also issues for nursing cows, as reviewed by Kälber and Barth (2014). Further studies on these issues are needed.

4. Long term effects of dam rearing

Long-term benefits of dam rearing include improvements in milk production, health or longevity of the "dam reared" cow as well as benefits for the calf including improved growth, health and even social and learning skills.

Studies have shown that feeding calves more milk (Soberon et al., 2012) and even feeding whole milk rather than milk replacer leads to a higher milk production in first lactation (Bar-Peled et al., 1997; Shamay et al., 2005; Moallem et al., 2010) and lower culling rates before puberty (Lidfors, personal communication). A combination of good milk yields, fertility and longevity ensures high lifetime milk productivity (Wathes et al., 2008).

Ensuring a high milk allowance to calves does not require suckling, although suckling is a way of ensuring high growth rates before weaning. When dam rearing is practiced, the long-term effects of high milk allowances cannot be separated from those of the dam rearing per se. For examples, Brouček et al. (2006) found that free suckling calves had higher body weight at first calving and higher milk production (not statistically significant) in first lactation but the comparison was made with restricted fed (milk replacer) calves. Wagenaar et al. (2011) did not find any differences between nursed calves and conventionally reared calves (milk allowance not reported) regarding body condition score (BCS), age at first calving, udder health or milk yield in first lactation. However, the authors did not distinguish between dam reared and fostered calves, where up to eight calves were fostered by one cow probably reducing their milk intake. Ufer (2014), on the other hand, studied heifers reared with high milk allowance (16 l per day) either nursed or fed via automatic milk feeder, and did not find long-term differences regarding milk production, fertility and udder health. Nevertheless, first service conception rates were higher in the "dam reared" cows in first lactation (but not in the second), and insemination index (i.e., number of inseminations divided on number of cows) was lower and calving interval shorter for the "dam reared" cows. Jainudeen and Hafez (2000) reported that the uterus of cows nursing their calf involutes faster than in non-nursing cows, possibly due to higher peripheral oxytocin in suckled cows. Impaired fertility is one of the main reasons for culling cows on modern dairy farms. Thus, letting cows nurse their calves might improve their fertility and thus their longevity and be an advantage for modern dairy farms.

Studies looking at lifetime performance of dam reared vs. non-dam reared animals are lacking. Longevity depends on several factors. One area that has received little attention is how the cow's social skills (defined as ability to communicate with its conspecifics and to improve the communication in a way to make it efficient and effective) could influence her lifespan in modern dairy systems. Investigations of how to use learning skills and social behaviour to improve the welfare of calves and cows would also be of interest. Le Neindre (1989) observed that cows which were allowed to suckle their dam as calves, licked and nursed their own calves longer than did conventionally reared cows, so there seems to be a long term effect of dam rearing on a calf's future behaviour. Le Neindre and Sourd (1984) reported that heifers that had been nursed by a foster cow showed more agonistic social interactions than conventionally reared calves. Regrouping of unfamiliar animals occurs frequently during the life of a dairy cow and can result in distress especially for the introduced animal, expressing less lying, less feeding and less allogrooming (von Keyserlingk et al., 2008). According to Bøe and Færevik (2003) previous social experience, the number of animals that are mixed and the group composition are important factors that can influence social integration. When heifers were individually introduced to the milking herd shortly before calving, the heifers that had been allowed to suckle their dam, tended to show more submissive postures than heifers that were reared on the automatic milk feeder without contact with adult cows (Wagner et al., 2012). Submissive postures may reduce the number of aggressive interactions and thus be an effective communication and coping strategy for an animal in unfamiliar situations, however the authors found no differences in number of fights or displacements between the two groups of animals.

Recent research has demonstrated how individual housing of dairy calves can limit the development of the calf's cognitive

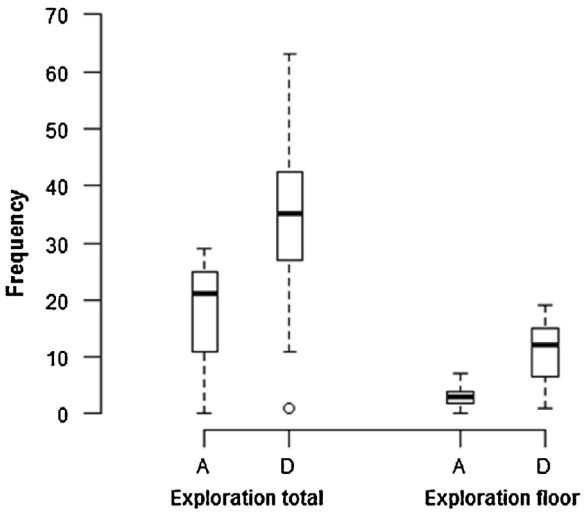

Fig. 2. Exploratory behaviour of primiparous cows reared conventionally (A; $n = 7$) or with dam contact (D; $n = 12$) during a 15 min isolation period. Total exploration had a trend for ($p = 0.07$) and exploration of floor was significantly different ($p = 0.01$) between groups (figure based on results published in Kälber et al., 2013).

abilities. Costa et al. (2014) found that dam reared calves, when tested at 10 weeks of age, tasted novel feed sooner after introduction of the food and ate more of it, compared to calves individually reared. Meagher et al. (2014) found that social rearing, and especially dam rearing, improved the calves' ability to learn "reversal learning" as compared to calves from individual rearing. Whether these social skills and learning abilities are maintained and are of advantage to adult cows and/or the herd of cows is not yet known. However, according to Latham and Mason (2008), maternal deprivation reduces an animal's capacity to cope with normal social interactions with conspecifics. Calves reared without contact to their dam or with other calves are reported to be dominated by their nursed conspecifics (Le Neindre and Sourd, 1984), to show a decline in learning and social skills (Vieira et al., 2010; Gaillard et al., 2014) and an increased responsiveness to stress (Duve et al., 2012). On the other hand, Kälber et al. (2014) studied antepartum heifers during the first 12 h after integration to the dairy herd and did not find differences in social behaviour between dam reared heifers and heifers reared conventionally, without contact to mature cows. Introduction to a group of lactating cows following calving is very stressful and it seems that, for primiparous cows especially, five days of habituation is needed (Kälber et al., 2014). Studies on the long-term effects of dam rearing on heifers during their first months postpartum would shed light on how dam rearing can shape social skills in cows.

When tested in isolation, dam reared in comparison to conventionally reared cows tended to show more exploratory behaviour (Fig. 2; Kälber et al. (2013) and be more active (Wagner et al., 2015). This might reflect a higher social motivation to re-join the herd, which has also been shown in dam reared calves (Wagner et al., 2013).

Some farmers are concerned that the human–animal relationship is weakened in dam rearing systems, where humans are no longer hand feeding milk to the calves. This concern is supported by Albright (1982) who found that primiparous cows which themselves had been allowed contact with the dam for the first 72 h postpartum, had a significantly poorer milking temperament score than cows that were separated from their dams immediately after birth. On the other hand, no deleterious effects on the human–animal relationship have been reported for calves group reared with automatic milk feeders. Nevertheless, no one has investigated the human–animal relationship of "dam reared" cows during their first lactation. There is also a need to test practical ways of securing a good human–calf relationship in systems with free cow–calf contact.

5. Discussion and suggested research questions

5.1. Cow–calf systems

The free cow–calf contact system best mimics the natural situation and allows full maternal behaviours, but it does have practical drawbacks. First, the calves and cows are not prepared for the premature separation and weaning which is considered necessary in dairy production. The cow and calf both react with loud vocalization, and this is also distressing for their human caretakers. Second, the sudden change in feed and feeding system often causes a growth check and even weight loss for the calves. Third, it can be more difficult for caretakers to establish a good human–calf relationship due to a lack of opportunity to have contact with the calves. This might result in animals having less trust in people and being harder to handle. All these issues may be solved with the half day contact system; calves are habituated to daily separation from the dam and to being handled by humans, and can learn to drink milk from a feeder helping them adapt after separation. Compared to restricted suckling, the half day contact system ensures high milk intake and pre-weaning growth as well as facilitating social behaviours for the calves. The foster cow system is perhaps the most attractive for implementation in practice, and if well run, it is a good alternative when dam rearing is not feasible. Whatever the suckling system, it is essential to ensure that calves consume good quality colostrum early on and in sufficient quantity.

Automation technology offers a new potential for designing the modern dairy farm to meet the needs of cows and calves as well as those of the producers, giving more freedom and comfort to both parties. New high tech environments can be used to create complex physical and social situations that calves and cows must learn to navigate in. In this context, the recent findings of more flexible learning abilities of calves reared with their dam or in other rich social environments are very promising (Costa et al., 2014; Meagher et al., 2014). Further research looking at how rearing systems can promote long term animal cognitive ability and flexibility is needed. One objective could be to develop training procedures for animals so that they efficiently use resources and automatic equipment like "smart" gates giving access to calving pens, automated feeders and milking stations, which can improve the functioning of the farm, while allowing dam rearing. General hygiene issues and health control measures are important challenges to address in further research.

To make the transition at separation and weaning more smooth, research on practical approaches to loosen the bond between dam and calf and reduce the calf's nutritional dependency on nursing (e.g. increase the early intake of concentrates) before separation are welcomed. Investigating the effect of cow and calf feeding and grazing together on the development of the feeding as well as the social behaviours of the calf and their effects on behaviour later in life would also be of interest. Taking calves with the cows to pasture might be challenging and critical points and solutions need to be found to make this feasible.

5.2. Influence of suckling on milking performance

Milk ejection disturbances have been reported in nursing dairy cows at milking (e.g., Barth et al., 2007; Schneider et al., 2007; de Passillé et al., 2008; Mendoza et al., 2010; Zipp et al., 2013). Such problems may represent more work, loss of delivered milk and, at least a theoretical, risk of mastitis due to residual milk.

The role of the human–animal relationship between the dam and the milker on milk let-down should be considered as well as the effects of the timing of the nursing relative to the milking. The effects of the suckling calf on residual milk should also be investigated with respect to expected total delivered milk. Research to develop feasible solutions to impaired milk let-down is welcomed.

Suckling reduces the fat content of delivered milk while the studies on milk protein content are inconclusive. Both protein and fat content can impact the profitability of the farm, and the effect of suckling compared to other factors influencing milk composition should be studied. Carbonneau et al. (2012) made a first attempt at investigating not only milk yield and fat content but also metabolic responses in cows nursing vs. cows being milked. It can be argued that the welfare benefits associated with the expression of maternal behaviours outweigh possible moderate welfare impairments during the relatively short milking procedure. The lower oxytocin secretion during milking of the nursing cow may also reflect another maternal response of the cow ensuring that milk is available for her calf. Nevertheless, research on options to improve the milking procedures for nursing cows should be explored.

More studies examining the health of nursing cows and their metabolic responses are needed to identify what might be beneficial or detrimental to overall cow welfare.

Also the effect of suckling on delivered milk yield over the full lactation period needs more research. In low yielding dairy cattle the calf drinks a large proportion of the daily milk yield, so the loss in income may be substantial. However, in high yielding cattle, and in low yielding cows with half day contact, many studies find that nursing does not significantly reduce delivered milk over the whole lactation, as shown in Table 2. Research on the best separation age regarding both calf performance and milk production is encouraged.

5.3. Long term effects of suckling

Studies on the long term effects of suckling on calf and cow production parameters such as growth, onset of puberty, fertility, milk production, health, longevity, social behaviour, and last not but the least farm economics are largely lacking.

It is well known that high milk allowances promote growth, and that heavy heifers come sooner into puberty, and that they produce more milk during the first lactation. These advantages do not necessitate dam rearing. High milk allowances and “feed on demand” systems may easily be implemented using e.g., automated milk feeders. However, it would be important to investigate other possible advantages of the dam rearing per se. For instance, more research examining the possible benefits of dam rearing on social and other behaviours (e.g., oestrus behaviour) of the growing heifer and adult cow are needed.

Research on dam rearing is mainly done on research farms where only a few cows from the herd have contact with their calves. In the studies of dam reared heifers (Wagner et al., 2012; Zipp et al., 2015; Kälber et al., 2014; Putzmann, 2014) possible learning by control heifers when kept together with dam reared heifers after weaning, was not investigated. Research on long term effects of dam rearing on social learning is encouraged, especially if this can be done in herds where all calves have been raised by their dam over several cow generations. This would give valuable insight into long term effects on maternal behaviours and social learning as well as cognition, coping with stressors and health.

Mothering a calf could also influence the behaviour of other cows. Szabo et al. (2013) reported that the introduction of a milking goat into an unfamiliar herd of adult goats was less stressful when the kid was present than when the goat was introduced alone. To our knowledge no such study has been done with dairy cows and calves.

5.4. Other aspects

Keeping cattle in mixed age groups may be challenging for the control of transmissible or contagious diseases. Older calves and cows are believed to be a reservoir of infectious pathogens for younger calves, and paratuberculosis represents a special challenge. The cow barn environment may need special arrangements to be suitable for calves. Therefore, suitable housing conditions for suckling systems and the effects of suckling on cow and calf immune system and disease resistance, needs further evaluation.

Final remarks

Public concern about separating cow and calf immediately after birth is increasing and so is the interest in alternative rearing systems for dairy calves. We discussed the different dam rearing systems and suggested a number of areas for further research. The main conclusion of the work shop was that cow–calf systems can be a viable option for some producers even in our modern dairy systems.

Acknowledgements

The authors want to thank the participants of the ISAE satellite workshop on dam rearing for their comments and the discussion about these systems. We would also like to thank the conference organizers for the opportunity to have the workshop and to publish this account of our discussions.

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