Sow Reproduction and Piglet Performance in Multi-Suckling Pens

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Abstract

Production systems with group housing of sows at different stages of production are increasing in Europe, as an effect of public demand for more animal welfare-friendly pig production. Some niche certified piglet production systems keep lactating sows with piglets in groups in multi-suckling pens. However, three factors have been identified as affecting certified piglet production in systems with multi-suckling pens: The occurrence of lactational oestrus, piglet mortality and within-litter weight variation at weaning. This thesis investigated the possibility to affect these three factors by altering management routines. Three different management routines that differed in terms of time spent in an individual farrowing pen post-farrowing, before the lactating sows with piglets were group-housed in a multi-suckling pen, were created. Time spent in the individual farrowing pen was one (W1), two (W2) or three weeks (W3). Piglets in all management routines were weaned at six weeks post-farrowing.

Only one of 43 sows ovulated during lactation. This was determined by post-mortem macroscopic examination of the ovaries and progesterone metabolite concentration in faeces. Interestingly, the weaning to standing oestrus interval was significantly shorter ($p<0.001$) for W2 (2.6 ±0.3 days) and W3 (2.7 ±0.2 days) than W1 (4.0 ±0.3 days). Piglet mortality in the multi-suckling pen was significantly lower ($p<0.05$) in W3 and W2 than W1. Within-litter weight variation did not differ between the management routines.

Stress induced by reallocation and mixing of sows can affect ovarian activity and was therefore assessed during the group-housing period by measuring cortisol concentrations in saliva sampled during the first four days post-mixing. Analysis showed that W3 sows were less stressed in the multi-suckling pen than W1 sows.

Overall, the results in this thesis on sow reproduction and piglet performance can be used for development of housing and management routines.

Keywords: Cortisol, Lactational oestrus, Multi-suckling pen, Organic piglet production, Piglet mortality, Stress.

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Dedication

To the loves of my life

Shut up, Flanders!
Homer J. Simpson

Om matematik,
kemi och fysik
vet grisar det mesta.
Ja, mer än de flesta.
Lotta Garthon

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 Thomsson O, Sjunnesson Y, Magnusson U, Eliasson-Selling L, Wallenbeck A, Bergqvist A-S (2016). Consequences for Piglet Performance of Group Housing Lactating Sows at One, Two or Three Weeks Post-Farrowing. *PLoS ONE 11*(6): e0156581. Doi10.1371/journal.pone. 0156581.

II Thomsson O, Magnusson U, Bergqvist A-S, Eliasson-Selling L, Sjunnesson Y, (2017). Sow performance in multi-suckling pens with different management routines. *Manuscript*

III Thomsson O, Bergqvist A-S, Sjunnesson Y, Eliasson-Selling L, Lundeheim N, Magnusson U, (2015). Aggression and cortisol levels in three different group housing routines for lactating sows. *Acta Veterinaria Scandinavica 57* (6), s.5.

IV Thomsson O, Holst-Strom B, Sjunnesson Y, Bergqvist A-S (2014). Validation of an enzyme-linked immunosorbent assay developed for measuring cortisol concentration in human saliva and serum for its applicability to analyze cortisol in pig saliva. *Acta Veterinaria Scandinavica,* 56(1), s. 55.

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Abbreviations

E2	Estradiol
FSH	Follicle-stimulating hormone
GH	Growth hormone
GnRH	Gonadotropin-releasing hormone
IGF-1	Insulin-like growth factor 1
KRAV	Incorporated Swedish Organic Association
LH	Luteinising hormone
W1	Management routine with sows and piglets kept for one week in individual farrowing pens before transfer to multi-suckling pens
W2	Management routine with sows and piglets kept for two weeks in individual farrowing pens before transfer to multi-suckling pens
W3	Management routine with sows and piglets kept for three weeks in individual farrowing pens before transfer to multi-suckling pens

1 Introduction

In Europe, production systems with group housing of sows at different stages of production are becoming more common, due to public demand for more animal welfare-friendly pig production (Einarsson *et al.*, 2014; Nieuwamerongen *et al.*, 2014; Kemp & Soede, 2012). Certified organic piglet production[1] is one such form of niche production. The main certification body in Sweden is the private label KRAV (Incorporated Swedish Organic Association). Certified production is characterised by a requirement for outdoor access during lactation. In KRAV-certified production systems, sows must have outdoor access no later than 21 days post-farrowing (KRAV, 2016). However, the interval from farrowing until outdoor access previously set by KRAV was 14 days (KRAV, 2014). In Sweden, the outdoor access requirement is commonly met by group housing lactating sows and piglets in multi-suckling pens, from where the pigs gain outdoor access. Besides outdoor access, the length of the lactation period differs from that in non-certified piglet production. In non-certified production, piglets may be weaned from 28 days post-farrowing (Swedish Board of Agriculture, 2010). In certified production, however, piglets are not allowed to be weaned before 40 days post-farrowing if batch-wise production is practised (KRAV, 2016; Council Regulation (EC) No. 834/2007, 2007), or otherwise not before 49 days post-farrowing (KRAV, 2016).

In 1986, Sweden banned the use of antibiotics as growth promoters. To prevent disease transmission between pigs of different ages, batch-wise production in an ‘all-in, all-out’ system has since been implemented in Sweden (for reviews see Einarsson *et al.*, 2014; Wallgren, 2009). An important factor in the batch-wise production system is the sow’s reproductive ability to remain anoestral during lactation and return to oestrus post-weaning. This permits

[1] Hereafter referred to as certified production

batches of sows to be weaned, inseminated and farrow at the same time. The batches allow an entire pig house to be emptied, cleaned and disinfected before a new batch of pigs enters. This governs the production from farrowing to finishing unit. Batch-wise production is also employed in certified production.

From 2010 to 2015, the total number of sows and slaughter pigs in non-certified production in Sweden decreased, but the average number of sows per herd increased, from 156 to 186 (Statistics Sweden, 2016). The average number of sows per herd in certified production also increased, from 58 to 68. Overall, however, in contrast to non-certified production, the total number of sows kept in certified production systems has increased, from 1,919 in 2010 to 2,729 in 2015 (Swedish Board of Agriculture, 2016b). In addition to this increasing number of sows in certified production, there has been an increase in the number of slaughtered pigs originating from certified production. In 2015, certified production produced 48,233 fattening pigs for slaughter. However, slaughtered pigs from certified production only represent 1.9% of the total number of pigs slaughtered in Sweden (Swedish Board of Agriculture, 2016a). On herd level, three factors have been identified as affecting piglet production in certified systems. These are the occurrence of lactational oestrus, which disrupts batch-wise production, pre-weaning mortality and within-litter weight variation at weaning (Lindgren *et al.*, 2013; Milligan *et al.*, 2002a; Hultén *et al.*, 1995).

1.1 Nursing-suckling interaction

Nursing-suckling behaviour is a complex matter that involves the sow and piglets, their respective interests and the conflict between those interests (Baxter *et al.*, 2011). At the beginning of the lactation the sow initiates the majority of nursings (Bøe, 1993). However, by week two post-farrowing, the number of sucklings initiated by the piglets increases, while there is a simultaneous increase in nursings terminated by the sow. The shift in nursing-suckling initiator from sow to piglets illustrates the conflict between the sow's risk of weight loss during lactation, due to the high energy demand for milk production, and piglet weight gain and survival (for review see Drake *et al.*, 2007). Total milk production increases with litter size and the peak of lactation occurs in around week three of lactation (Gill & Thomson, 1956).

At farrowing, the digestive tract of the piglet is immature (Bøe, 1991). Piglets are completely dependent on the sow for nutrition, growth and survival in the first weeks post-farrowing (for review see Hurley, 2001). They are then gradually introduced to solid feed around week three post-farrowing (Bøe, 1991). However, the total creep feed consumption during lactation in non-certified production is low and milk remains the main source of energy until weaning (Kuller *et al.*, 2004; Sorensen *et al.*, 1998). The slow increase in solid feed intake prepares the digestive tract for solid feed consumption post-weaning.

1.1.1 Nursing

A single nursing can be divided into five phases (for review see Fraser, 1980). However, it is more common in analysis to divide the nursing process into three phases (for review see Algers & Uvnäs-Moberg, 2007; Gill & Thomson, 1956). A nursing begins with the pre-let down phase, in which piglets stimulate the udder and prepare it for the subsequent milk-let down phase. After the milk-let down phase, the piglets stimulate milk production for the following nursing by massaging their specific udder compartment (Algers & Jensen, 1985). This last phase is known as the post-let down phase.

1.1.2 Nursing-suckling interaction in relation to certified production

Nursing behaviour is established around day nine post-farrowing (Jensen, 1986). By then, a stable teat order among the piglets has been established and udders not occupied have undergone atrophy (Skok & Škorjanc, 2014; Hultén *et al.*, 1995). In other words, the sow has optimised her milk production to the size of her litter.

In certified production, however, the nursing-suckling interaction established in the individual farrowing pen can be disrupted when the sows and piglets are group-housed in a multi-suckling pen (Wattanakul *et al.*, 1997). Recently group housed lactating sows have been reported to allocate more time to exploring the environment and fighting than to nursing (Li *et al.*, 2012; Arey & Edwards, 1998; Wattanakul *et al.*, 1997). Moreover, fighting is a stressful event and stress, as such, can affect milk production (Pedersen *et al.*, 2011b). Consequently, mixing lactating sows and piglets could affect piglet growth performance.

Nursing synchronisation

Throughout a nursing event, there is an ongoing communication between the nursing sow and the suckling piglets (Algers & Jensen, 1985). The suckling piglets respond to the sow's grunt pattern, which alters both in frequency and level. The grunt pattern related to nursing has an effect not only on the sow's own piglets, but also on sows with litters within the audible vicinity, causing synchronisation of nursings (Silerova *et al.*, 2013). Studies have shown that when a group of sows in a multi-suckling pen synchronise their nursings, this reduces the incidence of cross-suckling piglets present at a nursing (Maletínská

& Špinka, 2001; Illmann *et al.*, 1999). This is beneficial, since the presence of cross-suckling piglets at the udder during a nursing bout increases fighting and screaming, and has been demonstrated to reduce the sow's motivation to nurse (Pedersen *et al.*, 1998). In addition, a reduction in the incidence of cross-suckling piglets at a nursing increases the chances of the milk, produced at great cost by the sow, being consumed by her own piglets.

1.2 Lactational oestrus

After farrowing, sows usually remain in anoestrus during lactation and return to oestrus within 10 days post-farrowing (Soede & Kemp, 1997; Sterning *et al.*, 1990). However, there are a number of conflicting and interacting factors that influence whether the sow returns to oestrus during lactation. These factors include: housing conditions (Stolba *et al.*, 1990), catabolic state of the body (Einarsson & Rojkittikhun, 1993), lack of boar (Alonso-Spilsbury *et al.*, 2004) and suckling frequency (Bøe, 1993).

1.2.1 Ovulation

In order for ovulation to take place, a series of hormonal events needs to occur. During the follicular phase, follicle-stimulating hormone (FSH) begins the recruitment and development of follicles to a size of 3-6 mm (for review see Lucy *et al.*, 2001). The final development of follicles to pre-ovulatory size (7-9 mm) is then a result of gonadotropin-releasing hormone (GnRH) and luteinising hormone (LH) undergoing a pulsatile shift from a low frequency with high amplitude to a higher frequency with lower amplitude (Shaw & Foxcroft, 1985). In addition to the higher frequency and lower amplitude, the shift results in a higher LH baseline. Concurrently with the increase in LH and follicular growth, the number of LH receptors on the follicular theca cells increases (for review see Knox, 2005). When there is a sufficient number of LH receptors, the granulosa cells of the follicle start to produce estradiol (E2) (for review see Soede *et al.*, 2011). The production of E2 exerts positive feedback on the release of LH and FSH. The positive feedback in E2 causes an LH surge and, 30±3 h (mean ±SD) later, ovulation occurs (Soede *et al.*, 1994; Andersson *et al.*, 1984).

1.2.2 When and how lactational oestrus occurs

The occurrence of lactational oestrus among group-housed sows varies from 0% to 50% when no means to induce oestrus are used (Wallenbeck *et al.*, 2009; Wattanakul *et al.*, 1997; Hultén *et al.*, 1995). However, when lactating group-housed sows have boar contact, up to 100% occurrence of lactational oestrus has been reported (Kongsted & Hermansen, 2009; Henderson & Stolba, 1989; Bryant *et al.*, 1983). In a longitudinal study in which the total occurrence of lactational oestrus was 47%, it was found that the occurrence rate was affected by season (Hulten *et al.*, 2006). The season with the highest occurrence rate was December-February, with 74%, followed by March-May (64%), August-November (23%) and June-July (10%) (Hulten *et al.*, 2006). Greater willingness to return to oestrus during cooler seasons and under increasing light exposure has been reported in other studies (Tummaruk, 2012; Untaru *et al.*, 2011).

In addition to more space per sow, outdoor access and social interactions with other sows, the multi-suckling pen provides the sows with greater opportunities to express their natural behaviour compared with the individual farrowing pen (Dybkjær *et al.*, 2001). However, the multi-suckling pen also allows the sows to escape their piglets, thus resulting in a reduced suckling frequency compared with an individual farrowing pen (Bøe, 1993). As a consequence of the reduced suckling frequency, inhibition of the GnRH pulse generator is weakened, resulting in an increase in LH pulsatility (Sesti & Britt, 1994; Sesti & Britt, 1993). The anoestral sow is therefore given the conditions to resume ovarian activity and return to oestrus during lactation.

The complete mechanism behind the suckling inhibition of GnRH is not fully known. However, it has been suggested to involve external stimuli, *e.g.* visible piglets and udder stimulation, lactational hormones such as prolactin and oxytocin, and endogenous opioid peptides (Wylot *et al.*, 2013; for review see Quesnel & Prunier, 1995).

Although suckling as such is considered to be the main cause, the occurrence of lactational oestrus cannot be explained entirely by a reduction in suckling frequency (for review see Quesnel & Prunier, 1995). The suckling affects *e.g.* the metabolic state of the sow and thus the metabolic state of the sow also plays an important role in the occurrence of lactational oestrus (Soede *et al.*, 2011; Hulten *et al.*, 2006). Insulin and insulin-like growth factor 1 (IGF-1), metabolic hormones that are involved in maturation of follicles, are affected by the metabolic state of the sow (for review see Prunier & Quesnel, 2000). A sow with negative energy balance has lower levels of insulin and IGF-1, which could result in a delay in ovulation or a decreased ovulation ratio (Cox *et al.*, 1987; King & Williams, 1984). In studies measuring back-fat depth at weaning in group-housed sows, it has been found that sows with greater back-fat depth are more likely to ovulate during the course of lactation (Wallenbeck *et al.*, 2009; Hulten *et al.*, 2006).

Lastly, the grouping of lactating sows, with associated aggressive confrontation and determination of rank, is a stressful event (Li *et al.*, 2012;

Wattanakul *et al.*, 1997). However, the stress experienced by the sow at group housing can have a positive effect on reproductive functions (for review see Einarsson *et al.*, 2008; Rojanasthien, 1988). Cortisol and catecholamine, released as a result of transient stress, have been reported to affect the hypothalamus and consequently increase the LH-pulsatile, which causes the sow to return to oestrus and ovulate (Dalin *et al.*, 1993; Dalin *et al.*, 1988).

1.2.3 Consequences of lactational oestrus on production

Sows that return to oestrus and ovulate during the course of lactation can pose problems in batch-wise production. Sows ovulating in late lactation will not return to oestrus within the desired week post-weaning (Hultén *et al.*, 1995). Consequently, these ovulating sows make it difficult to keep batches intact. In addition to making batch-wise production more difficult, the occurrence of lactational oestrus results in more costly non-productive days, and thus fewer piglets per sow and year (Terry *et al.*, 2014; Lindgren *et al.*, 2013). Most lactational oestrus events occur from the fifth week of lactation (Wallenbeck *et al.*, 2009; Hulten *et al.*, 2006). However, if ovulation were to be concentrated to the fourth week of lactation, the subsequent oestrus would occur within the first week post-weaning, given that weaning occurs at six weeks post-farrowing (Wallenbeck *et al.*, 2009). Thus, depending on when ovulation occurs in relation to weaning, it may or may not pose a problem for batch-wise production. However, the longer lactation period in certified production still results in fewer piglets per sow and year being produced (Lindgren *et al.*, 2013; Soede *et al.*, 2012). All in all, lactational oestrus counteracts production efficiency.

1.3 Pre-weaning piglet mortality

Pig breeding companies have for the last 30 years focused on increasing litter size at birth in order to increase litter size at weaning, which is considered to be one of the most important reproduction traits (Guo *et al.*, 2016). In general, the profitability of piglet production depends on the number of piglets sold or slaughtered. However, breeding solely for litter size may increase the number of dead piglets pre-weaning (Lund *et al.*, 2002). Pre-weaning mortality is both an economic concern and a welfare concern (Phillips *et al.*, 2014).

1.3.1 Causes of pre-weaning piglet mortality

The causes of pre-weaning piglet mortality can be divided into three categories: piglet-related factors, sow-related factors and environmental-related factors (for review see Muns *et al.*, 2016) (Figure 1). However, even if the causes can be partitioned, they interact with each other. Piglet mortality is highest within the first week post-farrowing, especially within 72 h post-farrowing (Su *et al.*, 2007). The increasing pre-weaning mortality associated with breeding for larger litter size in the past three decades has been suggested to be a consequence of the unfavourable relationship between litter size and decreased piglet birth weight (Phillips *et al.*, 2014; Rutherford *et al.*, 2013; Johnson *et al.*, 1999).

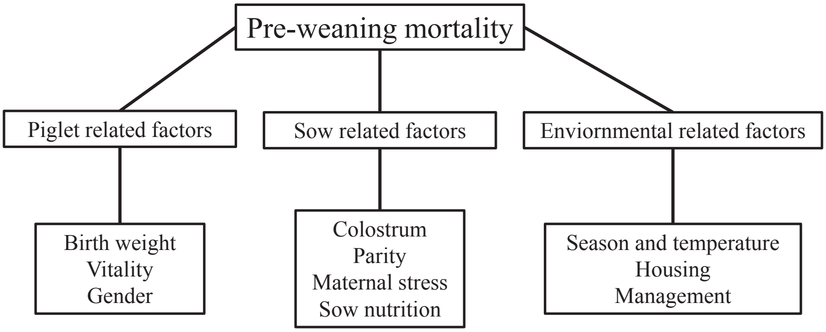

Figure 1. Summary of factors related to pre-weaning mortality grouped into piglet, sow and environmental factors according to Muns *et al.* (2016).

As an example, piglets with birth weight <700 g have less than 40% survival rate, while piglets with birth weight >1500 g have more than 80% survival rate (Fix *et al.*, 2010).

For live-born piglets, the main cause of death is crushing by the sow (Wientjes *et al.*, 2012; Edwards *et al.*, 1994). However, crushing may be the final step in a series of events that often begins with chilling and starvation (Westin *et al.*, 2015; Andersen *et al.*, 2005).

At farrowing, piglets experience a 15-20°C drop in environmental temperature on exiting the intra-uterine environment (for review see Herpin *et al.*, 2002). To cope with the temperature drop and avoid chilling, piglets need colostrum soon after birth. Colostrum intake is vital because piglets are born with a low energy reserve (Declerck *et al.*, 2016). However, the amount of colostrum produced by the sow is limited (Quesnel, 2011). Piglets in large litters therefore have difficulties obtaining the ≥200 g colostrum they need to reach adequate immunoglobulin levels and minimum growth (for review see Spinka & Illmann, 2015). Piglets with low birth weight are at particular risk in this regard, because they tend to have longer duration from birth to first colostrum intake than their heavier litter-mates, according to Tuchscherer *et al.* (2000). Thus piglets with low birth weight are at greater risk of being exposed to cold stress and these chilled piglets seek to stay close to the sow for heat and for easy access to the udder (Vasdal *et al.*, 2010; Weary *et al.*, 1996). There, due to underlying chilling and starvation, these weakened piglets are at greater risk of being crushed by the sow than vigorous piglets (Melišová *et al.*, 2011; Alonso-Spilsbury *et al.*, 2007; Edwards, 2002). Management that assists piglets to obtain colostrum immediately post-farrowing decreases piglet mortality, according to Andersen *et al.* (2007).

It has been reported that pre-weaning mortality is also related to the maternal behaviour of the sow and there is variation among sows with regard to maternal behaviour, so breeding against pre-weaning mortality is possible (Phillips *et al.*, 2014; Weber *et al.*, 2009; Lund *et al.*, 2002).

1.3.2 Pre-weaning piglet mortality in certified piglet production

Certified piglet production has higher pre-weaning mortality than non-certified piglet production (KilBride *et al.*, 2014; Lindgren *et al.*, 2013; Hultén *et al.*, 1996). In comparison with non-certified production, litter sizes in certified production are reported to be larger (Lindgren *et al.*, 2013; Leenhouwers *et al.*, 2011). The reason for this could be that litter size is affected by the length of the previous lactation (Xue *et al.*, 1993). During a longer lactation, the uterus has time to recover and uterine involution can be completed, increasing embryonic survival rate and resulting in greater litter size (Costa *et al.*, 2004).

In certified production, piglets are transferred from individual farrowing pens to a multi-suckling pen around 2 to 3 weeks post-farrowing. The multi-suckling pen environment reduces suckling frequency by allowing the sow to escape the piglets (Dybkjær *et al.*, 2001; Hulten *et al.*, 1995; Bøe, 1993). Piglets may therefore be weakened by reduced or missed nursing opportunities, as previously suggested by Lindgren *et al.* (2013). In addition, it has been reported that a majority of the piglets that die do so within the first week after introduction to the multi-suckling pen and mainly by crushing (Dybkjær *et al.*, 2003; Dybkjær *et al.*, 2001). These results suggest that there is a second wave of piglet mortality in certified piglet production after the sows and piglets are introduced to a multi-suckling pen.

1.4 Within-litter weight variation

Several studies have shown that the within-litter weight variation at farrowing increases with increasing litter size, contributing to pre-weaning mortality in addition to low birth weight (Rutherford *et al.*, 2013; Pedersen *et al.*, 2011a; Milligan *et al.*, 2002b). Besides an increase in pre-weaning mortality, a litter with large weight variation at farrowing results in a large weight variation at weaning, as previously reported by Milligan *et al.* (2002a) and Zindove *et al.* (2013).

The within-litter weight variation has been reported to increase throughout lactation (Bøe, 1993; Thompson & Fraser, 1986). The weight variation at weaning is detrimental for batch-wise production and increases labour, according to Milligan *et al.* (2002b) and Nielsen *et al.* (2001). For instance, weaned piglets of different weights have different feed requirements post-weaning, and thus some piglets need to be kept back while others are transferred to the next production stage. In addition, sorting piglets post-weaning according to weight demands a great deal of work. Therefore the within-litter weight variation is an important production factor as reported by Milligan *et al.* (2002a).

2 Aims of this thesis

The overall aim of this thesis was to investigate whether different group housing routines with varying length of time spent in individual and multi-suckling pens affect sow reproduction and piglet performance. In particular, the occurrence of lactational oestrus, piglet mortality and within-litter weight variation at weaning were studied. Such information can be used to develop and market new housing routines for lactating sows in both certified and non-certified production.

Specific objectives of the thesis were to compare three group housing routines with respect to:

- Nursing-suckling interactions.
- The occurrence of lactational oestrus.
- Piglet mortality.
- Within-litter weight variation at weaning, within-litter weight gain, piglet weight gain and piglet weight at weaning.
- Stress and agonistic behaviour at the time of group housing.

3 Methodological considerations

This chapter provides a summary of the materials and methods used in Papers I-IV and some comments on these. More detailed descriptions of the procedures used can be found in Papers I-IV.

3.1 Animals, housing and experimental design

3.1.1 Pre-multi-suckling pen

Hereafter, 'sows' refers to both primiparous and multiparous sows unless otherwise stated. In total, 43 pure-bred Yorkshire sows of parity one to nine were used in this research. The sows were inseminated with Hampshire sperm, and thus the piglets were Yorkshire-Hampshire crosses. The sows were housed in group gestation pens until one week prior to farrowing and then transferred and loose-housed individually in 8.2 m^2 farrowing pens. Each farrowing pen was equipped with horizontal rails along the walls to decrease the risk of piglets being crushed between the sow and the pen wall. Furthermore, each pen had a piglet creep area with a heating lamp. Consequently, the available free space for the sow was 6.4 m^2. Straw for bedding was provided daily. Cross-fostering was not practised.

The sows were fed according to a Swedish feeding regime standard, adjusted for litter size. As specified in KRAV organic production standards (KRAV, 2016), the sows were also provided with hay *ad libitum*.

3.1.2 Multi-suckling pen

There are many different group housing systems with different designs and management requirements (for review see Nieuwamerongen *et al.*, 2014). The design of the multi-suckling pen used in this study was based on existing conditions in the facilities at the Swedish Livestock Research Centre at Funbo-Lövsta, available staff and management possibilities. Conditions that need to be take into account when planning a production system as reported by Peltoniemi *et al.* (1999).

In an uninsulated barn at the Research Centre, three multi-suckling pens were built. Adjacent to each 62.5 m^2 multi-suckling pen, there was a 5.5 m^2 piglet creep area equipped with a roof, elevated floor and four heating lamps (Figure 2). This piglet creep area was inaccessible to the sows.

An internal wall divided the multi-suckling pen into two smaller areas, referred to here as the lying area and the feeding area. The feeding trough and the piglet creep area were situated in the feeding area. The bedding material consisted of peat and straw in the feeding area and only straw in the lying area.

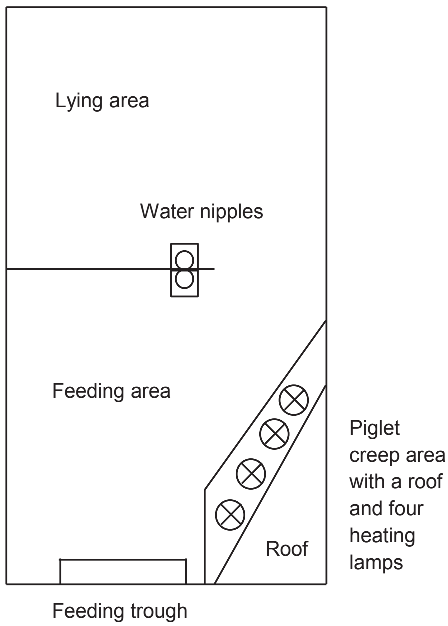

Figure 2. Design of the multi-suckling pen (reproduced with the permission of BioMed Central original publisher; (Thomsson *et al.*, 2015).

Each multi-suckling pen had one water nipple with a bowl underneath on each side of the internal wall. In order to allow the piglets access to the water, a wooden box was mounted underneath each bowl.

The feeding trough in the multi-suckling pen provided the sows with dry feed (the commercial product DIA 120; 12.8 MJ metabolisable energy/kg, 160g crude protein/kg; Lantmännen, Sweden) intended for lactating sows. The feeding trough was also accessible to the piglets. In addition to the dry feed, hay was provided *ad lib*.

3.1.3 Experimental design

Three management routines were compared. The difference between these three management routines was the time spent in the individual farrowing pen before transfer to the multi-suckling pen (Figure 3). In management routine 1 (W1), sows spent one week before being transferred to the multi-suckling pen. In management routine 2 (W2), the duration of the period before transfer to the multi-suckling pen was two weeks and in management routine 3 (W3) it was three weeks. All sows were weaned six week post-farrowing. The number of weeks spent in the multi-suckling pen was five, four and three for sows in management routines W1, W2 and W3 respectively. At the time of study, management routine W2 fulfilled the requirement on outdoor access at two weeks post-farrowing in group housing of sows and piglets specified in certified production regulations (KRAV, 2014). Therefore the W2 regime can be regarded as a control management routine for certified production.

Each management routine was repeated once. Within each management repeat (batch), the lactating sows were divided into two subsets ('early' and 'late'). The sows in each batch that were first to farrow were assigned to the early subset. The grouping of sows into early and late was done so that the piglets had reached a certain age before being introduced into the multi-suckling pen. The early subset was transferred to the multi-suckling pen first and the late subset was transferred on the following day. However, the subsets within one W3 batch were transferred two days apart.

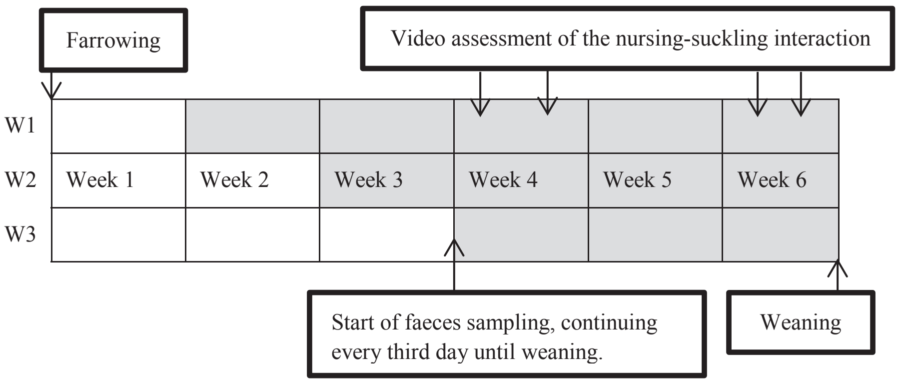

Figure 3. Schematic diagram of the three management routines (W1-W3), showing the start of faeces sampling and the time of nursing-suckling interaction assessment (see sections 3.2 and 3.3). A white square indicates a week of individual housing and a grey square indicates a week of group housing.

A particular management routine was never repeated in the same multi-suckling pen.

In addition, nine lactating sows served as a reference group. The sows in the reference group were kept untethered in individual farrowing pens from farrowing to weaning at 35 days post-farrowing. They were assigned to the same feeding regime as the other sows. Data obtained from the reference group were piglet weaning weight, within-litter weight variation at weaning and pre-weaning piglet mortality.

3.1.4 Distribution of sows

The selection of sows was based on the time of farrowing. Each batch could contain a maximum of eight sows. Sows farrowing within 0-4 days were assigned to one batch. As a consequence of selecting participating sows based on farrowing day, the number of sows varied among management routines, batch and subset. Furthermore, parity could not be balanced across management methods. The distribution of sows and parities within management routine, batch and subset is presented in Table 1.

Table 1. *Number of sows within management routines, batches, subsets and by parity.*

	Management routine					
	W1		W2		W3	
	Batch		Batch		Batch	
	I	II	I	II	I	II
Subset						
Early	3	4	3	5	5	6
Late	5	2	2	3	3	2
Total	8	6	5	8	8	8
Parity						
1st parity	1	2	0	2	3	3
2nd parity	3	3	1	3	1	3
>2nd parity	4	1	4	3	4	2

3.2 Video recordings

Two out of the three multi-suckling pens had three infra-red sensitive cameras each and the third pen was equipped with four cameras. The cameras were aimed so that the entire pen area was captured. Video recordings were used to study nursing-suckling interaction in Paper I and agonistic behaviour in Paper III. The sows were sprayed with colour on the back to enable identification on the video.

The protocol used to assess nursing-suckling interactions (see Table 2) was modified from previously described protocols (Valros *et al.*, 2002; Dybkjær *et al.*, 2001). Initiator was not defined or recorded in the observations and therefore nursing is used hereafter as a generic term for both nursing and suckling events.

Unfortunately there was a power failure that resulted in no recordings being made for five days. Therefore the nursing-suckling interactions were only analysed and compared for week 4 and week 6. Luckily the power failure did not interfere with the agonistic behaviour analysis.

The nursing-suckling interaction was assessed during 7.5 h/day for two days during week 4 and 6 of lactation (Figure 3). The assessment period within days was from 09.00 to 16.30. During that time period, no other sampling activity in the pen interfered.

Table 2. *Activities related to the nursing-suckling interaction studied in video recordings and their definition (adapted from Valros et al., 2002; Dybkjær et al., 2001).*

Action	Definition
Start of nursing/suckling	≥5 piglets active at the udder
End of nursing	<5 piglets active at the udder or the sow rolls over from the side to sternal recumbency.
Termination	Piglet: <5 piglets active at the udder Sow: If the sow rolls over from the side to sternal recumbency or stands up and walks away.

Agonistic behaviour (Paper III) was studied from the day of entry into the multi-suckling pen of the late subset and over the following three days (Figure 5). Two hours each day were observed. The starting time of the two hours for each batch was set to when the last sow entered the pen. The behaviours recorded were threatening, biting, fighting, pushing and hunting (Kirchner *et al.*, 2012).

3.3 Detection of lactational oestrus [Paper II]

In the study reported in Paper II, faeces samples from sows were collected every third day from day 21 post-farrowing until the day of weaning, resulting in eight or nine samples per sow depending on time spent in the multi-suckling pen. Progesterone metabolites were extracted from the faeces by a method modified from Palme *et al.* (1997) and Wasser *et al.* (2000). A solid-phase ^{125}I-radioimmunassay (Coat-a-count Progesterone, Siemens Healthcare Diagnostic In, Los Angeles, CA, USA) was used for the analysis. Elevated level of progesterone metabolites post-ovulation can be measured in faeces and indicates whether ovulation has occurred (Schwarzenberger *et al.*, 1996; Hultén *et al.*, 1995). In addition to the faeces samples, the staff at the Research Centre performed manual oestrus detection on two occasions per day from day 21 post-farrowing. The detection procedure consisted of checking redness and swelling of the vulva and the back pressure test (for review see Cornou, 2006). The manual oestrus detection continued post-weaning until the sows displayed standing oestrus.

After the sows had displayed standing oestrus post-weaning, they were sent to slaughter. At the slaughter house, the reproductive tract was retrieved and the ovaries were macroscopically examined for corpora lutea of pregnancy (Figure 4) and regressed cyclic corpora lutea, indicating an ovulation post-weaning or during lactation (Kunavongkrit *et al.*, 1982). The results from examination of the ovaries were used in combination with the results from progesterone metabolite analysis.

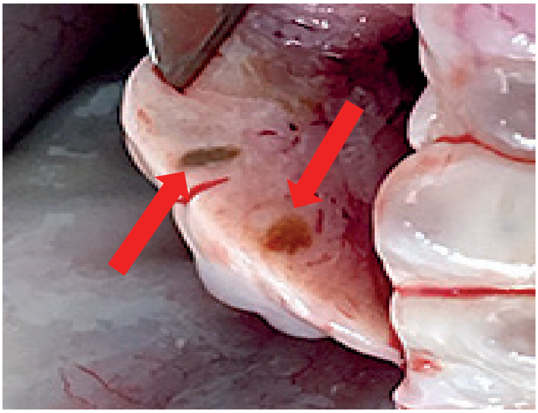

Figure 4. Section of an ovary, where the dark spots (indicated by red arrows) indicate a corpus lutea of pregnancy.

3.4 Stress and cortisol [Papers III-IV]

In order to assess the stress around the time of group housing, saliva was collected and analysed for cortisol. Saliva was sampled by allowing the sow to chew on a cotton swab until it was saturated (approximately 20 to 60 seconds). The sampling was conducted in the morning (from 07.00) and in the evening (from 17:00). Saliva sampling started two and a half days before a subset (early/late) was transferred to the multi-suckling pen (Figure 5). Thus the last sample collected in the individual farrowing pen was a morning sample and the first sample collected in the multi-suckling pen was an evening sample. In the multi-suckling pen the sampling continued for three days. A Cortisol-ELISA test validated for pig saliva was used to analyse the saliva for cortisol (Thomsson *et al.*, 2014) (Paper IV).

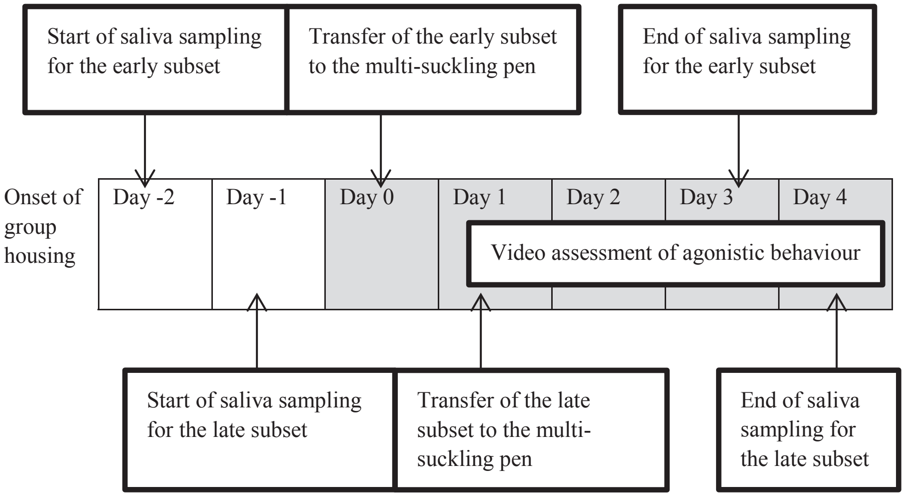

Figure 5. Schematic diagram showing the start and end of saliva sampling for the early subset and late subset of sows and the times when agonistic behaviour was assessed (see section 3.2). Each square represents one day. A white square indicates housing in an individual farrowing pen and a grey square indicates housing in a multi-suckling pen for the early group.

3.5 Additional data

3.5.1 Piglet data

Piglets were individually marked and weighed once a week from farrowing until weaning (Paper I). When a piglet died (individual farrowing pen or multi-suckling pen), staff recorded the date and probable cause of death. For all piglets that died in the multi-suckling pen, an elementary post-mortem examination was performed. The body condition of the dead piglet was assessed (normal/thin) and the stomach was examined for signs of feeding.

3.5.2 Sow data

Data on sow weight and back-fat depth at farrowing and at weaning were collected (Paper II). Udder palpation was performed on each sow from farrowing until weaning to determine udder filling. In addition to the palpation, teat injuries were recorded. Shoulder scratches were recorded and classified according to Séguin *et al.* (2006) (Paper III).

3.6 Statistical analyses

For all statistical analyses the SAS software (version 9.3, SAS Institute Inc., Cary, NC, USA) was used. This section provides only a brief description of the statistical analyses performed. A detailed description of the statistical models and methods used can be found in the individual papers.

In Paper I, differences in nursing-suckling interaction between the management routines were analysed using PROC MIXED, with day of lactation nested within week of lactation and sow nested within management routine and batch as a random effect. Management routine, batch, subset and week of lactation, interaction between management routine and batch, and interaction between management routine and week of lactation were included as fixed effects. Analyses were performed on three datasets: all nursings, only sow-terminated nursings and only piglet-terminated sucklings. Furthermore, piglet and litter performance (Paper I) were analysed with general linear models using PROC GLM. Management routine, batch, subset, parity and the interaction between management routine and batch were included as fixed effects. Total litter weight at birth was included as a covariate when within-litter weight variation at weaning, litter weight at weaning and litter growth from birth until weaning were analysed. Mean litter birth weight was included when mean piglet weight at weaning and mean piglet growth were analysed. When analysing total piglet mortality, litter size at birth was included in the model. In addition to litter size at birth, litter size at group housing was added as covariate when analysing piglet mortality in the multi-suckling pen. Correlations between nursing-suckling behaviour and piglet performance were calculated using residual Pearson correlations.

In Paper II, PROC MIXED with batch nested within management routine and subset as a random effect was used to analyse differences between management routines in the weaning to standing oestrus interval. Management routine, batch, parity and subset were included as fixed effects. Progesterone metabolites were analysed according to Hultén *et al.* (1995). In brief, the 99^{th} and the 97.5^{th} percentiles of the progesterone metabolite concentration from every faeces sample collected at 21 days post-farrowing were estimated. Ovulation was considered possible if one sample from a sow had a progesterone metabolite concentration above the 99^{th} percentile or if two consecutive samples from a sow had a concentration above the 97.5^{th} percentile. One sow had elevated progesterone metabolite concentrations throughout the lactation and was excluded when the 99^{th} and the 97.5^{th} percentiles were estimated.

The statistical analyses in Paper III were made across management routines, across groups (subsets) and across parities (primiparous compared with multiparous). Furthermore, differences between housing systems (individual farrowing pen compared with multi-suckling pen) were analysed. Cortisol was analysed both as actual concentration and within-sow coefficient of variation (CV). The reason for introducing CV was to facilitate comparison of stress-induced cortisol response among sows with different basal cortisol levels and capture changes in the diurnal rhythm within sows (Becker *et al.*, 1985; Barnett *et al.*, 1981).

4 Main results and discussion

4.1 Nursing-suckling interaction [Paper I]

Among the three management routines, where lactating sows were group housed in multi-suckling pens at one (W1), two (W2) or three weeks (W3) post-farrowing, there were no difference in nursing duration, nursing frequency or duration per nursing for any nursing, regardless of terminator (Table 2 in Paper I). The nursing frequency was similar to values reported in previous studies with lactating sows kept in groups of four to eight sows (Wallenbeck *et al.*, 2008; Jensen, 1986).

The three adjacent multi-suckling pens were not vocally and visually separated from each other. Consequently, grunting or other vocalisation indicating a nursing-suckling interaction in one multi-suckling pen could have influenced piglets in the neighbouring multi-suckling pens to initiate a nursing attempt. Such vocal influence on nursing-suckling interaction in adjacent pens has been reported by Illmann *et al.* (2005) and Silerova *et al.* (2013). The influence of neighbouring pens on nursing attempts possibly eradicated any potential differences between management routines W1-W3.

There was no difference between week 4 and week 6 for total nursings per day, nursing frequency per day or duration per nursing event for the different management routines. However, there were pair-wise differences within W2 (Figure 1 in Paper I). In management routine W2, the total nursing duration, duration of sow-terminated nursings and the duration per nursing of sow-terminated nursings were significantly longer in week 6 than week 4. In addition to the longer nursing durations, the nursing frequency of sow-terminated nursings was higher in week 6 than week 4.

The higher frequency of sow-terminated nursings during week 6 within management routine W2 may indicate an ongoing weaning process by the sow.

Sows terminating more nursings in late lactation is in agreement with other studies (Wallenbeck *et al.*, 2008; Valros *et al.*, 2002; Bøe, 1993).

The nursing-suckling observations made during week 4 correspond to a time when W3 sows had recently been transferred to the multi-suckling pen. A group of sows usually becomes socially stable around seven days post-mixing as aggression subsides (Arey, 1999) The group of sows in management routines W1 and W2 could therefore have been socially stable at week 4, unlike the sows in management routine W3. A less socially stable management routine W3 in week 4 could have been expected to cause the nursing-suckling interaction to differ from that in management routines W1 and W2. However, the cortisol concentrations in saliva indicated that W3 sows were less stressed in the group housing pen post-mixing (week 4 post-farrowing) than in the individual farrowing pen (0.47 µg/dL compared with 0.82 µg/dL; $p<0.01$). It might be therefore be the case that there was no difference in nursing-suckling interaction between the management routines during week 4.

4.2 Occurrence of lactational oestrus [Paper II]

Of the 43 sows included in the study only one (in routine W3) ovulated during lactation. Ovulation was determined for that sow by progesterone metabolite concentrations, since two consecutive samples were above the lower threshold level (Figure 6), and by macroscopic examination of the ovaries, where fresh corpora lutea, regressed cyclic corpora lutea and corpora lutea of pregnancy were observed. In addition to the ovulating sow in W3, one sow in W1 had elevated progesterone metabolite concentration, but no macroscopic indication of lactational ovulation (Figure 6).

The lack of lactational oestrus was quite unexpected. However, the literature reports a disparity in the occurrence of lactational ovulations (Weary *et al.*, 2002; Wattanakul *et al.*, 1997; Henderson & Stolba, 1989).

Pig reproduction has been reported to be influenced by season of the year (Peltoniemi *et al.*, 1999; Petchey & Jolly, 1979). Season also influences the occurrence of lactational oestrus (Hulten *et al.*, 2006). The occurrence of lactational oestrus is reported to vary throughout the year, with the highest rate in the period December-May, months which correspond to the natural seasonal fertility period in sows (Peltoniemi *et al.*, 1999). This seasonality could perhaps have influenced the overall occurrence of lactational oestrus in this thesis, since the entire experiment was conducted from 7 September to 14 December.

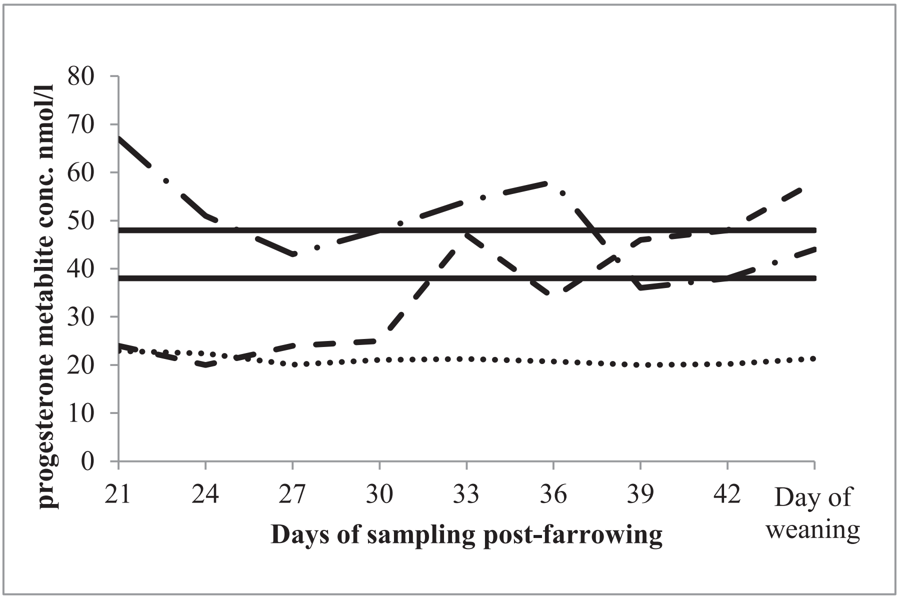

Figure 6. Mean progesterone metabolite concentration for all sows and for the ovulating and non-ovulating sows exceeding the lower and upper thresholds. All sows (•••), ovulating sow (▬ ▬), non-ovulating sow (▬ •). The non-ovulating sow was excluded from the estimation of the upper and lower thresholds.

The group size in Paper II varied between five and eight sows. Large groups of >10 sows have been reported to increase the incidence of lactational oestrus (Hulten, 1998). However, other studies have reported occurrence of lactational oestrus in groups of less than 10 sows (Weary *et al.*, 2002; Wattanakul *et al.*, 1997). Therefore other factors might be more crucial for the occurrence of lactational oestrus than group size.

The design of a group housing pen can affect the occurrence of lactational oestrus (Stolba *et al.*, 1990; Henderson & Stolba, 1989). It is possible that the simple pen design used in this thesis work did not allow sows to escape their piglets during the group housing period. As a consequence of the pen design, the nursing-suckling interaction perhaps remained sufficient for all management routines throughout the group housing period (Paper I), resulting in no ovulation in late lactation. The incidence of late lactational ovulation would perhaps have differed if the sows had had *e.g.* outdoor access, allowing them to put a greater distance between them and their litter.

The one sow ovulating during lactation was in management routine W3. Ovarian examination showed that ovulation had occurred soon after the transfer to the multi-suckling pen. Relocation and transportation have been reported to induce ovulation (Dalin *et al.*, 1988; Rojanasthien, 1988), and therefore this ovulation was perhaps a result of the stress triggered by the transfer from the individual farrowing pen to the multi-suckling pen.

In addition to corpora lutea, progesterone can be produced by the adrenal glands during times of stress (Mwanza *et al.*, 2000; Tsuma *et al.*, 1998). The elevated levels of progesterone metabolites in the non-ovulating W1 sow could thus have been an effect of the stress experienced by this particular sow.

4.2.1 Weaning to standing oestrus interval

Interestingly, weaning to standing oestrus interval differed between the management routines. Management routines W2 and W3 had a significantly shorter ($p<0.001$) interval, 2.6 ±0.3 days and 2.7 ±0.2 days, respectively, than W1 (4.0 ±0.3 days). The interval for W1 sows was closest to the normal 3-6 days (Kemp & Soede, 1996). The shorter weaning to standing oestrus interval in W2 and W3 sows indicates that weaning had progressed further during the lactation than in W1 sows. In this thesis the lactation period lasted for 44 days, but if the lactational period had lasted longer (*e.g.* 49 days as stated in KRAV regulations), it might have resulted in more sows returning to oestrus during lactation, as reported by Hultén *et al.* (1995).

In this thesis work, sows in the W1 regime lost significantly more back fat than W2 sows during lactation. The difference in weaning to standing oestrus interval between management routine W2 and W1 could be explained by differences in back-fat loss during lactation. Back-fat loss during lactation has been reported to increase weaning to standing oestrus interval (De Rensis *et al.*, 2005; Zak *et al.*, 1997). However, there was no significant difference in back-fat loss between sows in management routines W1 and W3.

The timing of the group housing could perhaps have resulted in a difference in the start of follicular wave development (for review see Lucy *et al.*, 2001). For sows in W2 and W3 a follicular wave was perhaps closer to the pre-ovulatory stage at weaning, resulting in a shorter weaning to standing oestrus interval compared with management routine W1. In addition to the timing of group housing, the nursing-suckling interaction in different management routines could perhaps have changed differently between the individual farrowing pen prior to the transfer and the multi-suckling pen post-mixing. Management routines W2 and W3 may have resulted in a greater change in nursing-suckling interaction due to the sows being closer to peak lactation than W1 sows and due to the piglets having a more mature digestive tract and thus beginning to consume solid feed in group housing before piglets in W1 (Bøe, 1991; Gill & Thomson, 1956). Consequently, W2 and W3 sows had a difference in the onset of ovarian activity in the multi-suckling pen compared with W1 sows.

4.3 Pre-weaning piglet mortality [Paper I]

A summary of the number of piglets that died in the individual farrowing pen and multi-suckling pen is presented in Table 3. For more detailed data on piglet mortality from birth to weaning, see Figure 2 in Paper I. Most of the piglets died within the first week post-farrowing. In management routine W1, seven of the 16 piglets that died in the multi-suckling pen had no stomach contents. In management routine W2, all eight piglets that died in the multi-suckling pen had stomach contents. In management routine W3, three piglets died in multi-suckling pen. One of these piglets was euthanised due to suspected infection (exudative epidermitis) and was found to have no stomach contents.

Piglet mortality did not differ between management routines with regard to total pre-weaning mortality and mortality in the individual farrowing pen. However, in the multi-suckling pen, management routines W2 and W3 had significantly lower piglet mortality than W1 (Table 4). The difference in pre-weaning piglet mortality in the multi-suckling pen could perhaps be explained by the piglets in W2 and W3 being more robust at the time of group housing than the W1 piglets. The lower robustness of the W1 piglets was supported by the fact that almost half of the 16 W1 piglets that died in multi-suckling pen lacked stomach contents. Total mortality at five weeks post-farrowing did not differ between management routines and the reference group.

Table 3. *Number of piglets that died in the individual farrowing pen and multi-suckling pen within each management routine W1-W3.*

Management routine	Individual farrowing pen	Multi-suckling pen	Total
W1	32	16^{a}	48
W2	44	8^{b}	52
W3	38	3^{b}	41

^{a,b} Different superscripts within columns indicate significant difference (p<0.05).

The mortality for the piglets in the multi-suckling pen in management routine W3 was not correlated to the total mortality (Table 4). This suggests that it is more favourable to group house lactating sows and piglets at three weeks than at one week post-farrowing. In practice, when group housing piglets at three weeks post-farrowing, efforts to reduce piglet pre-weaning mortality should be targeted at reducing the mortality in the individual farrowing pen.

Table 4. *Piglet mortality (%) and the correlations between total mortality and mortality in the individual farrowing pen and in the multi-suckling pen.*

	Management routine		
	W1	W2	W3
Total pre-weaning mortality (%)[1]	27.1 ±3.7	24.1 ±4.1	19.8 ±3.6
Individual farrowing pen (%)[1]	17.3 ±3.5	19.8 ±3.9	18.1 ±3.4
Multi-suckling pen (%)[1]	12.0 ±2.0[a]	5.8 ±2.2[b]	1.7 ±1.9[b]
<u>Correlations (r)</u>			
Total pre-weaning morality and multi-suckling pen mortality	0.61*	0.62*	0.36
Total pre-weaning morality and individual farrowing pen mortality	0.92*	0.91*	0.65*

[1]LSmean ±SEM.

[a,b]Different superscripts within rows indicate significant difference (p<0.05).

*Indicates a significant correlation (p<0.05).

Each sow's litter size can be recorded at the time of group housing, but at weaning the litter size of each sow becomes an average of total number of weaned piglets from that multi-suckling pen. In Paper I, the litter size at the time of group housing and the total pre-weaning mortality were negatively correlated. This negative correlation indicates that recording litter size at group housing could be a useful tool when selecting sows for breeding or culling in certified piglet production. Recording litter size after a week post-farrowing has been reported to be a better means to predict litter size at weaning than recording litter size at farrowing (Su *et al.*, 2007).

4.4 Within-litter weight variation at weaning [Paper I]

There was no difference between the management routines in within-litter weight variation at weaning (Table 3 in Paper I). Furthermore, there were no differences between the management routines in mean piglet weight at weaning, mean piglet weight gain, litter weight at weaning or litter weight gain. Table 5 shows the heaviest and lightest piglets within each management routine and the reference group and mean piglet weight at weaning.

Table 5. *Heaviest, lightest and mean (Lsmean ±SEM) piglet weaning weight (kg) in management routines W1-W3 and the reference group.*

	Management routine			
	W1	W2	W3	Reference group
Heaviest (kg)	21.4	21.9	24.0	17.4
Lightest (kg)	7.3	5.5	5.2	3.6
Mean (kg ± SEM)	14.1 ±0.4	13.7 ±0.4	14.3 ±0.4	11.0 ±0.5

The within-litter weight variation at weaning was 2.3 ±0.2, 2.6 ±0.2 and 2.3 ±0.2 kg for management routine W1, W2 and W3, respectively. The within-litter weight variation did not differ from the reference group (2.0 ±0.2 kg) at 35 days post-farrowing In a Swedish on-farm field trial where piglets were weaned between 23-37 days of age, the weight variation was ±1.3 kg (Westin *et al.*, 2014). The prolonged lactation period in certified production may make the within-litter weight variation at weaning more noticeable, because litter weight variation increases with piglet age (Bøe, 1993; Algers *et al.*, 1990; Thompson & Fraser, 1986). Moreover, compared with an individual farrowing pen, the multi-suckling pen is a more competitive environment for the piglets. Factors such as more piglets, cross-sucklers and deep straw bedding can add to the within-litter weight variation (Vasdal & Andersen, 2012; Pedersen *et al.*, 2011a).

For both litter and individual weight gain, easy access to the udder and teat plays an important role (Vasdal & Andersen, 2012). A deep straw bed can possibly obstruct easy access to the teats, because as part of their pre-lying behaviour sows prepare a pit in which to lie down (for review see Damm *et al.*, 2005). Consequently, when the sow then rolls over to expose her udder, the teat row closest to the bed is most likely covered by straw. In a deep straw bed it is probably more difficult for the piglets occupying a teat on the lower teat row to have easy access to their teat, thus affecting the within-litter weight variation. Furthermore, with growing piglets the space at the teats decreases, possibly making it more difficult for the entire litter to gain easy access to the teats.

For both observation days in week 6, duration per nursing event for sow-terminated nursings was positively correlated to total litter weight at weaning (r = 0.94: $p<0.001$; r = 0.91: $p<0.05$) and litter size at weaning (r = 0.90: $p<0.05$; r = 0.96: $p<0.05$) for management routine W1. These correlations indicate that the sows were willing to allow their piglets to stimulate and maintain milk production in late lactation, perhaps as a result of a strong mother-offspring bond. The mother-offspring bond possibly further influenced the piglets to consume milk rather than solid feed during lactation. The development of the strong mother-offspring bond in management routine W1 was perhaps because the W1 piglets were completely dependent on the sow for food at the time of group housing. In contrast, in management routines W2 and W3 the piglets had a more mature digestive tract at the start of group housing period and could thus begin to consume solid feed when group housed. Consequently, the sows and piglets in management routines W2 and W3 perhaps did not develop a strong mother-offspring bond in the multi-suckling pen and the piglets thereby became less dependent on milk for growth and survival in late lactation.

4.5 Stress and agonistic behaviour [Paper III]

Cortisol, a hormone produced by the adrenal glands, is commonly used to assess stress (Hellhammer *et al.*, 2009). Besides measuring cortisol in saliva, cortisol can be measured in plasma and serum (Colson *et al.*, 2012; Kerlik *et al.*, 2010). However, sampling of blood requires either stressful restraint of the animal or the insertion of a surgical catheter. The use of permanent catheter is not appropriate in less strictly controlled environments such as the multi-suckling pens used in this thesis (Cook *et al.*, 1997). Therefore saliva sampling for analysing cortisol was deemed more appropriate for this study. However, cortisol in saliva represents only the free bound cortisol and the correlation with cortisol in plasma has been reported to vary (Brandt *et al.*, 2009; Bushong *et al.*, 2000). Furthermore cortisol levels peak at around 5-20 minutes post-stress (Kirschbaum & Hellhammer, 2000). This time lag could have influenced the results, as a fight between sows prior to sampling could have affected the cortisol concentration measured.

4.5.1 Stress

Sows within management routine W3 had significantly lower (p<0.01) cortisol levels when group housed (0.47 ± 0.24 µg/dL) than when housed in the individual farrowing pen (0.82 ± 0.49 µg/dL). Because the W3 piglets were heavier than the W1 and W2 piglets, the W3 sows were perhaps more stressed in the individual farrowing pen two days prior to the transfer due to crowding. Crowding has been reported to trigger stress in pigs (Yen & Pond, 1987). In addition, when mixing pigs three factors have been reported to reduce stress and aggression: more bedding material, *ad libitum* feeding and greater space allowance per sow (Hemsworth *et al.*, 2013; Merlot *et al.*, 2012; De Leeuw & Ekkel, 2004; Weng *et al.*, 1998). The multi-suckling pen provided all three factors, and thus the combination of these three factors could also have contributed to the lower cortisol levels for W3 sows in the multi-suckling pen.

The cortisol variation was significantly lower in W3 sows than in W1 sows (Figure 8 in Paper III). In comparison with W1 sows at group housing, W3 sows had progressed further in lactation and the piglets were the main initiator of nursing. The W3 sows may therefore have had less maternal will to nurse the litter post-mixing than the W1 sows. Less maternal will to nurse the piglets possibly resulted in the W3 sows only needing to focus on agonistic interactions and environmental exploration at mixing, and thus W3 sows experienced the time post-mixing as less stressful.

4.5.2 Agonistic behaviour

There were no differences in agonistic behaviour (attacks initiated and attacks received) between the management routines. However, there was a difference in the number of attacks initiated and received by the early (resident) and late (intruder) subset. The sows in the early subset initiated more ($p<0.001$) and received fewer attacks ($p<0.01$) than the sows in the late subset. These results are in agreement with findings in other resident-intruder studies on pigs (D'Eath & Pickup, 2002; Deguchi & Akuzawa, 1998).

Multiparous sows initiated more ($p<0.001$) and received fewer attacks ($p<0.001$) than primiparous sows. Previous studies have shown that larger sows attack smaller sows when mixed (Li *et al.*, 2012; Arey & Edwards, 1998), and therefore the attacks observed in this thesis work may have been due to the difference in body size between the larger multiparous and the smaller primiparous sows.

5 Conclusions

The results presented in this thesis add to the body of knowledge about management routines with lactating sows with piglets group housed at one week (W1), two weeks (W2) and three weeks (W3) post-farrowing. The conclusions that can be drawn from the data obtained are as follows:

- The nursing-suckling interaction was not affected by group housing routines. However, the short weaning to standing oestrus interval suggested that sows in management routines W2 and W3 had progressed further in the weaning process at weaning than those in management routine W1.

- Only one sow returned to oestrus during lactation. This low incidence of lactational oestrus could perhaps be a result of both season and pen design.

- The W3 routine resulted in lower piglet mortality in the multi-suckling pen than the W1 routine. There was a negative correlation between litter size at group housing and total pre-weaning mortality.

- Within-litter weight variation at weaning, within-litter weight gain, piglet weight gain and piglet weight at weaning did not differ between the management routines. However, the within-litter weight variation at weaning was more pronounced in all these routines than the reference group and than literature values reported for non-certified production.

- Group housing three weeks post-farrowing seems to be less stressful for the sows than group housing one week post-farrowing.

Taken together, the knowledge gained in this thesis on sow reproduction and piglet performance in multi-suckling pens can be of assistance in development of housing and management routines.

6 Thoughts for the future

The implementation of the results and conclusions drawn from this thesis in future work, consideration must be given to the design of the multi-suckling pen, pig genotype and time of the year. For instance, there are several different types of multi-suckling systems, each with its own advantages and disadvantages regarding *e.g.* nursing-suckling interaction, lactational oestrus and piglet performance (for review see Nieuwamerongen *et al.*, 2014). Overall, a group nursing system must be suited to the farm on which it is implemented, because factors such as the experience and the educational level of the stockperson and their managerial ability are important for the outcome of the production system (Li *et al.*, 2010; Peltoniemi *et al.*, 1999).

With increasing demand for more welfare-friendly pig production, group housing systems for lactating sows could also be of interest for non-certified pig production in future. However, besides promoting animal welfare, such group housing systems need to be efficient in order to attract new users. One possible way to increase efficiency could be to inseminate sows that return to oestrus during lactation (Terry *et al.*, 2014; Soede *et al.*, 2012). Many previous studies that have focused on inducing lactational oestrus and inseminating sows during lactation have housed sows crated or loose in individual farrowing pens, and not in groups (Gerritsen *et al.*, 2009; Langendijk *et al.*, 2009; Kuller *et al.*, 2004). In a study by Kongsted and Hermansen (2009), sows were housed under certified production conditions and lactational oestrus was induced. However, the sows were still being housed individually at day 35 post-farrowing, *i.e.* far later than when group housing commences in Sweden. A study with experimental conditions closest to Swedish certified conditions is that by Hulten *et al.* (2006). However, that study did not induce oestrus but showed that oestrus during lactation is difficult to detect, because the visible signs are less conspicuous. Soede and Kemp (2015) concluded that management, during lactation and post-weaning, should focus on optimising follicular development in order to maximise the fertilisation of the oocytes during the first oestrus post-weaning. From a management point of view, it might therefore be more practical to have the sow remain in anoestrus during lactation and to inseminate post-weaning. Efforts should also be made to find other means to improve efficiency, thus increasing the attractiveness of this production system.

Another way to improve efficiency could be to focus on breeding and breeds. As previously mentioned, breeding to date has focused on increasing litter size, with an associated unfavourable increase in within-litter weight variation and piglet mortality (Rutherford *et al.*, 2013; Lund *et al.*, 2002). This focus has most likely resulted in animals that are less suited for group housing during lactation. It has been suggested that, through breeding, the modern prolific sow has become more prone to ovulate, which includes during lactation even when individually housed (Soede & Kemp, 2015; van Wettere *et al.*, 2013; Kuller *et al.*, 2004). Moreover, studies report that in certified production using commercial breeds, the preferences of certified pig producers are not matched by current breeding goals (Wallenbeck *et al.*, 2016; Rydhmer *et al.*, 2014). In addition, both those studies suggest that future breeding programmes should give more consideration to the production systems in which the animals will be kept. However, breeding with less emphasis on litter size for certified production (Wallenbeck *et al.*, 2016; for review see Prunier *et al.*, 2014) is perhaps difficult to justify, as certified pork production accounts for less than 2% of pork production in many European countries (for review see Früh *et al.*, 2014). Therefore, use of different breeds or crosses that are more suited to certified production systems than commercial breeds could be an option.

Even though it is common to group-house lactating sows and their piglets, there is no such demand in the certification regulations. An alternative to group housing during lactation would perhaps be to house the sow and her piglets in an individual farrowing pen with outdoor access according to certified production regulations. This type of housing could perhaps influence the sow to remain anoestral and reduce piglet mortality to lower levels than observed in multi-suckling pens. However, longitudinal studies would be required to *e.g.* capture the effect of reproduction seasonality in the sow in this case (Hulten *et al.*, 2006; Peltoniemi *et al.*, 1999; Petchey & Jolly, 1979). Moreover, individually housed sows provide a better opportunity to monitor each sow, thus making it easier to evaluate the performance of each sow. However, individual housing, is it animal welfare friendly?

7 Populärvetenskaplig sammanfattning

I Europa har det blivit allt vanligare att hålla grisar i grupp under vissa delar av uppfödningen. Detta är en konsekvens av ett ökat tryck från konsumenter för en bättre djurvälfärd inom grisproduktionen. Det har i sin tur lett till en ökning av certifierad ekologisk grisproduktion med krav på grupphållning av suggor. Vanligt för certiferade produktionssystem i Sverige är att digivande suggor med smågrisar hålls i gruppdibox från och med två till tre veckor efter grisning fram till avvänjning vid sex veckor efter grisning. Dock kan grupphållningen i gruppdiboxen ha en negativ inverkan på smågrisproduktionen; i) dels förekommer brunster under digivning, ii) dels är dödligheten hög bland smågrisarna samt iii) variationen i avvänjningsvikt mellan smågrisar är stor.

Syftet med denna studie var att undersöka ifall dessa tre negativa faktorer kunde påverkas genom alternativa skötselrutiner. Tre skötselrutiner jämfördes. I den första rutinen tillbringade suggorna och smågrisar en vecka (W1), i den andra två (W2) och in den tredje tre (W3) veckor i grisningsboxen innan de flyttades ut till gruppdiboxen. I alla rutinerna avvandes smågrisarna sex veckor efter grisning. Totalt ingick 43 suggor i försöket. Varje skötselrutin upprepades en gång. Det fanns även en referensgrupp som bestod av nio suggor som hölls i individuella grisningsboxar och avvandes 35 dagar efter grisning.

Tiden i gruppdiboxen filmades och studerades med avseende på di-beteende och aggressioner. Träck samlades in och analyserades för progesteron och efter avvänjning skickades suggorna till slakt och äggstockarna undersöktes därefter. Stress är en faktor som påverkar både dibeteendet och reproduktionen därför samlades även saliv från suggorna vid tiden kring utsläpp i gruppdiboxen och analyserades för stresshormonet kortisol. Smågrisarna vägdes veckovis från födsel till avvänjning.

Det var bara en sugga som hade ägglossning under digivningsperioden. Skötselrutin W2 och W3 hade i jämförelse ett kortare intervall mellan avvänjning och brunst än skötselrutin W1.

Det var inte någon skillnad i smågristillväxt, kulltillväxt eller viktvariationen inom kull vid avvänjning mellan de tre skötselrutinerna. Däremot var smågrisdödligheten i skötselrutin W3 lägre i gruppdiboxen än i skötselrutin W1.

Suggorna i W3 hade en mindre variation i kortisolkoncentrationen jämfört med W1 och bedömdes därför vara mindre stressade under den första tiden efter utsläpp. Suggor i W3 hade också en lägre koncentration av kortisol saliven i gruppdiboxen efter utsläpp än före, i den individuella grisningsboxen.

Den låga förekomsten av brunster under digivning i denna studie skiljer sig från tidigare studier och kan ha berott på faktorer som boxutformning och säsong. Det kortare intervallet mellan avvänjning till brunst för skötselrutiner W2 och W3 indikerar att den gradvisa avvänjningen var mer framskriden hos suggorna i W2 och W3 jämfört med suggorna i W1. Att vänta med att hålla suggor i grupp och smågrisar upp till tre veckor efter grisning visade sig reducera smågrisdödligheten i gruppdiboxen och vara mindre stressande för suggorna. Skillnaden i avvänjningsvikter skiljde sig inte åt mellan de tre skötselrutinerna och referensgruppen, den blir dock mer tydlig i certifierad produktion med längre digivningsperiod än i icke-certifierad produktion.

Sammansfattningvis kan resultaten i denna studie ligga till grund för utvecklingen av skötselrutiner och inhysningssystem.

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