Development of a lactational oestrus induction protocol that can be implemented in confinement-free sow housing systems.

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Co-operative Research Centre for High Integrity Australian Pork

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Executive Summary

In the previous work funded by Pork CRC, piglet and sow separation (intermittent suckling) and fence line boar exposure were essential components in the development of lactation oestrus induction protocols. The current project further develops those strategies by investigating the most suitable period of separation and the extent of boar exposure to achieve industry acceptable mating and farrowing rates.

The project investigated both 16 h and 8 h periods of separation over 3 days with fence line boar exposure, or full boar contact without piglet separation, had on lactational oestrus and compared these strategies to conventional weaning, with all treatments commencing at day 21 of lactation. Lactation is an energy demanding phase of the reproductive cycle and places sows in a catabolic state. The role sow catabolism might have on lactation oestrus induction has been evaluated here. While separating sows and their piglets prior to weaning can stimulate lactational oestrus, the consequences of this separation on the welfare of both the sow and piglets were also explored in the current project. In the previous work it was evident that a percentage of lactating sows spontaneously ovulate during lactation. The rate of spontaneous ovulation was expected to be influenced by suckling litter size. Sows with different litter sizes were monitored for the evidence of spontaneous ovulation.

Three days of sow and piglet separation for 16 h/day resulted in 82% of sows mated in lactation with 92% of these sows going on to successfully farrow. The mating results were similar to those of sows conventionally weaned at day 21 of lactation. The induced sows produced similar number of piglets born alive as the conventionally weaned sows. An 8 h separation period or providing 30 min of full boar contact daily resulted in oestrus induction during lactation but the response rates were lower than the 16 h separation sows, particularly in the case of the 8 h separation protocol. The metabolic status of the sow had no influence on the ability of sows to respond to the oestrus induction protocols. The amount of body protein lost did affect subsequent pregnancy rate and there was no interaction with the type of oestrus induction protocol used.

Separation of sows and piglets for 8 h periods over 7 days failed to alter sow or piglet behaviour in a manner that was indicative of a welfare concern. Once piglets were re-joined, they spent increased time at the udder but this did not lead to increased damage of the udder. Interestingly, separated piglets spent a proportionally greater amount of time around at the creep feed feeder which may be advantageous as stimulating creep feed intake.

While there were significant logistical problems monitoring ovarian follicle development during lactation, some useful results were recorded on the incidence of spontaneous oestrus during lactation. Using the information available it was estimated that around 8-9 % of the sows monitored, ovulated during lactation.

The pig industry has been faced with significant pressure to change some of the long established management strategies. Expectations are that pig production systems will provide the best possible animal welfare. The reliance on having to wean piglets places limitations on management decisions. Mating in lactation would allow weaning age to be increased and weaning to be staged over time without reducing litter number per sow per year. An increased weaning age would reduce weaner ‘setback’ and reduce the use of antibiotics in weaners. The failure to detect sows that spontaneously ovulate in lactation results in long WOI and lower litters/sow/year. Mating in lactation overcomes the failure to detect sows that spontaneously ovulate in lactation. Spontaneous ovulation is likely to be a greater problem if the industry is required to limit the time sows can be housed in farrowing crates and forced to move to a combination of farrowing crates and some type of group lactation. Mating in lactation eliminates the need for sows to be housed in a mating

shed and removes the difficulties associated with oestrus detection when sows are weaned into groups.

Detractors of lactation oestrus induction using piglet separation have questioned the welfare implications for the sows and piglets. No significant welfare concerns were detected when sows and piglets were separated for 8 h per day over 7 days.

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1. Introduction

1.1. *Lactation oestrus induction*

It is clear that suckling load has a major influence on determining whether sows remain anoestrous in lactation, because reducing suckling load (Reviewed by Matte, et al., 1992) or intermittent suckling (reviewed by Langendijk, et al., 2007) can result in sows displaying oestrus and ovulating during lactation. It is probably that selection directly or indirectly for a short weaning to oestrus interval (WOI), has changed the sow's reproductive status during lactation. There is a threshold above which neural inhibition of gonadotrophin secretion inhibits the final stages of follicle development and ovulation. The threshold for effective neural inhibition is likely modified by factors such as genotype, individual responsiveness, suckling load, parity, season, the sow's metabolic status, feed intake, social interactions (group housing) and boar exposure. The combination of these stimuli places the sow above or below this threshold in lactation. If the sows responsiveness is modified, say through management, sows might well be below this threshold and ovulate while still lactating.

It is natural for the neural threshold to diminish as lactation length advances, probably because the hypothalamic-pituitary-adrenal (HPA) axis gradually escapes from the influence of suckling inhibition (Britt et al., 1985; Varley and Foxcroft, 1990) as well as having the suckling intensity decrease. So if lactation length is long enough, sows will eventually display oestrus and ovulate. In older genotypes, commercial weaning most likely occurred before this reduced inhibition on luteinising hormone (LH) was experienced and so sows failed to display lactational oestrus unless some degree of intervention was instigated. Modern sow genotypes have much shorter WOI's. It is proposed that one consequence of this has been sow genotypes that are less responsive to the inhibition placed on gonadotrophin secretion during lactation. The TopPigs 40 genotype, was selected for a short WOI interval and responded better to lactational oestrus induction compared to the TopPigs 20 genotype which has been selected for litter size (Gerristen, 2008). It is further proposed that for these recent sow genotypes, the gradual decrease in HPA responsiveness to the suckling-induced inhibition on ovarian activity occurs earlier in lactation, and this acts to allow a higher degree of lactational oestrus in sows.

Reducing suckling load (either by management or as a normal manifestation of commercial production) and boar exposure are factors that act to reduce the inhibition threshold, allowing sows to ovulate in lactation. Exposure to boars (Newton et al., 1987 a & b; Costa and Varley, 1995; Mota, et al., 2002; Downing et al., 2009; Kongsted and Hermansen, 2009; van Wettere et al., 2013) and grouping sows (Rowlinson and Bryant, 1981, 1982; Hulten, et al., 2006) have been used to induce oestrus during lactation. The extent of boar exposure has an influence on the responsiveness of sows to lactation oestrus induction. Between day 12 and day 21 of lactation 1 h/d of boar exposure was not enough to induce oestrus in lactating sows and overcome suckling inhibition (Costa and Varley, 1995). In our Pork CRC studies, we have used the boar essentially as an aid to oestrus detection and exposure to a boar has been only for a short period. Recent results indicate that this level of exposure has a limited effect on induction of oestrus. Results from other CRC projects have indicated that moving the sow to the boar and increasing the exposure time to direct boar stimuli results in more effective oestrus induction (van Wettere et al., 2013).

1.2. *Metabolic status of the sow and the response to lactational oestrus induction*

To meet the nutritional requirements of milk production, the sow uses energy derived from feed or mobilises tissue reserves (Vinsky et al., 2006). The effect of sow catabolism during lactation has been reviewed by Foxcroft et al., (2009). There appears to be a threshold on body reserve losses which if breached, will negatively affect follicle development, oocyte quality and embryo survival. A 12% loss in protein mass between farrowing and weaning is reported to decrease follicle diameter and follicular fluid IGF-1 concentrations (Clowes et al., 2003). During the same production interval, a 9% decrease in body weight decreased embryo weight at day 30 of gestation but had no effect on ovulation rate or litter number (Patterson, et al., 2011). Schenkel et al., (2010) found that an 8% loss in body weight during lactation was sufficient to decrease litter size in the subsequent farrowing. Foxcroft et al., (2009) state very confidently, that there is probably a sub-set of very catabolic sows that are susceptible to poor embryo development following a post weaning mating. This is given further support by Patterson et al., (2011). These concerns are likely to be more problematic if lactation is increased from the industry standard of 21-23 days to 28 or even 35 days in an effort to increase weaning weight and reduce weaner 'set back'.

1.3. *Sow and piglet welfare during intermittent suckling*

Traditionally piglets are weaned from sows at three to four weeks of age (Langendijk *et al*. 2007a, b). Abrupt weaning, with the change to a solid diet, along with the mixing of unfamiliar litters, causes stress and reduced growth for the piglets (Kuller *et al*. 2004). While early weaning has obvious economic benefits, an increased lactation length assists in the growth and development of the piglets. However, with traditional weaning and mating, this comes at a cost to sow lifetime reproductive output (Berkeveld *et al*. 2007a, b; Hoshino and Koketsu 2008).

The need for economically viable production, which promotes both sow fertility and post weaning piglet growth rate has led to considerable research effort trying to identify methods to reduce the farrowing to oestrus interval or non-productive days of the sow without negatively impacting upon the welfare of sows or piglets (Kirkwood and Thacker 1989; Zak *et al*. 2008). Currently, the most successful strategy has been to induce oestrus during lactation, which also allows for an increased weaning age but at the same time maintaining sow reproductive rate (Langendijk *et al*. 2007a; Gerritsen *et al*. 2008).

Intermittent suckling has been identified as a method to alleviate the restraints placed on LH release due to the suckling suppression (Kuller *et al*. 2004). This process involves separating the sow and piglets for a period of time each day during lactation. However, a difference in the response to this separation has been identified between primiparous and multiparous sows (Hulten *et al*. 2006). During lactation, primiparous sows have been recognised as forming stronger bonds with their litters (Hulten *et al*. 2006). Without separation, primiparous sows are more likely to remain anoestrous during lactation, while multiparous sows are more likely to spontaneously ovulate (Kunavongkrit *et al*. 1982; Newtown *et al*. 1987). While separating sows and their piglets prior to weaning can stimulate sows into a lactational oestrus, the consequences of this separation on the welfare of both the sow and piglets need to be explored. Substantial and prolonged behavioural and physiological responses can have effects on biological fitness by affecting growth performance, reproduction, injury, health and survival (Broom and Jonson 1993; Barnett and Hemsworth, 2010).

1.4.*Previous research findings*

The current project developed further, strategies reported on previously to the Pork CRC, where we were able to successfully induce oestrus in lactating sows under commercial conditions (Downing et al., 2007, Downing et al., 2009). The initial protocol involved the use of PG600, piglet separation (16 h/d) until the time of oestrus, boar exposure and AI at oestrus detection. The protocol resulted in reproductive performance similar to conventional weaning (Downing et al., 2009). While the protocol was successful, it was unclear as to the relevance that individual components of the protocol had to the overall success of the oestrus induction procedure. To help answer this question the Pork CRC funded a project, 'Strategies to enhance oestrus induction in lactating sows', with the objective being to refine the original induction protocol and investigate the relevance of the various components.

From those studies it was found that:

1. Using the initial protocol, oestrus induction can be started as early as day 14 of lactation but the limit is probably day 16 to achieve acceptable mating and farrowing rates and litter size.
2. Starting at an average of day 18 (range 16-20) of lactation, three consecutive nights (16 h/d) of separation is sufficient to induce oestrus without PG 600. Separation for 8 h/d over 3 days is not adequate at this time in lactation but could be all that is needed if the induction occurs later in lactation at say day 22-24.
3. Starting the separation and mating too close to weaning doesn't affect mating rate but does influence pregnancy rate, with a higher rate of returns to oestrus.
4. Spontaneous ovulation occurs in lactating sows probably as early as day 16 of lactation.
5. Fence line boar exposure alone was not sufficient to induce ovulation in a high percentage of sows.

The observation that sows ovulate spontaneously in lactation identifies a major management issue, even for conventional weaning as it will result in long WOI's, as reported by Hulten et al. (1998). The extent of spontaneous ovulations could be related to suckling litter size and sow metabolic state (Patterson et al., 2011) and needs to be investigated.

Current Project objectives:

Based on previous results the project objectives were:

1. To finalise the essential components of an oestrus induction protocol in lactating sows involving piglet separation and boar exposure
2. To monitor follicle development in lactating sows with different suckling litter size to identify the pattern of follicular development that results in spontaneous ovulation and the factors that determine when sows might be most responsive to a minimalist induction protocol.
3. Investigate the significance that sow metabolic status could have on the success of oestrus induction in lactation
4. Investigate the behaviour and welfare of sows and piglets during periods of separation as part of an oestrus induction protocol.
5. Assess oestrus behaviour and spontaneous ovulation in a confinement free group housing system during late lactation. Results of this objective are reported in the Final Report of the Pork CRC Project; 1A-105.

2. Methodology

2.1. *Animal ethics*

All studies were conducted at the Research and Innovation Unit of Rivalea Pty. Ltd., Corowa, NSW, Australia. The use of animals complied with the Australian Code of Practice for the use of Animals for Scientific Purposes and the protocols were approved by the Animal Care and Ethics Committee of Rivalea Pty. Ltd.

2.2. *Study 1 - Oestrus induction using piglet separation and boar exposure*

2.2.1. *Animals*

The experiment was conducted in four consecutive replicates of 50 batch-farrowed sows. The 200 multiparous sows used were all F1 Large White x Landrace (PrimeGro™ Genetics). The average parity of the sows was 3.5 ± 0.1. The sows were group housed in eco-shelters until an average of day 106 of gestation when they were moved into the farrowing shed and housed in conventional farrowing crates.

2.2.2. *Feeding*

Sows were fed once daily with 2.5 kg of a standard gestation diet until farrowing. On the day of farrowing (day 1) sows were fed 2.5 kg of a lactation diet in the morning and offered a further 1 kg in the afternoon. Sows were fed 3 kg of lactation diet in the morning on day 2 of lactation and offered a further 1 kg in the afternoon. On day 3 of lactation sows were fed 4 kg of lactation diet in the morning and offered a further 1 kg in the afternoon. From day 4 of lactation and onwards sows were offered 3 kg of lactation diet three times a day, morning, noon and afternoon. Sow feed refusals were estimated daily prior to the morning feeding. Sow feed intake was assumed to be equal to the amount of feed offered less the feed refusals. At the start of treatment on day 21 of lactation, piglets were offered fresh creep feed daily. For the first replicate, creep feed was estimated for each pen by recording the number of kilograms of creep feed used divided by the number of pens. The methodology was refined for the subsequent replicates and the number of scoops of feed dispensed to each pen was recorded. Taking into account the feeding system used and wastage, piglet creep feed intake was assumed to be 25% of the amount offered. The nutrient composition of the gestation diet, the lactation diet and the creep diet are presented in Table 1.

Table 1: The calculated nutrient of experimental diets

Nutrient	Gestation Feed	Lactation Feed	Creep Feed
Metabolisable Energy (MJ ME/kg)	13.3	14.3	14.9
Protein (%)	14.5	18.6	22.1
Fat (%)	7.2	6.7	6.4
Fibre (%)	7.3	1.7	1.5
Calcium (%)	0.9	0.9	1.1

2.2.3. *Oestrus induction protocols*

Prior to the commencement of oestrus induction, the sows were assigned to one of four treatments groups with the allocation being random within parity and suckling litter size. Treatment 1 (control), was a group of sows conventionally weaned at day 21 of lactation. At weaning the sows were removed from the

farrowing shed to a separate mating area. The piglets remained in the farrowing crate. For treatment 2 (16h-SEP), piglets were separated from the sow for 16 h (15:30-07:30) for three consecutive days starting on day 21 of lactation, by placing a board in the farrowing crate between the sow and piglets. For treatment 3 (8h-SEP), piglets were separated from the sow for 8 h (07:30-15:30) for three consecutive days starting on day 21 of lactation. For treatment 4 (Boar Exposure); no piglet separation was performed, sows were removed from their farrowing crates and walked to a separate group pen and given direct physical contact with a mature boar for 30 minutes from day 21 until oestrus was detected. After this they were returned to their farrowing crate.

For all sows, oestrus detection was performed twice daily using the back pressure test in the presence of a mature boar held in front of the farrowing crates. All sows that showed behavioural signs of standing oestrus during treatment, were inseminated for up to three consecutive days. Litters from sows on all the three treatments were weaned at an average age of 28 days and all unmated sows were transferred to the breeding shed for mating on their first return to oestrus after weaning. Those sows mated during lactation and the conventionally weaned control sows mated during the experimental period were followed throughout gestation. All returns to oestrus before day 40 were recorded and those remaining on day 40 of gestation were subjected to real time ultrasound to determine their pregnancy status (Agroscan, ECM Manufacturers, France). At the subsequent farrowing, litter characteristics were recorded.

2.2.4. *Statistical analysis*

The reproductive responses of sows to the induction protocols were analysed using a chi squared test or where numbers were small, differences were examined by the Fisher's exact test. Piglet performance was analysed using ANOVA and where significant effects were detected, individual comparisons were made using the Turkey-Kramer test.

2.3.***Study 2 - The effect of sow metabolic status, boar exposure and timing of piglet separation on lactational oestrus induction***

2.3.1. *Animals and feeding*

The study was run in conjunction with study 1. The animals and feeding was as described in sections 2.2.1 and 2.2.2

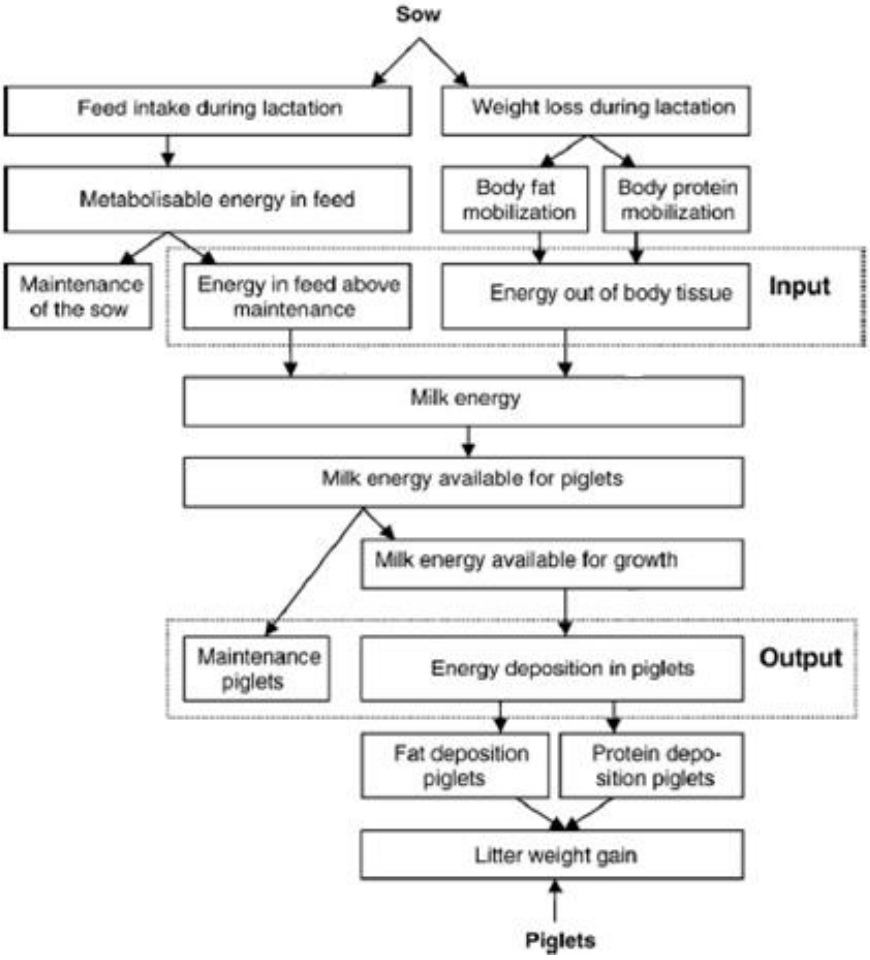
2.3.2. *Measurements*

The weight and back fat of the sows was measured three times during the experiment, at introduction into the farrowing shed, at commencement of oestrus induction (day 21) and at weaning. Back fat level at the P2 site was measured ultrasonically (3.5-MHz Vetkoplus Linear Probe, Noveko, Canada). The number and weight of live, stillborn and mummified piglets was recorded at birth as well as any transfers during the cross fostering period. The weight of any piglet deaths was determined daily. The piglets were weighed again at day 21 and then at weaning.

2.3.3. *Metabolic calculations*

The movement of energy from sow as inputs to piglet as outputs is illustrated schematically in Figure 1 and is based on information provided by Bergsma et al., (2009). Energy inputs include energy derived from feed intake and from metabolised body tissues (protein and fat).

Figure 1 - Energy flow of sow inputs and outputs during lactation (taken from Bergsma et al. 2009).



Energy from feed intake during lactation was estimated as the amount of feed offered excluding the feed residues multiplied by the metabolisable energy (DE x 0.96) content as MJ/kg (Eq. 1). Energy from metabolised body protein was calculated by determining the difference between body protein mass at farrowing and weaning and using the energy content of 1 kg of protein as 23.8 MJ (Eq. 2). Energy from metabolised fat was similarly determined and energy content of 1 kg of fat was defined as 39.5 MJ (Eq. 3).

Equation list -

1. Energy from feed (MJ ME) = (feed offered – residue) × (13.8 MJ x 0.96)
2. Protein (kg) = 1.90 + 0.1711 × Body weight (kg) - 0.3113× BF (mm)
3. Fat (kg) = -11.58 + 0.1027 × Body weight (kg) + 1.904 × BF (mm)

Energy outputs include the energy required for sow maintenance, piglet maintenance and piglet growth minus the amount of energy the piglets derived from creep feed. Sow and piglet maintenance was calculated by determining daily maintenance and multiplying this by the number of days of lactation (Eq. 4 and 5). Sow energy invested in piglet growth was determined from the increase in piglet fat and protein body mass from birth to weaning using the same energy content of fat and protein described above (Eq. 6 -8). Piglet body protein mass at birth was assumed to be 11.6% of birth weight and fat mass was assumed to be 1.4%

(Bergsma et al., 2009). In these calculations the birth weight of piglets born alive and weaning weight was adjusted for piglets fostered and piglet deaths.

4. Sow Maintenance (MJ ME) = (0.440 × (average weight (kg)$^{0.75}$) × days of lactation
5. Piglet maintenance (MJ ME) = (0.485 × (average weight (kg))$^{0.75}$) × days of lactation
6. Average piglet daily gain (kg) = ((weaning weight - birth weight)/days of lactation) × 1000)/weaned litter number
7. Piglet fat mass (kg) = (birth weight × 0.014) + (weaning weight – birth weight) × (0.135 + 0.00014 × average daily gain)
8. Piglet protein mass (kg) = (birth weight × 0.116) + (weaning weight – birth weight) × 0.16

To perform these metabolic calculations it was necessary to estimate the farrowing weight of the sows as this measurement was not taken as disturbance at this time was considered to be a welfare concern. Day of pregnancy after entry to the farrowing house was assumed to be 114, less the number of days between entry to the farrowing house and time of farrowing. The total weight of foetuses, weight of placenta and weight of intra-uterine fluid was estimated for day of entry to farrowing house and at farrowing using Equations 9-11.

9. Total weight foetuses (g) = $e^{(8.72962 - 4.07466 \times e^{\wedge}(- 0.03318 \times (\text{days of pregnancy} - 45)) + 0.000154 \times \text{daily energy intake during gestation (MJ ME/d)} \times \text{days of pregnancy} + 0.06774 \times \text{number of foetuses})}$
10. Weight of placentas (g) = $e^{(7.02746 - 0.95164 \times e^{\wedge}(- 0.06879 \times (\text{days of pregnancy} - 45)) + 0.000085 \times \text{daily energy intake during gestation (MJ ME/d)} \times \text{days of pregnancy} + 0.09335 \times \text{number of foetuses})}$
11. Weight of intra-uterine fluid (g) = $e^{(- 0.2636 + 0.18805 \times \text{days of pregnancy} - 0.001189 \times \text{days of pregnancy}^{\wedge}2 + 0.13194 \times \text{number of foetuses})}$

The estimate of the total foetus weight at farrowing was then compared to the recorded total born litter weight and the ratio for the disparity was then applied to the estimates of foetus weight, placental weight and intra-uterine fluid weight at entry as well as the placental and intra-uterine fluid weight at farrowing. The weight gain of the foetuses and the placenta from entry to farrowing was then determined and the fat and protein gained during this time were assumed to be 1.4% and 11.6% of weight, respectively. The energy expended by the sow to produce this growth was calculated using the estimate of energy content of 1 kg of protein as 23.8 MJ ME and 1 kg of fat as 39.5 MJ ME. The maintenance requirements of the sow during the period from entry to farrowing were calculated using Equation 4, using the sow entry weight as the average weight. The energy derived from feed during this time was then calculated and the energy required for foetal and placental growth as well as the energy required for sow maintenance was subtracted from this amount. The remaining energy was then assumed to be utilised for sow growth with 50% of this energy assumed to be used for protein deposition and 50% for fat deposition. Farrowing weight was then estimated by adding the protein and fat deposition weights to sow entry weight and subtracting the adjusted placenta and intra-uterine weights and the recorded total born litter weight.

2.3.4. *Statistical analysis*

The influence of parity, metabolic output of the sow, and body fat and body protein loss during lactation on the subsequent reproductive performance of the sows was determined by a generalised linear mixed model analysis (GLMM: Genstat V 15). The models were generated using mating rate, pregnancy rate or return rate as the response variates, and shed (i.e. replicate) as the random model. The factors included in the fixed model were oestrus induction treatment, parity, sow

energy output (MJ ME/d), sow body fat loss (MJ ME) and sow body protein loss (MJ ME), while shed replicate was added to the fixed model. As the response variates were all binary, a binomial distribution was selected with a total of 1 in each model and link function selected as logit. Significance was established using the Wald tests for fixed effects. Differences between the treatment groups for day of treatment at first mating, sow parity, litter size at weaning, entry weight and entry back fat were analysed using an ANOVA. When a significant effect was detected in the GLMM or ANOVA, individual means were compared using the tables of predicted means and the LSD (least square difference) which was equal to twice the SED (standard error of difference). In all analyses significance was determined at $P < 0.05$.

2.4. *Study 3 - Monitoring follicle development and the occurrence of spontaneous ovulation in lactating sows under different suckling loads*

2.4.1. *Animals*

The experiment was conducted in three consecutive replicates using a cumulative total of 170 sows, according to the weekly batch farrowing system used at Rivalea. The 170 multiparous sows used were all F1 Large White x Landrace (PrimeGroTM Genetics). The average parity of the sows was 3.5 ± 0.1. All data and full farrowing histories of each animal was recorded, including their identification tag number, parity at present farrowing, born alive litter size, number of still births, mummies and piglets weaned.

2.4.2. *Housing*

The sows were housed as groups in eco-shelters until an average of day 106 of gestation when they were moved into the farrowing shed and housed in conventional farrowing crates, on metal slatted flooring with a small heated creep area for the piglets. The sows had ad lib access to nipple drinkers and were fed a lactational diet (See Table 1) once farrowed, for the duration of the study.

2.4.3. *Measurements*

The number and weight of live, stillborn and mummified piglets was recorded at birth as well as any transfers during the cross fostering period. The weight of any piglet deaths was determined daily. The piglets were weighed again prior to weaning. Sows were allocated to suckling load categories. These were the sows suckling 5-6 piglets, those suckling 7-8 piglets, those suckling 9-10 piglets and those suckling more than 11 piglets.

The weaning to oestrus interval was recorded as the number of days taken after weaning for the sow to shows signs of standing oestrus and be successfully mated. This can be used to judge whether or not they may have cycled during lactation. Subsequent litter data was recorded including litter size, born alive, still born and mummies.

Trans-rectal ultrasound scanning was done on days 20, 22 and 24 of lactation following farrowing. If sows scanned on these days showed signs of follicular growth or follicles larger than 4mm, the aim was to scan sows every second day after this. If the largest follicle reached 6mm, the aim was to increase the scanning frequency to once daily.

2.4.4. *Statistical analysis*

Sows were placed in categories based on the diameter of the largest follicle identified from the ultrasound analysis. The categories were sows where the maximum follicle diameter was <3mm, 3-4 mm 4-5 mm and those <5mm. Differences in the distribution of sows in different follicle categories was determined using a Fisher exact test.

A Two-Way ANOVA analysis was used to determine the effects of litter size weaned, total litter weight weaned and average individual piglet wean weight on the maximum follicle size. A simple linear regression was used to determine the relationship between maximum follicle size and subsequent WOI.

2.5. ***Study 4 - Behavioural and physiological implications of intermittent suckling on primiparous sows and their litters***

2.5.1. *Animals*

This study was associated with a larger experiment, which focused on protocols to induce oestrus in lactating primiparous sows. For the current work a total of 22 Large White x Landrace primiparous sows and their litters were used from three consecutive weekly batch farrowings. Each farrowing unit comprised 64 farrowing crates. Crates had slatted floors, with rubber mats in the creep area with a single overhanging heat lamp provided for the piglets. Sows were fed three times a day (*ad libitum*) and had unlimited access to water. Piglets could move freely around the farrowing crate and had unlimited access to drinking water. In addition, they had access to creep feed *ad libitum* from the start of the treatment separation period. Gilts were randomly assigned pens based on the order they entered the farrowing shed. Treatment and control groups were housed on opposing sides of the farrowing shed. This was aimed to minimise the effects of fence line boar exposure, which was part of the larger study; on control sows. The piglets were weaned at approximately 28 days of age.

2.5.2. *Treatments*

There were two treatments, a control group of sows (C), who had a conventional lactation in which litters remained with the sow until weaning. The second treatment was a group of sows that were intermittently suckled (IS) for 7 days prior to weaning at about 28 days of age. Here piglets were separated from the sow for eight hours each day (from 07:00 to 15:00 h). This was achieved by positioning a wooden panel between the sow and her litter within the crate. Piglets were given access to both water and creep feed from the start of separation. Approximately 30 minutes prior to re-joining, the IS piglets were provided with supplemental milk in an attempt to reduce the suckling intensity when they re-joined the sow. As part of the oestrus induction protocol, a mature boar was moved down the lane in front of the farrowing crates of the treatment sows twice daily but not in front of the control sows.

2.5.3. *Behavioural observations*

The postures and activities recorded for each sow and piglets are described in Table 2.

Table 2 - Ethogram of sow and piglet behaviour recorded on days one, three and six after the start of separation. The behaviours determined for the sows and piglet are identified as yes (Y) or no (N).

Behavioural measure	Description	Sow	Piglet
Standing	Standing on all four feet	Y	Y
Sitting	Upper body held up by front legs	Y	Y
Lying	Involves both sternal and lateral recumbence	Y	Y
Lying with the sow	Lying in contact with the sow	N	Y
Nursing	Lying of side with udder exposed and piglets nursing	Y	Y
Resting/asleep	Lying with any movement	Y	Y
Feeding/drinking	Eating from the feed bin or drinking for the drinker		
Watching	Lying, sitting or standing, showing no other state but visually awake	Y	N
Looking for pigs	May be nudging board separating sow and piglets or looking in piglets general direction (only displayed during separation)	Y	N
Watching piglets	Making contact with piglets or moving head in the direction of piglets for some period of time	Y	N
Walk/Run	Movement around the pen	N	Y
Looking for the sow	When separated piglets look up at board or jumping on board to try and see the sow	N	Y
Massaging the udder	Nursing the udder or visually massing the udder to stimulate milk release	N	Y
Play/Frolicking	Interaction with another piglet , themselves or an object in the pen, such as the feeder	N	Y
Playing with the sow	Piglets interacting the sow	N	Y
Nudging	Nudging any part of the sow in an attempt to have her to nurse.	N	Y

Digital video cameras (Signet; Model OV-3063) and recorders (Electrus Distribution, Rydalmere, NSW, Australia) were set up above each farrowing crate. Video surveillance of sows and piglets in individual crates was conducted from 06:00 until 18:00 h on days one, three and six after the start of separation. The same four piglets for each litter were selected as focal animals for cortisol sampling and behavioural observations. Each sow and four piglets within the litter had their posture and activities recorded in the following time frames; one hour before separation (Pre-sep: 06:00 to 07:00 h); and one hour after separation (Post-sep: 09:00 to 10:00 h); then one hour before re-joining (Pre-join: 13:00 to 14:00 h); and one hour after re-joining (Post-join: 15:00 to 16:00 h). For each hour of observation, the sows' and piglets' behaviours were recorded continuously for one minute every five minutes (12 minutes in total per hour).

In each pen, the light from the heat lamp obstructed the view of piglets, therefore, when piglets were under the heat lamp, they were classified as resting. On day one, for replication one, a power outage occurred at 12 noon restricting the number of post-sep observations on this day.

2.5.4. *Salivary cortisol*

Saliva samples were collected on day one before separation (06:00 h) and then at 12:00 h to 12:30 h on days two, four and seven after separation started. Saliva samples were taken for each replicate and collected from each sow and the four focal piglets, 2 males marked as A and B and 2 females marked as C and D, in each litter. Saliva was collected using a commercial collection tube (Salivettes, Sarstedt Australia, South Australia, Australia). Two operators collected samples in order of pen number (Rodate *et al*. 2010). For sows, 500 mm cable ties were used to hold the cotton swab, which was then placed in the sow's mouth. Sows were given one minute to chew on the cotton swab. Piglets had 200 mm cable ties attached to one end of the cotton swab, which was coated in icing sugar. Piglets were placed on each handler's lap and the cotton swab was inserted into their mouth for two minutes (Escribano *et al*. 2012). Piglet sampling occurred subsequent to sow sampling in order to minimise any likely sow stress. The collections occurred in two rounds. The first samples were collected from piglets A and C and the second samples were collected from piglets B and D. After centrifugation (3000 rpm for 6 minutes at 4^0 C), cotton swabs were removed and saliva was stored at -20˚C until assayed. Cortisol was then analysed using a commercial cortisol EIA kit (No. 500360, Cayman Chemical Company, MI, USA). Sufficient saliva for analysis was obtained from all sows and 85% of the piglets sampled.

2.5.5. *Udder scoring*

Udder injury scoring of all sows was carried out at the start of piglet separation, on day two after separation and then at the time of weaning. The same observer made all assessments. Udder scoring consisted of counting the number of functional teats and identifying the extent of any injuries. Five categories, A to E, were used: with A, being a fresh scratch or cut; B, as an old scratch or cut; C, as bruising/swelling; D, as a damaged teat but still functional; and E as a severely damaged teat which was non-functional.

2.5.6. *Suckling bouts after joining*

During the two hour period after re-joining, the number of lactational suckling bouts was recorded. Suckling bouts were only recorded when the sow was lying and presented her udder to the piglets. No record was made of suckling bouts while the sow was standing due to the difficultly of determining if piglets were nursing or not. Data was collected on day one, three and six of the study.

2.5.7. *Statistical analysis*

Data was collected from 22 sows and four piglets within each litter. Statistical analysis was carried out using a Generalised Linear Mixed Model (GLMM) in Genstat 15^{th} Edition (2012). For all behaviour models the random terms were, replicate, replicate x pen. The fixed terms in the final model were treatment, time frame (pre-sep, post-sep, pre-join, post-join), treatment x time frame, time frame x minute, treatment x time frame x minute. For comparing day effects, the fix term included was treatment x day and the random model included replicate and replicate x pen. Terms found to be non-significant were dropped from the model. Significance was determined as $P<0.05$. Because it was considered that there would be a significant correlation between time points, whereby one time point affected the result observed at the next time point, a covariant was created for each parameter and included in the model to account for this effect. All results from the GLMM behavioural analysis are given as a probability of the sow or piglet

engaging in the behaviour or not (binomial). Where effects were found to be significant, individual comparisons were made using Fisher's LSD (calculated to be 2 X SED).

Suckling bouts after re-joining was analysed using a Linear Mixed Model in Genstat 15th Edition. In the model, the random terms were replicate and pen and the fixed model included treatment and day. Terms found to be non-significant were dropped from the model and, a P value <0.05 indicated a significant effect. An ordinal regression using weighted values was used to analyse the udder score data and was conducted in Minitab version 16 (2013). Ordinal regression was used, as scores were categorized A-E in terms of severity. Counts on the number of wounds were used as the weighted values.

Cortisol data was analysed using a Linear mixed model in Genstat 15th Edition (2012). For this model, the random terms were replicate and pen and the fixed model terms were treatment and day.

3. Outcomes

3.1. *Study 1 - Oestrus induction using piglet separation and boar exposure*

Of the 200 multiparous sows allocated to treatments, 8 were removed prior to the oestrus induction period. The type of induction protocol had a significant effect (P=0.002) on the proportion of sows mated within 7 days of weaning (control) or 7 days after the initiation of stimulation in lactation (treatments) (see Table 2). For the control sows 44 out of 47 (93.6%) were mated after being conventionally weaned at day 21 of lactation. Using the 16h-SEP treatment, 41 of 50 (82%) sows were mated during lactation. With the 8h-SEP treatment, 25 of 47 sows (53.2%) were mated during lactation, while full boar exposure resulted in 36 of 48 sows (75%) being mated in lactation. The mating rate of the conventionally weaned sows was significantly higher than that of sows of the 8h-SEP and full boar exposure treatments (P<0.05), but not those sows of the 16h-SEP treatment. Sows of the 16h-SEP treatment had a significantly higher (P<0.05) mating rate than sows of the 8h-SEP treatment but not those sows given full boar exposure.

For sows mated during lactation, treatment had a significant impact (P=0.03) on the number of sows that returned to oestrus or were not pregnant at day 40 (see Table 3). More sows were not pregnant at day 40 for the 8h-SEP and full boar exposure treatments than the 16-SEP treatment (P<0.05).

For the control sows (CONTROL), 34 out of 41 mated (83%) were pregnant at day 40 of gestation. In the 16 SEP-16 group 36 out of the 39 sows mated (92.3%) were pregnant, for the SEP-8 group, 15 of 24 mated sows (62.5%) were pregnant and 25 out of 34 (73.5%) sows mated in lactation having full boar exposure (BOAR) were pregnant at day 40 of gestation.

The farrowing rate of the sows mated during the treatment period was not different (P=0.1) but tended to be lower for the 8h-SEP treatment. However, based on the initial treatment numbers the pregnancy rate was different (P<0.001). The 8h-SEP treatment sows had a lower pregnancy rate (32.6 %) than other treatments (P<0.05), while it was similar for the control sows (73.8%) and the sows given full boar exposure (54.3%). The 16h-SEP treated sows had a higher pregnancy rate than the sows given full boar exposure (P<0.05).

Table 2 - The reproductive performance of control sows weaned at day 21 of lactation and those exposed to IS for 16 h per day (16h-SEP), 8 h per day (8h-SEP) or given full boar exposure for 7 days before weaning until weaning at day 28.

	Treatments				
	Control	16h-SEP	8h-SEP	Boar Exposure	P Value
Sows treated (n)	47	50	47	48	-
Sows mated in lactation (n) (%)	#44[a] (93.6%)	41[ab] (82.0%)	25[c] (53.2%)	36[b] (75.0%)	0.002
Day to first mating (mean ± SEM)	4.3 ± 0.2[b]	5.5 ± 0.2[a]	5.0 ± 0.3[ab]	5.1 ± 0.3[ab]	0.01
Sows removed before weaning *	3	2	1	2	-
Sows mated but returned or not pregnant by day 40 (%)	8[ab] (19.5%)	3[a] (7.7%)	9[b] (36.0%)	9[b] (26.5%)	0.03
Pregnant sows removed before farrowing	2	0	0	0	-
Sows mated that subsequently farrowed (%)	31 (79.5%)	36 (92.3%)	15 (62.5%)	25 (73.5%)	0.1
% farrowed of total treated sows	73.8[ab]	75.0[a]	32.6[c]	54.3[b]	<0.001

Values within a row without common superscripts are significantly different (P<0.05).
Control sows were weaned on day 21 of lactation.
Control sows were mated within 7 days of being weaned and treatment sows were those mated within 7 days of the start of lactational stimulation
*These sows were removed before weaning for reasons not related to treatments

Treatment had no effect on the total average litter size subsequently born (P=0.06), although it tended to be lower for the 8h-SEP than the control sows (See Table 3). Also there was no treatment effect on the total average litter number subsequently born alive (P=0.26), number still born (P=0.27) or born mummified (P=0.18). The total number of piglets born per treatment is a combination of the mating rate, farrowing rate and litter size. The control and 16h-SEP treated sows had a similar average litter size born alive and this was higher than the other treatments especially the 8h-SEP treatment. This resulted in more total pigs born alive for the control and 16h-SEP treated sows.

Treatment had a significant effect on average daily piglet growth rate over days 21-28 (P<0.001). Naturally, it was lower in the control piglets than other treatments (P<0.05). It was also lower in the piglets from the 16h-SEP treated sows compared to those from the 8h-SEP sows and those given full boar exposure (P<0.05). When the growth rate was determined over the 28 day lactation period there were treatment effects (P<0.001). Control piglets had lower growth rate than other treatments (P<0.05), it was similar for the 8h-SEP piglets compared to 16h-SEP piglets and full boar treated piglets but different between the 16h-SEP and full boar treated piglets (P<0.05).

Table 3 - The litter characteristics of control sows weaned at day 21 of lactation and those exposed to IS for 16h per day (16h-SEP), 8h per day (8h-SEP) or given full boar exposure for 7 days before weaning until weaning at day 28 and mated at the subsequent oestrus.

	Treatments				
	Control	16h-SEP	8h-SEP	Boar Exposure	P Value
Litter size born alive	11.56 ± 0.50	10.54 ± 0.60	9.75 ± 0.73	10.96 ± 0.56	0.26
Litter still born	1.84 ± 0.29	1.63 ± 0.30	1.06 ± 0.31	1.17 ± 0.29	0.27
Litter born mummified	0.12 ± 0.06	0.23 ± 0.08	0	0.25 ± 0.09	0.18
Total litter size born	13.53 ± 0.44	12.40 ± 0.64	10.81 ± 0.87	12.37 ± 0.59	0.06
Average number piglets born alive/treated sow	8.89	9.00	3.45	6.42	-
Total number of piglets born alive	358	379	146	274	-
Average daily gain Day 21-Day 28 (g/d)	70 ± 10^{c}	191 ± 10^{b}	220 ± 8^{ab}	244 ± 9^{a}	<0.001
Average daily gain Birth-Day 28 (g/d)	177 ± 4^{c}	218 ± 5^{b}	228 ± 6^{ab}	241 ± 5^{a}	<0.001
Average piglet day 21 weight (kg)	6.23 ± 0.15	6.08 ± 0.12	6.20 ± 0.15	6.27 ± 0.13	0.78
Average piglet weight at 28 days of age (kg)	7.02 ± 0.16^{c}	8.23 ± 0.16^{b}	8.58 ± 0.18^{ab}	8.95 ± 0.17^{a}	<0.001

Values within a row without common superscripts are significantly different (P<0.05).
Control sows were weaned on day 21 of lactation.

3.2. *Study 2 - The effect of sow metabolic status, boar exposure and timing of piglet separation on lactational oestrus induction.*

The treatment effects on changes in bodyweight, back fat depth and litter weight during lactation is given in table 4. While body weight and back fat changed overtime, there was no significant effect of treatment on either measure except for litter weaning weight. The control treatment average total litter weight was lower than other treatments (P<0.05), and the average total litter weight of the 16h-SEP piglets was lower than the litters from the sows given full boar exposure treatment (P<0.05). The difference between 8h-SEP litters and the full boar exposure litters was not different.

Table 4 - Changes in bodyweight, back fat depth and litter weight during lactation in control sows weaned at day 21 of lactation, and those exposed to IS for 16 h per day (16-SEP), 8 h per day (8h-SEP) or given full boar exposure for 7 days before weaning (Weaning-7)-until weaning at day 28.

	Control (n=47)	16h-SEP (n=50)	8h-SEP (n=47)	Boar exposure (n=48)	P value
Sow weight (kg)					
Farrowing (day 0)	292 ± 5	281 ± 5	287 ± 5	280 ± 5	0.34
Weaning -7d	279 ± 5	273 ± 5	278 ± 5	273 ± 5	0.77
Weaning	NR	261 ± 5	266 ± 5	258 ± 5	0.49
Back fat (mm)					
Farrowing (day 0)	28.3 ± 1.0	26.7 ± 0.9	26.6 ± 0.7	25.8 ± 0.8	0.27
Weaning -7d	23.9 ± 1.0	23.4 ± 0.9	23.8 ± 0.6	23.4 ± 0.8	0.96
Weaning	NR	22.3 ± 0.8	23.3 ± 0.9	21.8 ± 0.8	0.42
Total litter weight (kg)					
Birth weight	17.9 ± 0.5	17.5 ± 0.5	18.4 ± 0.6	17.3 ± 0.5	0.38
Weaning -7d	56.8 ± 1.8	59.9 ± 1.8	58.1 ± 1.9	59.5 ± 1.7	0.68
Weaning	68.8 ± 1.8^{bc}	77.7 ± 2.1^{b}	82.6 ± 2.6^{ab}	87.7 ± 2.1^{a}	<0.0001
Net Energy Balance (MJ ME/d)					
Energy input	70.3 ± 2.2^{b}	104.6 ± 0.7^{a}	105.8 ± 2.7^{a}	106.9 ± 1.9^{a}	<0.001
Energy out put	53.2 ± 0.8^{c}	57.4 ± 0.8^{b}	60.0 ± 1.0^{ab}	61.4 ± 0.9^{a}	<0.001
Energy efficiency (%)	78.6 ± 2.3^{a}	55.6 ± 1.0^{b}	57.7 ± 1.0^{b}	58.0 ± 1.1^{b}	<0.0001
Sow tissue metabolism during lactation (MJ ME)					
Total protein loss	58 ± 29^{b}	193 ± 31^{a}	219 ± 46^{a}	211 ± 44^{a}	0.01
Total fat loss	348 ± 61	376 ± 48	302 ± 59	362 ± 47	0.79

Values within a row without common superscripts are significantly different (P<0.05).
NR-no recording made as the sows had been weaned at day 21.

The treatment and parity effects on net energy balance are given in table 4 and 5, respectively. The daily net energy input was lower for the control sows than other treatments (P<0.05) but similar for the IS treatment sows and those given boar exposure. The net energy output was lower for control sows (P<0.05) compared to other treatments. The net energy output was lower for the 16h-SEP treatment sows compared to those with full boar exposure (P<0.05). The control treatment had a better lactational energy efficiency (P<0.05), but this was not different between other treatments.

Parity had no effect on net energy balance in lactation. There was a large degree of variation in the rate of tissue metabolism by individual sows. Control sows metabolised less tissue protein than other treatment sows (P<0.05) but the degree of metabolism was similar for other treatments. Treatment had no effect on the extent of sow tissue fat loss (Table 4). Parity had no effect on the degree of sow fat loss but parity 2 sows had less protein loss (P<0.05) compared to parity 5 sows (table 5).

Table 5 - The sow parity effects on changes in body weight, back fat depth and litter weight during lactation.

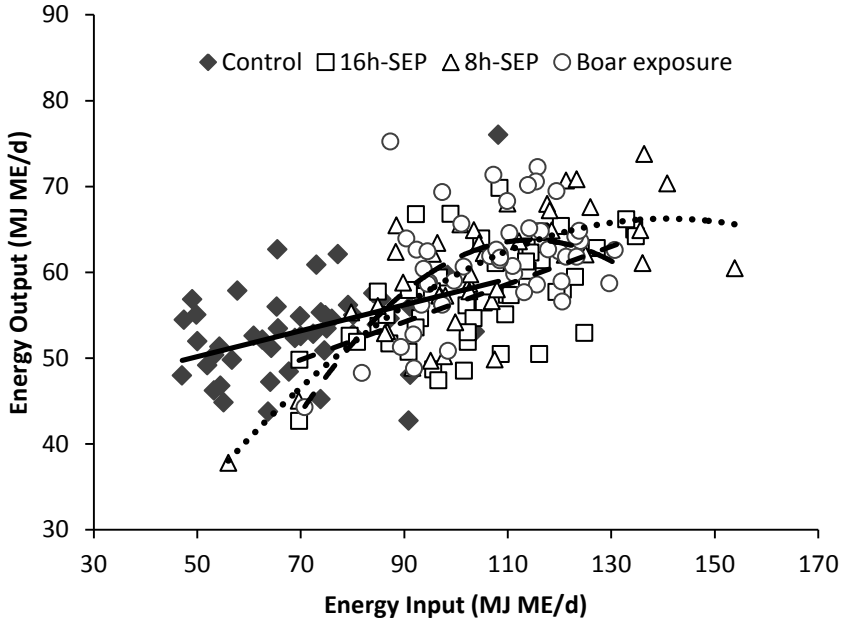
	Parity					P value
	2	3	4	5	6	
Sow weight (kg)						
Farrowing (day 0)	259 ± 3^{b}	266 ± 4^{b}	303 ± 4^{a}	319 ± 4^{a}	319 ± 6^{a}	<0.001
Weaning-7d	253 ± 3^{b}	257 ± 4^{b}	291 ± 4^{a}	308 ± 5^{a}	308 ± 6^{a}	<0.001
Weaning	243 ± 3^{c}	241 ± 4^{c}	277 ± 4^{b}	290 ± 6^{ab}	300 ± 8^{a}	<0.001
Back fat (mm)						
Farrowing (day 0)	27.1 ± 0.8	25.0± 0.7	26.7 ± 1.1	28.3± 1.0	27.2± 1.4	0.33
Weaning-7d	23.7 ± 0.7	22.0 ± 0.6	23.9± 1.1	25.3 ± 1.2	27.2 ± 1.2	0.29
Weaning	23.7 ± 0.8^{a}	19.9 ± 1.0^{b}	21.9 ± 0.9^{ab}	23.9 ± 1.4^{a}	21.6 ± 1.5^{ab}	0.04
Total litter weight (kg)						
Birth weight	18.6 ± 0.5	17.5 ± 0.5	17.6 ± 0.5	17.4 ± 0.6	16.7 ± 0.7	0.15
Weaning-7d	59.7 ± 1.5	59.5 ± 2.2	58.9 ± 2.2	55.5 ± 2.1	56.0 ± 2.1	0.90
Weaning	82.8 ± 1.9	80.5 ± 3.0	79.0± 2.7	75.7 ± 2.6	72.6 ± 3.2	0.07
Net Energy Balance (MJ ME/d)						
Energy input	98.1 ± 2.5	97.3 ± 4.1	96.2 ± 3.2	103.1 ± 4.9	90.0 ± 4.0	0.23
Energy out put	57.8 ± 0.9	56.5 ± 1.2	58.9 ± 1.1	59.6 ± 1.2	57.8 ± 1.4	0.47
Energy efficiency (%)	61.0 ± 1.4	60.7 ± 2.2	63.4 ± 2.0	61.4 ± 3.5	57.7 ± 3.0	0.25
Sow tissue metabolism during lactation (MJ ME)						
Total protein loss	98 ± 26^{b}	194 ± 41^{ab}	200 ± 35^{ab}	300 ± 82^{a}	159 ± 55^{ab}	0.02
Total fat loss	300 ± 46	406 ± 64	339 ± 46	346 ± 77	410 ± 86	0.61

The association of sow energy input (MJ ME/d) and sow energy output (MJ ME/d) during lactation is depicted in Fig.2. For all treatments there was a significant correlation between energy input and output. For control and the 16h-SEP treatments the best fit was a linear relationship. For these treatments as energy input increased the energy output increased. For the 8h-SEP and boar exposure treated sows the best fit was a second order polynomial relationship. For the 8h-SEP sows, the energy output increased as input increased but it reached an inflection point at around 115 MJ ME/d input providing an output of 63 MJ ME/d, and after this the output tended to decrease as energy input increased. For the sows exposed to full boar exposure, energy output increased as input increased but it reached a maximum around 138 MJ/ME/d energy input providing 66 MJ ME/d output and it then tended to remain constant as energy input increased.

Parity, sow energy output (MJ ME/d), body protein loss (MJ ME) and body fat loss (MJ ME) were found to have no significant influence on the mating rate (see Study 1). However, of these variables, body protein loss (MJ ME) was found to have a significant influence on the pregnancy rate (P=0.04). The average total protein loss (MJ ME) of the sows mated during lactation that were subsequently

determined to be pregnant at day 40 was 119 MJ ME (2.5% of their protein mass). This compared to the average protein loss of 209 MJ ME (4.4% of their protein mass) of those sows detected as not pregnant at day 40 of gestation.

Figure 2 - The relationship between energy input and output for Control sows (◆: y = 0.1503x+42.669; R^2 = 0.40; P=0.005) and those exposed to IS for 16h/d (□ : y = 0.2198x+34.431; R^2 = 0.33; P = 0.02) or 8h/d (△ : y = -0.0102x^2 + 2.2344x – 69.301; R^2 = 0.30; P = 0.04) or to full boar exposur○ (: y = -0.0039x^2 + 1.1019x – 11.411; R^2 = 0.57; P <0.001).



3.3. *Study 3 - Monitoring follicle development and the occurrence of spontaneous ovulation in lactating sows under different suckling loads*

Sows with different suckling loads had similar weaning ages and this average was 29.6 ± 0.2 days. The measurement of follicle size was compromised by the logistics of the experimental design. The three replicate farrowing batches were only one week apart and this resulted in a very large number of sows to ultrasound each day. This number was beyond the capacity of a single operator. An on-site decision to start all sows was probably not the best strategy because it resulted in all sows being started but the number scanned past day 24 of lactation was minimal. This meant that there was only scanning data until day 24 of lactation. In retrospect it would have been of more value to follow a small number of sows through the full lactation from day 20 rather than start all sows.

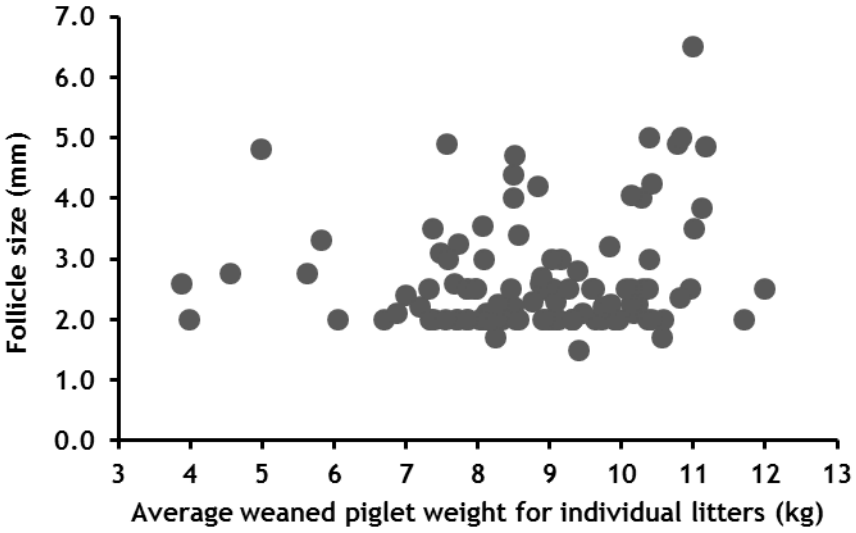
The distribution of maximum follicle size for the various suckling loads up to day 24 of lactation is given in table 6. The suckling litter size had no effect (P=0.26) on the maximum follicle size observed at day 24 of lactation. Approximately 80% of sows had a maximum follicle size of less than 3 mm. Only 2 sows had a maximum follicle size of greater than 5 mm.

Table 6 - The maximum ovarian follicle size (mm) observed after rectal ultrasound analysis of sows with different suckling loads during lactation. Also included is the average litter wean weight for sows with different suckling loads.

Suckling Litter size	Follicle size (mm)				Average litter wean weight (kg)
	< 3	3-4	4-5	>5	
5-6	6	0	0	0	8.36±1.31
7-8	9	2	3	0	8.33±0.55
9-10	39	8	5	1	9.08±0.18
11+	35	1	2	1	8.70±0.21
Total Sow number	89	11	10	2	107

The average weaned litter weight had no effect (P=0.15) on the maximum follicle size to day 24 of lactation (see Figure 3). Of the litters with average weaning weight below 6 kg, two were litters suckling 5-6 piglets, 3 were from litters suckling 7-8 and one from a litter suckling 11 piglets.

Figure 3 - The relationship between average piglet weight for individual litters and the maximum ovarian follicle size to day 24 of lactation



Three of the 6 sows with litter suckling loads of 5-6 piglets were removed at weaning and so because of the limited number of sows left in this category it was removed from analysis of the effect of suckling load on subsequent WOI. The suckling litter load had no effect on the WOI (P=0.90). For sows suckling 7-8 piglets it was 6.35±1.71, 9-10 piglets it was 6.02±0.69 and 11+ piglets was 5.70±0.68 days. The suckling load had no significant effect on the average weaned litter weight (P=0.30).

Based on the size of the largest follicles on day 24 of lactation and then the time sow returned to oestrus after weaning there was the possibility that 10 of the 112 (8.9%) sows scanned, actually spontaneously ovulated in lactation. These 10 sows had large follicles on day 24 of lactation and the time they came into oestrus post-weaning, was at a time, they would have been expected too if they had ovulated in the previous lactation. Because of the restricted scanning information this is only a possibility but does fit with previous observations that there is a percentage on sows that spontaneously ovulate in lactation. With the average lactation length being 29.6 days there is a strong possibility that some sows would have ovulated in lactation.

3.4. *Study 4 - Behavioural and physiological implications of intermittent suckling on primiparous sows and their litters*

3.4.1. *Sow behaviours*

The behavior of both sows and piglets at each minute within the different time periods was included as a factor in the statistical analysis. Where this factor was found to be part of a significant interaction it was considered difficult to interpret and so differences are discussed in light of the treatment and timeframe effects. The proportion of time sows spent in various behaviours and activities is given in Table 7.

Behaviour of the IS sows was similar to control sows during the hour before separation but as expected, once separation began, changes between the treatments were seen. For control sows the time spent standing was significantly lower in the post-join period compared to other times ($P<0.05$). For the IS sows the period spent standing was the same for all periods. It was only during the post-join period that there was a difference between the control and treatment sows, with it being greater for the IS sows ($P<0.05$).

Sows spent a large proportion of their time lying, and this was similar for control and IS sows, except in the post-join period, where control sows spent more time lying ($P<0.05$). For control sows they spent more time lying in the post-join period than other periods ($P<0.05$), whereas the IS sows spent similar time lying in all periods.

There was no treatment effect on nursing time during the pre-sep and post-join period. The time frame x minute interaction was significant ($P=0.04$). The nursing time was greater in the post-join period compared to the pre-sep period ($P<0.05$).

The IS sows spent less time asleep in the post-join period than control sows ($P<0.05$). For control sows they were recorded asleep for a longer period in the post-join period compared to other periods ($P<0.05$). The IS sows spent more time asleep in the post-sep and pre-join periods than the pre-sep and post-join periods ($P<0.05$).

The IS sows spent a similar proportion of their time eating and drinking in all time frames, whereas the control sows, spent less time eating and drinking in the post-join period than in other periods ($P<0.05$). During the pre-join period, IS sows spent more time eating and drinking than the control sows ($P<0.05$).

Sows in both treatment groups spent similar time watching piglets in all time frames. The time spent watching piglets was lower in the post-join period than other periods ($P<0.05$). The time spent watching and playing with the piglets was similar in the pre-sep period for both groups of sows but it was significantly higher in the post-join period for the IS sows ($P<0.05$). For the IS sows the period spent watching and playing with the piglets was greater in the post-join than the pre-

sep period (P<0.05). Control sows spent more time watching and playing with piglets in the post-join period than the pre-sep and pre-join periods (P<0.05).

Table 7 - The mean (± SEM) proportion of time (%) sows of the control and intermittent suckling (IS) treatments spent performing various behaviours and activities during the 1 h before (Pre-sep), 1 h after (Post-sep) the start of piglet separation, 1 h before re-joining (Pre-join) and 1 h after (Post-join) the end of the piglet separation.

Measurement	Treatment	Timeframe (%)				P value
		Pre-sep	Post-sep	Pre-join	Post-join	
Standing	Control	29.5±3.3	22.6±3.2	21.3±3.0	8.5±2.2	Txf
	IS	26.1±3.0	22.2±2.7	24.9±2.8	26.3±2	<0.001
Lying	Control	70.2±3.8	80.0±3.5	79.0±3.4	91.3±2.4	Txfxm
	IS	73.9±3.5	74.0±3.3	75.0±3.3	76.0±3.1	<0.001
Sitting	Control	7.0±1.7	6.4±1.7	6.0±1.6	4.7±1.5	fxm
	IS	6.4±1.5	8.7±1.7	5.7±1.4	4.8±1.2	0.038
Nursing	Control	9.7±1.9	8.2±1.8	10.8±1.9	11.5±2.0	fxm
	IS	8.5±1.5	*	*	17.4±2.0	0.038
Asleep	Control	45.5±4.1	54.0±4.4	52.0±4.1	67.7±3.9	Txfxm
	IS	50.7±3.8	58.6±3.6	59.9±3.7	42.7±3.6	0.004
Eating and drinking	Control	28.1±3.8	24.5±3.8	19.2±3.3	11.9±2.7	Txfxm
	IS	23.9±3.4	24.7±3.3	24.7±3.3	24.1±3.2	0.032
Watching	Control	9.6±2.9	10.4±3.2	11.0±3.2	5.4±1.9	Txfxm
	IS	12.3±3.3	12.5±3.4	9.9±2.9	4.6±1.6	0.003
Watching and playing with piglets	Control	19.6±2.3	17.1±2.9	19.1±2.8	11.0±2.9	Txf
	IS	19.3±3.0	*	*	31.0±2.6	<0.001

The P values are for the highest level significant interaction with the abbreviations being; treatment (T), time frame (f) and minute (m). Values are means ± SEM.

3.4.2. *Piglet behaviours*

The time that piglets spent standing is shown in Figure 4. The treatment x time frame x minute interaction was significant (P<0.001). While the minute changes are complex the observations of major relevance are the treatment effects in the different time periods. In the pre-sep period piglets from both the control and IS groups stood for similar time (29.3±1.6 Vs 29.1±1.8%), but in other periods the differences were significant (P<0.05), with it greater for control piglets in the post-sep (26.5±1.8 Vs 13.7±1.6 1.2 %), and pre-join (33.5±1.8 Vs 25.8±1.6%), periods but much greater for the IS piglets in the post-join period (19.2±1.8 Vs 57.5±1.6 %),. For IS piglets the standing time was greater in the post-join than other periods (P<0.05), and in the post-sep less time than in the pre-sep and pre-join periods (P<0.05). For the control piglets, the time spent standing was less in the post-join than other periods and the pre-join time was higher than the post-sep (all; P<0.05).

Figure 4 - The average proportion of time control (solid line) and intermittently suckled (dotted line) piglets spent standing during the 1 h before (Pre-sep), 1 h after (Post-sep) the start of separation and for the 1 h before (Pre-join) and 1 h after (Post-join) the end of the separation.

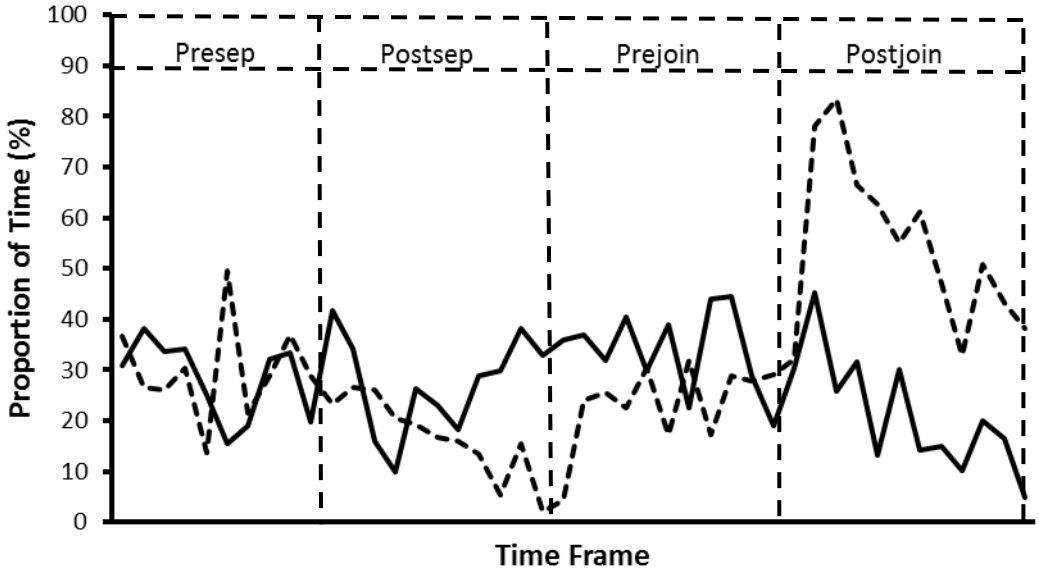
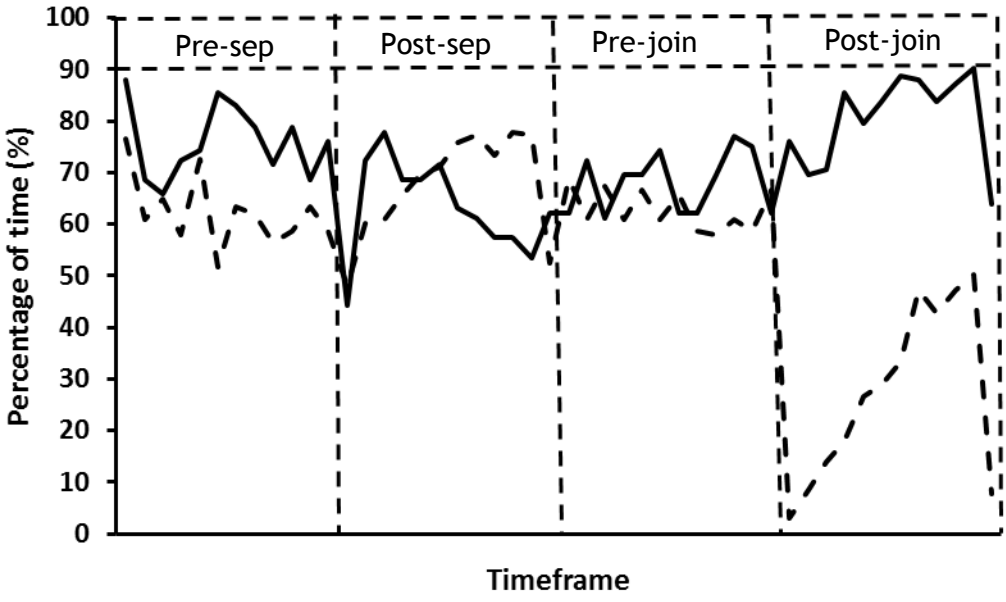


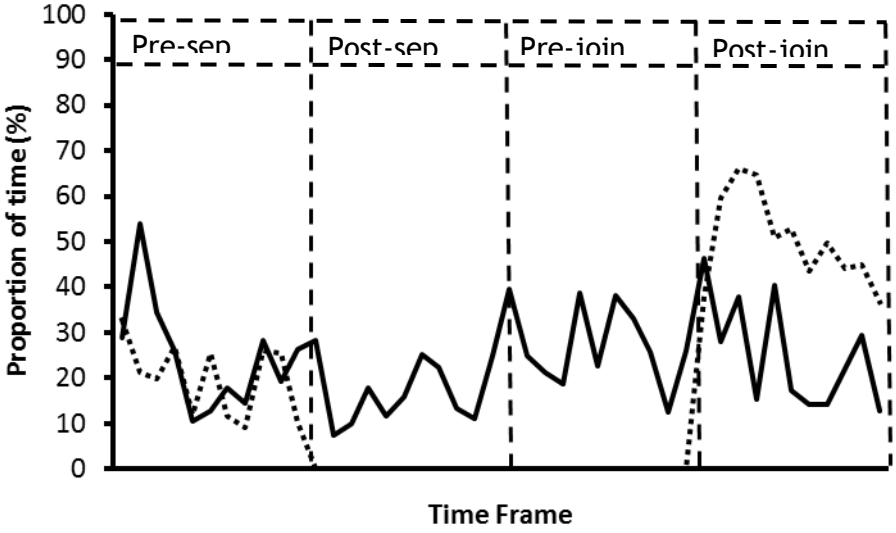
Figure 5 - The average proportion of time control (solid line) and intermittently suckled (IS--dotted line) piglets spent lying during the 1 h before (Pre-sep), 1 h after (Post-sep) the start of separation and for the 1 h before (Pre-join) and 1 h after (Post-join) the end of the separation, respectively.



The time that piglets spend lying is shown in Figure 5. The treatment x time frame x minute interaction was significant ($P<0.001$). In the pre-sep period piglets from the control group spent more time ($P<0.05$), lying than IS piglets (75.9±2.0 Vs 62.2±2.0%). The time spent lying in the post-sep (63.3±2.6 Vs 67.4±2.9%) and pre-join (68.1±1.7 Vs 62.8±1.1%). periods were similar. In the post-join period the IS piglets spent much less time lying ($P<0.05$), than the control piglets (80.5±2.5 Vs 27.2±4.9%).

Treatment had a significant effect on the time spent massaging the udder (See Figure 6), with it being less for IS piglets in the pre-sep period but greater in the post-join period ($P<0.05$).

Figure 6 - The average proportion of time that control (solid line) and intermittently suckled piglets (dotted line), spent massaging the sow's udder during the 1 h before (Pre-sep), 1 h after (Post-sep) the start of separation and for the 1 h before (Pre-join) and 1 h after (Post-join) the end of the separation.



The proportion of time piglets spent in other behaviours and activities is given in Table 8. Piglets in both groups spent more time sitting in the pre-sep than other time periods ($P<0.05$). The time spent idle for IS piglets compared to control piglets was greater in all periods except the pre-sep time frame ($P<0.05$) Control piglets spent less time idle in the post-join period compared to other periods ($P<0.05$), while for these piglets, the time spent idle was greater in the pre-join period compared to the pre- and post-sep periods ($P<0.05$). The IS piglets spent more idle time in the post-join period than other periods ($P<0.05$), and the idle time post-sep was less than that seen in the pre-sep and pre-join periods ($P<0.05$).

Both groups of piglets spent similar time sleeping in the pre-sep period. The IS piglets spent more time asleep in the post-sep and pre-join periods and less time asleep in the post-join period than the control piglets ($P<0.05$). The control piglets spent more time asleep in the post-sep and post-join periods than the other periods ($P<0.05$). For the IS piglets, the time spent asleep was different for all periods ($P<0.05$).

The time spent walking and running was similar for both groups in the pre-sep period but different in other periods. It was less for IS piglets in the post-sep and pre-join periods but greater in the post-join period ($P<0.05$). For control piglets the time spent walking/running was greater in the pre-join period compared to other periods ($P<0.05$), and it was greater in the pre-sep period compared to the post-join period ($P<0.05$). For IS piglets, the time spent walking/running was significantly greater in the post-join period than in other periods ($P<0.05$), while the in the pre-sep period, it was greater than that during the post-sep and pre-join periods ($P<0.05$).

The IS piglets played and frolicked more in the post-join period but less time than the control piglets in the post-sep and pre-join periods (P<0.05). For control piglets the time spent in play/frolicking was less post-join than at that other periods, while they spent more time in these activities pre-join than pre- and post-sep (all, P<0.05). For the IS piglets they spent more time in play/frolicking post-join than at other periods, and post-sep they spent less time in this activity than pre-sep and post-join (all; P<0.05).

The control piglets spent less time eating/drinking in the post-join period than other periods (P<0.05). For the IS piglets, less time was spent eating/drinking in the pre-sep period compared to other time frames (P<0.05). The IS piglets spend more time eating/drinking in all periods except the pre-sep period than the control piglets (P<0.05).

During the post-sep and post-join periods the IS piglets spent around 4-6 % of their time looking for the sow. This behaviour was not detected when sow and piglets had access to one another. The IS piglets watched and played with the sow more than the control piglets in the post-join period (P<0.05).

3.4.3. *Changes over time*

Changes to sow behaviours and postures were examined across days one, three and six. In sows, no significant effect of day on the treatment effects, for the time spent standing (P=0.62), sitting (P=0.39), lying (P=0.80), eating and drinking (P=0.08) or time spent nursing (P=0.09) was observed, The time sows spent watching piglets was significant (P=0.05), with control sows on day two, spending proportionally more time watching piglets than on other days.

For IS sows the time spent nursing was similar on days one and three but higher on day six (P<0.05; d1, 15.4±3.0%; d3, 14.6±3.2%; d6, 24.4±3.8%). For control sows nursing time was higher on day three than other days (P<0.05; d1, 10.1±3.3%; d3, 17.6±4.1%; d6, 9.0±3.1%).

Some changes in piglet behaviours and activities were seen across the experimental period. There was no significant treatment x day interaction for the proportion of time spent sitting (P=0.15), being idle (P=0.07), walking and running (P=0.17), playing (P=0.34), nudging (P=0.59) and watching the sow (P=0.93). The proportion of time spent lying with the sow for IS piglets declined significantly (P<0.05) from d1 (20.5±7.4%) to d6 (8.1±3.4%).

For the piglets, there were significant treatment x day interactions for time spent standing (P=0.01), eating and drinking (P<0.001) and massaging the udder (P<0.001). The proportion of time spent standing was similar on all days for the control piglets (d1, 26.6±2.3%; d3, 25.3±2.2%; d6, 28.4±2.5%), while this proportion was lower (P<0.05) on day 3 than other days for the IS piglets (d1, 31.2±2.7%; d3, 23.8±2.1; d6, 33.7±3.0%). The proportion of time spent eating and drinking was significantly different (P<0.05) between d1 and d3 while d6 was similar to both days for IS piglets (d1, 7.4±1.0%; d3, 4.8±0.7%; d6, 6.4±0.9%), while for control piglets there was a significant (P<0.05) increase in time spent eating and drinking on d6 compared to other days (d1, 1.7±0.4%; d3, 1.5±0.4%; d6, 4.1±0.7%). Overall, across all days the proportion of time spent eating and drinking was always significantly greater in IS litters compared to control (P<0.05). The time spent massaging the udder did not vary across days for IS piglets (d1, 55.1±5.5%; d3, 48.5±5.6%; d6, 59.4±5.4%), while for control piglets there was more udder nudging (P<0.05) on d3 and d6 compared to d1 (d1, 19.5±4.0%; d3, 32.7±5.2%; d6, 28.7±4.9%).

Table 8 - The mean (±SEM) proportion of time (%) sows and piglets of the control and intermittent suckling (IS) treatments (TRET) spent performing various behaviours and activities during the 1 h before (Pre-sep), 1 h after (Post-sep) the start of separation and for the 1 h before (Pre-join) and 1 h after (Post-join) the end of the separation. The P values are for the highest level significant interaction with the abbreviations being; treatment (T), time frame (f) and minute (m). Values are means ± sem

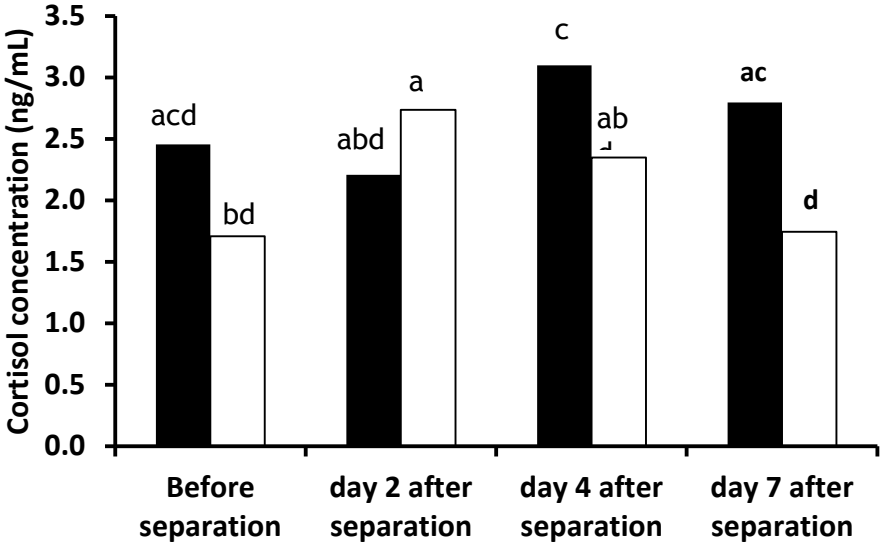
Measurement	TREAT	Timeframe (%)				P value
		Pre-sep	Post-sep	Pre-join	Post-join	
Sitting	Control	0.4±0.1	0.1±0.1	0.1±0.0	0.1±0.1	fxm
	IS	0.4±0.0	0.0±0.0	0.1±0.1	0.1±0.1	P<0.001
Idle	Control	12.5±0.9	9.9±1.2	16.5±1.4	6.8±1.2	Txfxm
	IS	10.5±1.5	6.3±0.8	12.6±1.1	22.4±1.0	P<0.001
Asleep	Control	67.6±2.4	76.5±2.3	64.2±2.7	74.2±2.6	Txfxm
	IS	72.1±2.7	86.9±1.6	79.1±2.0	36.1±2.3	P=0.003
Walking and running	Control	5.4±0.6	3.9±0.7	9.0±1.1	3.5±0.8	Txfxm
	IS	5.1±1.3	2.0±0.4	2.1±0.4	12.5±0.7	P=0.003
Playing and frolicking	Control	5.3±.0.5	5.4±1.2	9.2±1.8	1.7±1.2	Txfxm
	IS	5.8±2.1	2.3±0.6	5.8±1.2	11.7±1.2	P<0.001
Eating and drinking	Control	2.7±0.5	3.2±0.7	3.6±0.7	1.4±0.6	Txfxm
	IS	2.3±1.1	6.6±1.0	10.8±1.3	8.4±0.5	P=0.011
Looking for the sow	Control	*	*	*	*	NA
	IS	*	4.0±0.7	5.9±0.8	*	NA
Watching and Playing with sow	Control	0.7±0.3	1.9±0.6	1.7±0.5	1.0±0.3	T
	IS	1.6±1.1	*	*	4.7±0.5	P<0.001
Massaging the udder	Control	25.0±.2.6	17.1±2.1	27.5±2.7	25.0±2.6	Txt
	IS	19.9±3.1	*	*	50.8±2.1	P<0.001

NA – values not available for periods other the when piglets were separated
* No values determined for these behaviours because of the experimental design

3.4.4. *Salivary cortisol*

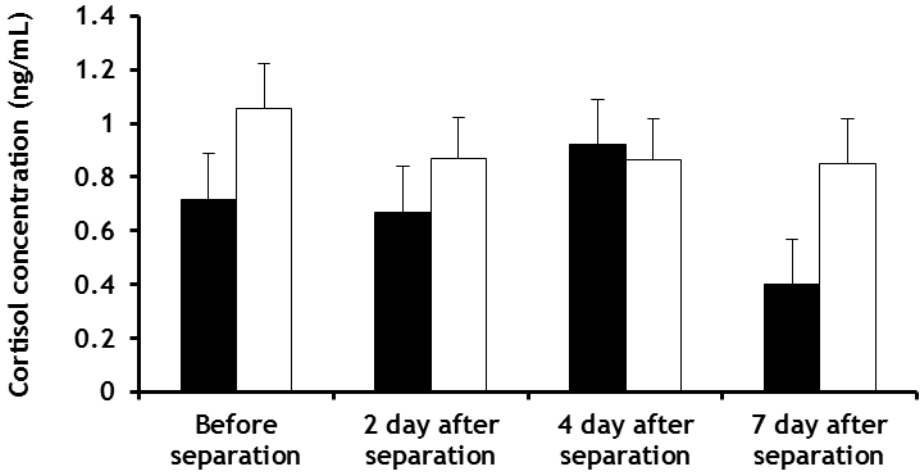
Piglet sex had no effect on salivary cortisol concentrations (P=0.63). For piglets, treatment had an effect on salivary cortisol (see Figure 7), but this changed with time as the treatment X day interaction was significant (P=0.01). On day two, IS piglet cortisol concentration was significantly greater than the concentration prior to separation (P<0.05). The concentrations on d 4 and d 7 were similar to the concentration before separation. Cortisol concentrations for control piglets were similar to IS piglets at all sampling times except on d7 when it was significantly higher (P<0.05).

Figure 7 - The mean salivary cortisol concentration of control (black) and IS (white) piglets. A basal sample was taken just before the IS separation started and then 2, 4 and 7 days after the start of separation. The treatment x day interaction was significant (P=0.01). Between and within treatments the values without common superscripts are are significantly different (P<0.05).



Sow salivary cortisol concentrations are given in Figure 8. For the sows, treatment had no effect on salivary cortisol concentrations (P=0.43) and there was no day effect (P=0.18). There was a large variation in individual values but they were all relative low with means values <1 ng/mL

Figure 8 - The mean salivary cortisol concentration of control (black) and IS (white) sows. A basal sample was taken just before the IS separation started and then 2, 4 and 7 days after the start of separation.

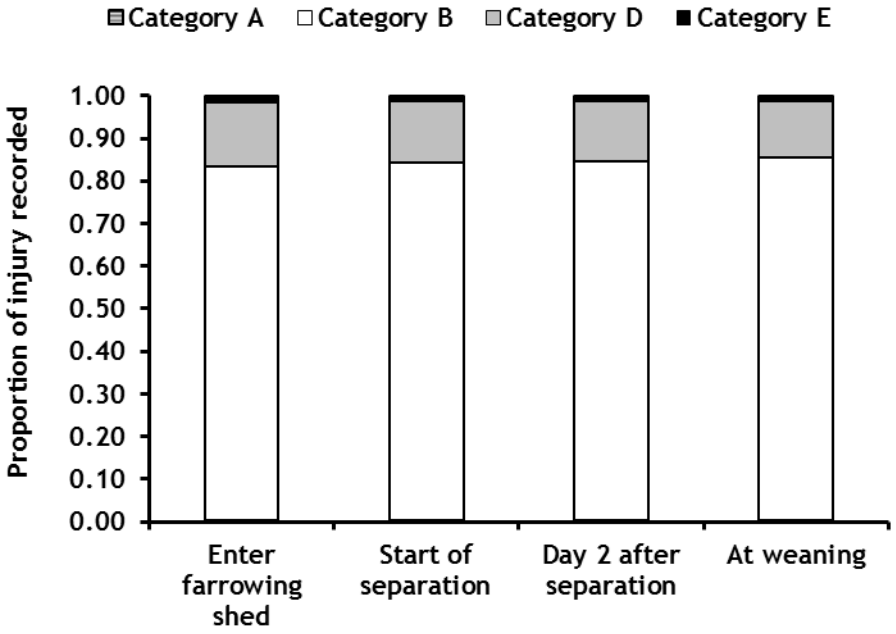


3.4.5. *Udder injury*

No significance difference in udder injury was found between IS and control sows (P=0.97). The udder injury scores from the time sows entered the farrowing shed until weaning are given in Figure 9. The injury score for the various categories did

not differ from the time the sows entered the farrowing house until they were removed at weaning (P= 0.91).

Figure 9 - The mean percentage of udder injury for the different categories when sows enter the farrowing shed, at the start of the separation period, 2 days after the start of separation and then at weaning. There were no category C and very limited category A injuries recorded during the study period.



3.4.6. *Suckling bouts*

There was a significant treatment effect on the number of suckling bouts in the 2 h after sows and piglets were re-joined but this changed overtime as the treatment X day interaction was significant (P=0.04). On day one the number of suckling bouts were similar (control at 2.9±0.1and IS at 3.8±0.5). On day 3 (2.4±0.2 vs 4.7±0.3) and day 6 (2.5±0.1 vs 4.4±0.2) the IS piglets suckled more than did the control sows (P<0.05) in the 2 h after the sows and piglets had been re-joined.

4. Application of Research

Current reproductive management requires sows to be weaned and have them return to oestrus and be mated. This requirement encourages producers to wean early to maximise the litters per sow per year. Early abrupt weaning comes at a cost to the weaned litter. The 'set-back' following weaning results in poorer welfare, reduced health and growth of piglets. Increasing weaning age and developing gradual weaning strategies would assist piglets post-weaning. Increasing weaning age would reduce the yearly litter number from sows and reduce productivity. Mating in lactation would allow producers to increase weaning age while maintaining the average yearly litter number per sow.

This work evaluated the success of protocols employing direct boar exposure and different periods of piglet separation to induce oestrus and subsequent ovulation during lactation without the use of exogenous gonadotropins. The work expanded on earlier efforts to develop a commercially suitable protocol to induce oestrus and mating during lactation. The studies also provided information on the success

of the mating strategies in relation the metabolic status of the lactating sows and what welfare implication there are for the sows and piglets when separation is used as the induction stimulus.

4.1. *Lactation oestrus induction with piglet separation and boar exposure*

Separation of piglets and sow for 16 h/d for three days starting on day 21 of lactation was sufficient to have 82% of sows mated within 7 days and then for 92% of these sows to successfully farrow. These results were similar to those of sows conventionally weaned at day 21 of lactation. The induced sows produced similar number of piglets born alive as the conventionally weaned sows. A shorter separation period of 8 h/d was not sufficient to achieve a commercially acceptable mating and farrowing rate. Removing sows from their farrowing crate and providing 30 min of full boar contact, also resulted in oestrus induction and a mating rate which was lower than the conventionally weaned sows. It also resulted in more sows returning to oestrus or not pregnant at day 40. Based on a treatment group basis, both full boar contact and separation for 8 h/d for 3 days resulted in a lower farrowing percentage than the conventionally weaned sows and the sows separated for 16 h/d for 3 days.

The negative impact of 16 h separation on piglet growth rate creates a concern when using separation as part of oestrus induction. While there has been no research initiated to solving this problem there are potential strategies that could be used. In this work piglets had access to creep feed only from the time of separation. Earlier provision of creep feed, say from day 10 of lactation could help to limit any effect of separation on growth rate of piglets. An extended weaning age and gradual weaning could also allow piglets time to compensate for any reduced growth rate during the separation rate. While 16 h separation was used in this study because it suited management of the labour available, it would be possible to reduce this to 12 h. Also while 3 days of separation was settled on here, less days of separation might also work.

4.2. *Metabolic status of sows undergoing oestrus induction protocols*

The metabolic status of the sow had no influence on the ability of sows to respond to the induction protocol. One concern has been how, would an extended lactation and any associated metabolic changes affect the response to lactational oestrus induction. The change in metabolic status between the control, conventionally weaned sows, and the induction sows saw a large difference in energy output. However, this had no effect on the rate of oestrus induction. The relationships between energy input and output was largely linear up to 100 MJ ME/d. So essentially, while sows can maintain energy input they would maintain energy output during the extended lactation. This could mean that the extended lactation was not metabolically taxing to the sows, and there was no metabolic effect on oestrus induction. The same situation was not seen when pregnancy is the end measure. The number of mated sows that failed to remain pregnant was affected by the rate of body protein loss. Sows which lost around 4.4% of their protein mass failed to remain pregnant compared to those who remained pregnant which lost only 2.5% of their body protein mass. These observations support the results from numerous sources in the literature that have shown reduced subsequent fertility and fecundity in sows that have lost appreciable amounts of body weight and more particularly body protein mass during lactation.

4.3. *Sow and piglet welfare during the intermittent suckling protocol*

Detractors of lactation oestrus induction using piglet separation have questioned the welfare implications for the sows and piglets, especially the potential for udder damage from excessive piglet attention after re-joining. This project evaluated the behaviour of primiparous sows and their piglets during 8 h periods of separation each day for 7 days from day 21 of lactation, as part of an induction protocol. The separation failed to cause alterations to sow or piglet behaviour to a point that would warrant concern. The main behavioural and physiological changes occurred after re-joining. For piglets these changes would not raise concerns for the piglet welfare. There were limited changes in salivary cortisol. Once piglets were re-joined, they spent increased time at the udder but this did not lead to increased damage of the udder. After re-joining the heightened levels of piglet activity declined over the first hour, illustrating no prolonged alteration in piglet behaviour. Interestingly, separated piglets spent a proportionally greater amount of time around the creep feed area during this period which may be advantageous in stimulating creep feed intake and help in any gradual weaning process.

4.4. *Spontaneous ovulation during lactation*

Previous work with oestrus induction has indicated that spontaneous ovulation is not unfamiliar in lactation. The extent of this spontaneous ovulation is no doubt influenced by numerous factors but an extended lactation could be expected to contribute to an increased occurrence. As part of the studies identified in this report, follicle development was to be investigated in sows with different litter suckling loads. Major problems were experienced with the experimental logistics of monitoring large numbers of sows using rectal ultrasound. Based on what follicle evidence was available and the subsequent weaning to oestrus intervals, it was estimated that around 8-9 % of the sows monitored potentially ovulated in lactation. While this estimation needs to be considered in light of the lack of follicle development data, it does fit with other evidence that spontaneous ovulation occurs during lactation, especially when lactation is extended beyond 21 days.

It is difficult to measure the cost of a short lactation on weaner welfare and productivity. In some EU countries long lactation length is legislated. Extended lactation with gradual weaning is a priority area for the Pork CRC in an effort to reduce weaner 'setback'. Increasing weaning age and relying on weaning to re-mate sows would decrease annual litter number per sows. Mating in lactation would overcome this limitation but would allow an increased weaning age while maintaining annual litter number.

Spontaneous ovulation during an extended lactation is likely to be a significant cost to efficiency by extending the weaning to mating interval. However, mating in lactation would identify these sows allowing them to be mated a full cycle earlier.

5. Conclusion

The main conclusions from work in this Project are:

- Piglet separation for 16 h overnight for 3 consecutive days starting on day 21 of lactation was a successful oestrus induction protocol, although there were adverse effects on piglet growth. For this protocol 82% of sows were mated within 7 days and 92% of these sows successfully farrowed with an acceptable litter size.
- Either a shorter separation period of 8 h/d or removing sows from their farrowing crate and providing 30 min of full boar contact, were not sufficient by themselves to achieve an adequate oestrus response and subsequent farrowing rates.
- The metabolism of sows subject to the induction protocols was monitored and there did not appear to be any effect of the metabolic status of sows during lactation on their ability to respond to induction protocols. However it appears that sows that lost more protein mass during lactation may have lower subsequent fertility.
- The 8-hr daily piglet separation protocol had little effect on the welfare of sows and their piglets. Sow udder injury or cortisol levels were unaffected by the separation protocol. Once piglets were re-joined with the sows after 8 hr separation, they spent increased time at the udder and increased activity, but this declined rapidly over the first hour or so after re-joining. There were no consistent effects on piglet cortisol and there appeared to be no long term adverse effects on the welfare and behaviour of piglets during the 8 hr separation protocol for the last 7 days of lactation.
- Previous work with oestrus induction has indicated that spontaneous ovulation is not unfamiliar in lactation. Examination of follicle size during lactation and weaning to oestrus interval data revealed that about 8-9% of the sows monitored potentially ovulated during lactation. These levels could influence the oestrus response to any stimulation protocol initiated at about day18-21 of lactation.

6. Limitations/Risks

The main areas where limitation to implication of the research are:

1. Separation of sows and piglets requires a labour efficient separation procedure. This cost would partly be offset by the movement of mating from a designated mating area in to the farrowing house.
2. The rate of spontaneous ovulation needs to be better researched under commercial conditions especially if weaning age is extended as is currently occurring in some parts of the industry.
3. Welfare measures should be part of protocols used to induce lactation oestrus to provide factual data and not rely on individual subjective opinion.

7. Recommendations

The pig industry has been faced with significant pressure to change some of its long established management strategies. A significant recent change has been the voluntary removal of gestation stalls from the production system. It is clear that group housing of gestating sows has created new issues for sow management. There is likely in the near future to be a strong impetus to limit the use of farrowing crates in the production system. Even though there is good justification to maintain farrowing crates based on piglet welfare, there could be limits put on the time sows can be maintained in a crate. There is the possibility that lactation could consist of a combination of using crates for 1-2 weeks and then grouping of sows for the remainder of the lactation period. It's clear that with the current changes and possible changes to pig production, new options are needed to accommodate mating and weaning.

Mating in lactation

1. Allows weaning age to be increased without reducing litter number per sow per year.
2. Increasing weaning age reduces weaner 'set-back' and the use of antibiotics.
3. An increased weaning age can be combined with gradual weaning strategies.
4. Eliminates the need for sows to be housed in a mating shed or removes the difficulties associated with oestrus detection when sows are weaned into groups.
5. Overcomes the failure to detect sows that spontaneously ovulate in lactation. This is likely to be a greater problem if the industry is required to move to some type of group lactation.

With the likely changes placed on the industry it a timely that the new strategies are investigated that integrate, increased weaning age, gradual weaning, group lactation and mating in lactation.

8. References

Barnett JL, Hemsworth PH (2010) Welfare Monitoring Schemes: Using Research to Safeguard Welfare of Animals on the Farm. *Journal of Applied Animal Welfare Science* **12**, 114-131.

Berkeveld M, Langendijk P, Bolhuis JE, Koets AP, Verheijen JHM, Taverne MAM (2007a) Intermittent suckling during an extended lactation period: Effects on piglet behavior. *Journal of Animal Science* **85**, 3415-3424.

Berkeveld M, Langendijk P, van Beers-Schreurs HMG, Koets AP, Taverne MAM, Verheijden JHM (2007b) Postweaning growth check in pigs is markedly reduced by intermittent suckling and extended lactation. *Journal of Animal Science* **85**, 258-266.

Britt, J.H., Armstrong, J.D., Cox, N.M. and Esbenshade, K.L. (1985) Control of follicular development during and after lactation in sows. Journal of Reproduction and Fertility Supplement, 33: 37.

Broom DM, Jonson KG (1993) 'Stress and animal welfare'. (London: Chapman and Hall).

Clowes, E.J., Ahemrne, F.X., Foxcroft, G.R. and Baracos, V.E. (2003) Parturition body size and body protein loss during lactation influence performance during lactation and ovarian function at weaning in first parity sows. Journal of Animal Science, 81: 1517.

Costa, A.N and Varley, M.A. (1995) The effects of altered suckling intensity, boar exposure in lactation and gonadotrophins on endocrine changes, fertility and the incidence of lactational oestrus in multiparous sows. Animal Science, 60: 485.

Downing J.A., Toribio, N. and Giles, L.R. (2007) Induction of oestrus during lactation using an injection of gonadotrophin and piglet separation. Manipulating Pig Production. Australasian Pig Science association, XI, 137.

Downing J.A., Broek, D., Smits, R.J. and Giles, L.R. (2009) Induction of oestrus in lactation results in normal mating and farrowing performance. Manipulating Pig Production. Australasian Pig Science Association, XII, 144.

Foxcroft, G.R., Dixon, W.T., Dyck, M.K., Novak, S., Harding, J.C.S. and Almedia, F.C.R.L. (2009) Prenatal programming of postnatal development in the pig In: 'Control of Pig Reproduction VIII' Eds. H. Rodriguez-Martinez, J.L. Vallet, and A.J. Ziecik, A.J. pp 213-232. Nottingham University Press: Nottingham.

Gerristen R. (2008) Lactational oestrus induction in sows: follicle growth, hormone profiles and early pregnancy in sows subjected to intermittent suckling. Thesis. Wageningen University, Netherlands.

Hoshino Y, Koketsu Y (2008) An evaluation of the Impact of Increased Lactation Length on the Reproductive Efficiency of Sows in Commercial Herds. *Theriogenology* **71**, 299-303.

Hulten, F., Lundeheim, N., Dalin, A.M. and Einarsson, S (1998) Reproductive performance among group-housed during late lactation. Acta Veterinaria Scandinavica, 38: 119.

Hulten, F., Wallenbeck, A. and Rydhmer, L. (2006) Ovarian activity and oestrus signs among group-housed lactating sows: influence of behaviour, environment and production. Reproduction of Domestics Animals, 41: 448.

Kirkwood RN, Thacker PA (1989) Failure of an induced ovulation during lactation to improve sow or litter performance. *Canadian Journal of Animal Science* **70**, 135-138.

Kuller WI, Soede NM, van Beers-Schreurs HMG, Langendijk P, Taverne MAM, Verheijen JHM, Kemp B (2004) Intermittent suckling: Effects on piglet and sow performance before and after weaning. *Journal of Animal Science* **82**, 405-413.

Kongsted, A.G. and Hermansen, (2009) Induction of lactational oestrus in organic piglet production. Theriogenology, 72: 1188.

Kunavongkrit A, Einarsson S, Settergren I (1982) Follicular development in primiparous lactating sows. *Animal Reproduction Science* **5**, 47-56.

Langendik, P., Berkeveld, M., Gerristen, R., Soede, N.M. and Kemp, B. (2007a) Intermittent suckling: tackling lactational anoestrus and alleviating weaning risks for piglets. In: Paradigms in Pig Science. Wiseman., Varley, M.A., McOrist, S. and Kemp, B. (eds) Nottingham University Press, Nottingham, Great Britain, pp-359.

Langendijk P, Dieleman SJ, van den Ham CM, Hazeleger W, Soede NM, Kemp B (2007b)

LH pulsatile release patterns, follicular growth and function during repetitive periods of suckling and non-suckling in sows. *Theriogenology* **67**, 1076-1086.

Mota, D., Alonso-Spilsbury, M., Mayagoitia, L., Truillo, M.E., Valencia, . and Ramirez-Necoechea, R (2002) Lactational oestrus induction in the Mexican hairless sow. Animal Reproduction Science, 72, 115.

Newton, E.A., Stevenson, J.S and Davis, D.L (1987a) Influence of duration of litter separation and boar exposure on estrous expression of sows during and after lactation. Journal of Animal Science, 65, 1500.

Newton, E.A., Stevenson, J.S., Minton, .E. and Davis, D.L (1987b) Endocrine changes before and after weaning in response to boar exposure and altered suckling in sows. Journal of Reproduction and Fertility, 81: 599.

Patterson, J.L., Smit, M.N., Novak, S., Wellen, A.P. and Foxcroft, G.R. (2011) Restricted feed intake in lactating sows. 1. Effect on sow metabolic state and subsequent reproductive performance. Reproduction, Fertility and Development, 23: 889.

Rowlinson, P. and Byrant, M.J. (1981) Lactational oestrus in the sow. 1. The interval between farrowing and grouping on the incidence and timing of lactational oestrus in sows. Animal Production, 32: 315.

Rowlinson, P. and Byrant, M.J. (1982) Lactational oestrus in the sow. 1. The interval between farrowing and grouping on the incidence and timing of lactational oestrus in sows. Animal Production, 34: 283.

Schenkel, A.C., Bernardi, M.L., Bortolozzo, F.P. and Wentz, I (2010) Body reserve mobilization in first parity sows and its effect on second litter size. Livestock Science, 132: 165.

Van Wettere, W.H.E.J., Kaisler-Smith, C.R., Terry, R., Waever, A.C. Herde, P.J., Kennaway, D.J., Hughes, P.E. and Kind, K.L. (2013) Boar contact is an effective stimulant of ovulation during early lactation. Livestock Science, 155, 454-458.

Varley, M.A and Foxcroft, (1990) Endocrinology of lactation and weaned sow. Journal of Reproduction and Fertility, Supplement, 40: 47.

Vinsky, M.D., Novak, S., Dixon, W.T., Dyck, M.K., and Foxcroft, (2006) Nutritional restriction in lactating primiparous sows selectively affects female embryo survival and overall litter development. Reproduction Fertility and Development, 18: 347.

Zak, L.J., Williams, I.H., Foxcroft, G.R., Pluske, J.R., Cegielski, A.C., Clowes, E.J., Aherne, F.X. (1998) feeding lactating primparous sows to establish three divergent metabolic states: I. Associated endocrine changes and post-weaning reproductive performance. Journal of Animal Science, 76: 1145.