The Effect of Sow Metabolic Status, Boar Exposure and Timing of Piglet Separation on Lactational Oestrus Induction

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Abstract

The objectives of the study were to determine the role of boar exposure and the minimal period of piglet separation needed to induce oestrus during lactation and the impact of sow metabolic status on the success of lactational oestrus induction. In this experiment, 200 multiparous sows were divided evenly into four treatment groups. Treatment 1 sows were conventionally weaned at day 21 of lactation (CONTROL), treatment 2 involved separation of piglets from the sow for 16 h for three consecutive nights starting on day 21 of lactation (SEP 16), for treatment 3, piglets were separated for 8 h (SEP 8) and for treatment 4, sows were given direct physical contact with a mature boar for 30 minutes daily from day 21 of lactation (BOAR). The results indicate that full direct boar exposure alone and three days of 8 h piglet separation were both not sufficient to induce lactational oestrus in a significant proportion of sows (75% and 53.2% mating rates respectively), however, increasing the separation length to 16 h was an effective treatment (82% mating rate). The various induction treatments had no significant influence on pregnancy rate. Sow energy output, body protein loss or fat loss during lactation had no effect on the ability of these protocols to induce oestrus during lactation. However, there was a significant effect of body protein loss on the rate of pregnancy in the sows mated during lactation and this may need to be addressed in the development of lactational oestrus induction protocols introduced into the pig industry.

Keywords

Introduction

The pork industry has placed an increasingly high demand on the sows' ability to produce larger litters more frequently. This focus on rapid turnover has impacted on the welfare of piglets as the average age of weaning has decreased to allow the sow to return to oestrus earlier. An extended lactation to improve the health and welfare of piglets is unlikely to be adopted by the industry due to the perceived occurrence of lactational anoestrus in sows. The development of a lactational oestrus induction protocol that supports oestrus and mating during lactation could increase industry productivity by allowing for a later day of weaning and by reducing the sows' non-productive days per cycle. The adoption of lactational oestrus induction in an extended lactation system will, however, increase a sow's energy requirements for milk production, further decreasing her tissue reserves. Previous research has illustrated that a decrease in body weight or protein mass during lactation impacts negatively on the reproductive potential of sows (Clowes et al., 2003; Quesnel et al., 1998; Schenkel et al., 2010; Vinsky et al., 2006), therefore, the sows' increased catabolism during an extended lactation may influence the success of any lactational oestrus induction protocols.

Research surrounding lactational oestrus induction has been conducted as early as 1946 to varying degrees of success. Cole and Hughes (1946) successfully induced oestrus in 26 of 27 lactating sows using a single injection of pregnant mare's serum gonadotrophin (PMSG) between day 39 and 68 of an extended lactation. Future experiments conducted throughout the 1970s and 1980s, the results of which were reviewed by Britt et al. (1985), used an injection of PMSG to encourage follicle development followed by an injection of human chorionic gonadotrophin (hCG) to induce ovulation. However, the results from these experiments were not as successful (Hausler et al., 1980; Heitman and Cole, 1956; Hodson et al., 1981).

More recent investigations address the main cause of lactational anoestrus in the sow, the reduction in luteinising hormone (LH) pulsatility due to the piglet suckling stimulus (Langendijk et al., 2005). The suckling stimulus inhibits the hypothalamic gonadotrophin releasing hormone (GnRH) pulse generator and this reduces LH secretion as GnRH regulates LH secretion from the pituitary (Armstrong et al., 1999; Cox and Britt, 1982; Langendijk et al., 2005; Shaw and Foxcroft, 1985; Soede et al., 2011). These experiments managed this issue through reducing the suckling stimulus by split weaning or piglet separation. Research surrounding induction of oestrus through piglet separation has exhibited conflicting results. Langendijk et al. (2005) reported a 90% ovulation rate when piglets were separated from the sow for 12 hours a day from day 14 of lactation. However, Kuller et al. (2004) using the same intermittent suckling protocol found only 22% of sows ovulated. Previous research conducted through the Australian Pork CRC has shown promising results when intermittent suckling is combined with boar exposure and exogenous gonadotrophin treatment (Downing et al., 2007; Downing et al., 2011). Expanding on these earlier studies, the current study was undertaken to determine the role of boar exposure, the minimal period of piglet separation needed to induce oestrus as well as the efficacy of oestrus induction without exogenous hormone use.

The reported success of experimental lactational oestrus induction protocols may be influenced by season (Britt et al., 1985), litter size (Fahmy et al., 1979), sow parity (Newton et al., 1987), genotype (Henderson and Hughes, 1984; Kuller et al., 2004; Langendijk et al., 2005; Newton et al., 1987) and metabolic status. Research reviewed by Foxcroft et al. (2007; 2009) has shown that a decrease in body weight, body protein mass or body fat mass during lactation impacts negatively on the reproductive potential of sows. Similar to the suckling stimulus, the metabolic status of the sow also affects LH secretion during lactation (Prunier et al., 2003; Zak et al., 1998). This is a concern in the adoption of lactational oestrus induction protocols as an extended lactation will increase a sow's energy requirements for milk production, further decreasing her tissue reserves. Quesnel et al. (1998) reported that an increase in sow catabolism using feed restriction caused a decrease in luteinising hormone (LH) secretion prior to and after weaning leading to an inhibition of ovarian activity. A 12% loss in body protein reserves was associated with decreased ovarian follicle size at weaning in work reported by Clowes et al. (2003). Vinsky et al. (2006) also studied the impact of nutritional restriction on reproductive potential and found a significant difference between feed restricted sows and control sows in the survival rate of embryos at day 30, but no difference in weaning-to-oestrus interval, ovulation rate or pregnancy rate. Schenkel et al. (2010) evaluated the effect of losses of body tissue reserves during a sow's first lactation on second litter size. They found that a body weight loss of 8% or body protein loss of 9% in first parity sows negatively affected second litter size. These studies illustrate the potential impact of increased sow

catabolism during an extended lactation on the success of lactational oestrus induction protocols. A further objective of the current study was to analyse the impact of sow catabolism during lactation on the success of lactational oestrus induction protocols involving boar exposure and piglet separation.

Materials and Methods

General

The study was conducted at the Research and Innovation Unit of Rivalea Pty. Ltd., Corowa, NSW, Australia during April and May 2012. The use of animals complied with the Australian Code of Practice for the use of Animals for Scientific Purposes and was approved by the Animal Care and Ethics Committee of Rivalea Pty. Ltd.

Animals

The experiment was conducted in four consecutive replicates using 50 sows according to the weekly batch farrowing system used at Rivalea. The 200 multiparous sows used were all F1 Large White x Landrace (PrimeGro[TM] Genetics). The average parity of the sows was 3.5 ± 0.1. These sows were housed as groups in ecoshelters until an average of day 106 of gestation when they were moved into the farrowing shed and housed in conventional farrowing crates.

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 approximately 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 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.

Oestrus Induction Procedures

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 groups. Treatment 1, was a control group of sows conventionally weaned at day 21 of lactation (CONTROL). For treatment 2, piglets were separated for 16h (15:30-07:30) from the sow by placing a board in the farrowing crate between the sow and piglets for three consecutive nights starting on day 21 of lactation (SEP 16). For treatment 3, piglets were separated from the sow for 8h (07:30-15:30) for three consecutive days from day 21 of lactation (SEP 8). For treatment 4, 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 (BOAR). For all sows, oestrus detection was performed twice daily using the back pressure test with fenceline exposure to a mature boar.

For those sows mated during lactation and the conventionally weaned control sows mated during the experimental period, any returns to oestrus before day 40 were recorded. At day 40 an ultrasound was used to determine pregnancy.

Measurements

The weight and backfat of the sows was measured three times during this experiment, at introduction into the farrowing shed, at commencement of oestrus induction (day 21) and at weaning. Backfat 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 at weaning.

Metabolic Calculations

To evaluate the metabolic status of the sow during lactation, the energy inputs and energy outputs were calculated. The movements of energy from sow inputs to the piglets as outputs are illustrated schematically in Figure 1 and were based on information provided by Bergsma et al. (2009). Energy inputs include energy derived from feed consumed and energy from metabolised body tissues (protein and fat). Energy of feed intake during lactation was estimated as the amount of feed offered excluding the feed residues multiplied by the metabolisable energy per kg of the feed (Eq. 1). Details of all equations used are given in the appendix and are adapted from Bergsma et al. (2009) unless otherwise stated. Energy from metabolised body protein was calculated by determining the difference between body protein mass at farrowing and weaning and estimating the energy content of 1 kg of protein as 23.8 MJ ME (Eq. 2). Energy from metabolised fat was similarly determined and energy content of 1 kg of fat was defined as 39.5 MJ ME (Eq. 3).

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 multiplying the daily maintenance requirements by the number of days of lactation (Eq. 4 and 11). 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. 5 -7). 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 'birth weight' is formulated as the birth weight of piglets born alive and weaning weight was adjusted for piglets fostered and piglet deaths.

To perform these metabolic calculations it was necessary to estimate the farrowing weight of the sows as this measurement was not taken. Day of pregnancy upon 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 8-10. The estimate of the total foetus weight at farrowing was then compared to the recorded total born litter weight and the ratio of 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 the sow entry weight as the average weight (Eq. 4). 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.

Statistical Analysis

The influence of oestrus induction protocol, sow parity, the metabolic output of the sow, 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). These models were generated using mating rate, pregnancy rate or return rate as the response variate 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). As the response variates were all binary a binomial distribution was selected with a total of 1in 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 backfat were analysed using a 1-way 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 $P < 0.05$.

Results

Of the 200 multiparous sows allocated to treatments, eight sows were removed due to illness or injury prior to the oestrus induction period. There was a significant effect of treatment (P = 0.002), on the mating rate of the sows (see Table 2). For the control sows (CONTROL) 44 out of 47 (93.6%) were mated after being conventionally weaned at day 21 of lactation. The 16 h of piglet separation (SEP 16) resulted in 41 out of 50 (82%) sows mated during the 28 day extended lactation. Eight hours of piglet separation (SEP 8) resulted in 25 of 47 sows (53.2%) mated during lactation, while full boar exposure (BOAR) saw 36 out of 48 sows (75%) mated in lactation. The mating rate of the conventionally weaned sows was significantly higher than the sows separated from piglets for 8 h (SEP 8) as well as those given full boar exposure (BOAR) but not those provided with 16 h piglet separation. Sows with 16 h of piglet separation (SEP 16) had a significantly higher mating rate than sows' having 8 h of piglet separation (SEP 8) but not those given full boar exposure (BOAR).

Treatment had a significant effect on the days to mating following start of treatments at day 21 (P = 0.01). The differences between the control group (CONTROL), the 8 h piglet separation group (SEP 8) and the full boar exposure treatment group (BOAR) were not significant. However, the sows from the 16 h piglet separation group (SEP 16) were mated significantly later than the control sows (CONTROL) (P < 0.05), but not later than sows from the 8 h separation (SEP 8) or the full boar exposure (BOAR) group (see Table 2).

For sows mated during lactation, treatment had no significant impact on the pregnancy rate at day 40 (see Table 2). For the control sows (CONTROL), 34 out of 41 mated (83%) were pregnant at day 40 of gestation. In the 16 hour piglet separation group (SEP 16), 36 out of the 39 sows mated (92.3%) were pregnant, for the 8 hour piglet separation group (SEP 8), 16 of 24 mated sows (66.7%) were pregnant and 24 out of 36 (66.67%) sows mated in lactation having full boar exposure (BOAR) were pregnant at day 40 of gestation.

The association of sow energy input (MJ ME/d) and sow energy output (MJ ME/d) during lactation is depicted in Fig. 2. 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. However, of these variables, body protein loss (MJ ME) was found to have a significant influence the pregnancy rate (P = 0.04). The average 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%). This compared to the average protein loss of 209 MJ ME (4.4%) of those sows detected as not pregnant at day 40 of gestation.

Discussion

Previous research has demonstrated promising results when intermittent suckling is combined with boar exposure and exogenous gonadotrophin treatments to induce oestrus in lactating sows (Downing et al., 2007; Downing et al., 2011). However, an unwillingness by the industry to include hormonal treatments into their mating regime has identified the need to determine the optimal timing of piglet separation and the effect of direct boar exposure on oestrus induction rates without any exogenous hormonal support.

Treatment had a significant impact on oestrus induction and mating rates in the current experiment. Piglet separation for 16 hours per day with fenceline boar exposure (SEP 16) gave a mating rate (82%) similar to that of the conventionally weaned sow group (CONTROL) (93.6%). Communication with industry members has revealed that the pork industry is willing to accept mating rates of 80-85% from lactational oestrus induction protocols not using exogenous hormones. This means that a 16 h piglet separation protocol meets the induction requirements of pork producers.

Using piglet separation for 8 h for three consecutive days to induce oestrus in the multiparous sows (SEP 8) resulted in only 53.2% being mated during lactation. This low induction rate may be due to an insufficient reduction in the suckling stimulus to allow resumption of LH pulsatility in the sow (Langendijk et al., 2005). It is clear that 8 hours of piglet separation is not sufficient to induce oestrus in a large enough proportion of lactating sows for this protocol to be adopted by the industry.

Oestrus was induced in 75% of sows directly exposed to mature boars for 30 minutes a day (BOAR). This proportion varies considerably from the oestrus induction rate of 100% purported to have occurred in other unpublished work (Van Wetter, personal communication). While the direct boar effect was substantial, the success rate is not adequate for commercial acceptance. These results indicate that a hormonal component, such as an injection of PG600 (PMSG + hCG), may be necessary to guarantee high and commercially viable farrowing rates in response to full boar exposure.

Interestingly, although the 16 h of piglet separation (SEP 16) provided high induction rates, it was associated with a significantly longer time to mating compared to the control sows (CONTROL). The other induction groups (SEP 8 & BOAR) had similar times to mating as the control sows (CONTROL). Nevertheless, the average days to mating for the 16 h piglet separation group was 5.5 days which is within the industry expectation for weaning-to-oestrus interval and therefore is acceptable (see Table 2).

The analysis of the day 40 pregnancy rates for those sows mated during the treatment periods illustrated no significant effect of treatment. This would suggest that the induction protocols have had no impact on the ability of mated sows to become and remain pregnant. Although there is no significant difference between treatment groups, the treatment with the greatest proportion of sows mated that remained pregnant was observed in the 16 hour piglet separation (92.3%) (SEP 16). It is also important to note that a decrease in group size may have affected the statistical validity of the analysis of treatment effect on pregnancy rate. Whilst the initial group size in each treatment was n = 50, sows were removed during the experiment due to illness or injury, reducing the group size in each treatment. The number of sows in each treatment was then decreased again when examining pregnancy rate, as only sows mated are included in this analysis. For example, the group size for the 8 h piglet separation treatment (SEP 8) was only n = 24 for the pregnancy rate analysis (see Table 2).

The relationship between the metabolic state of the sow and her reproductive potential has been reported on in recent years (Clowes et al., 2003; Foxcroft et al., 2009; Foxcroft et al., 2007; Patterson et al., 2011; Quesnel et al., 1998; Schenkel et al., 2010; Vinsky et al., 2006). These studies all indicate a decrease in reproductive performance when sows are catabolic. The current results revealed no significant influence of sow energy output (MJ ME/d), body protein loss (MJ ME) or body fat loss (MJ ME) during lactation on the mating rate. The absence of such a relationship may be due to the methodology used in the current experiment or the genetic traits of the sow genotype used. Previous experiments have generated a catabolic state among lactating sows by reducing the feed intake over set periods and comparing the subsequent reproductive performance of these sows to ad libitum fed sows (Patterson et al., 2011; Quesnel et al., 1998; Vinsky et al., 2006). It was hypothesised in this study that the extended lactation involved in oestrus induction protocols would

increase a sow's energy requirements for milk production, further decreasing her tissue reserves and affecting the success of oestrus induction protocols. However, in a commercial setting with sows being fed up to 9 kg of feed per day, a markedly catabolic state was not achieved and did not impact on the mating rate during lactation. This indicates that the experimental stimulation of a catabolic state in lactating sows may not reflect the reproductive potential of sows in a commercial environment (Patterson et al., 2011; Quesnel et al., 1998; Vinsky et al., 2006). These results may also reflect the suitability of the modern genotype sow to maintain reproductive performance in a commercial setting. This was originally hypothesised by Patterson et al. (2011) who stated that selection for improved litter quality and reproductive productivity in the pig industry may have altered the influence of metabolic challenges on reproductive performance.

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 treatment groups a positive relationship can be seen as output increases with increasing input. However, the strength of the relationship between input and output varies between the treatment groups with a poor relationship in the control group (r = 0.26) compared to a stronger relationship in the 8 h piglet separation group (r = 0.72). This correlation may be influenced by the length of lactation as the three treatment groups that underwent 28 days of lactation all have higher r values than the control group that underwent only 21 days of lactation (see Fig. 2). These results illustrate that sows with a greater energy input during lactation, i.e. those sows with a longer lactation that are therefore fed more, put more energy proportionately into litter growth and maintenance such that there may be a point where the relationship between sow energy input and output is so high, the energy requirements for reproduction cannot be met. This is the point at which sow metabolic status negatively impacts on reproductive capabilities.

The protein loss (MJ ME) of sows during lactation had a significant effect on pregnancy rate (P = 0.04). This is interesting, because body protein loss had no significant impact to lactational oestrus induction rate. Sows with greater body protein loss (MJ ME) during lactation were less likely to become pregnant and remain so until day 40 of gestation. Clowes et al. (2003) hypothesised that body protein loss could have a large influence on reproductive performance as mobilisation of protein may reach a point at which the amino acid supply is insufficient to support proper reproductive function. They then determined that a 9-12% loss of body protein tissue during lactation negatively affected the subsequent reproductive performance of gilts at their next weaning. The high protein loss gilts had fewer medium sized follicles and their follicles contained less follicular fluid. When the follicular fluid obtained from these follicles was used to culture oocytes from pre-pubertal gilts using a method described by Zak et al. (1997) and Yang et al. (2000), oocyte maturation was impaired if the follicular fluid was from gilts with higher protein loss. The loss of ovarian function observed by Clowes et al. (2003) provides a possible explanation for the effect of protein loss on pregnancy rate in the current study. The average body protein loss of sows mated but not pregnant was 4.4% compared to 2.5% for sows mated and pregnant at day 40. This indicates that a smaller body protein loss than reported by Clowes et al. (2003) and Schenkel et al. (2010) affects the reproductive abilities of sows.

Conclusion

This study evaluated the success of protocols employing direct boar exposure and different periods of piglet separation to induce oestrus during lactation without the use of exogenous gonadotrophins. Communication with industry members has revealed that the pork industry is willing to accept mating rates of 80-85% from lactational oestrus induction protocols not using exogenous hormones. Three days of 8 h piglet separation was not sufficient to induce lactational oestrus in a significant proportion of sows, however, increasing the separation length to 16 h was an effective treatment for inducing lactational oestrus as the mating rate was within the industry assigned limits of 80-85%. Full direct boar exposure alone will not induce a sufficient number of sows into oestrus for this protocol to be adopted by the industry.

In a commercial setting and using a modern genotype, sow energy output (MJ ME/d), body protein loss or body fat loss during lactation had no effect on the ability of these protocols to induce oestrus during lactation. However, there was a significant effect of body protein loss on the rate of pregnancy and the return to oestrus rate in the sows mated during lactation and this may need to be addressed in the development of lactational oestrus induction protocols introduced into the pig industry.

Future research into other factors affecting the success of oestrus induction protocols for example season, litter size and genotype as well as research into the use of hormonal stimulus to ensure adequate mating rates may be needed before these protocols are accepted by the pig industry. Previous research conducted by Vinsky et al. (2006) illustrated no effect of metabolic status on weaning to oestrus interval, ovulation rate or pregnancy rate, however, there was a significant effect on embryo survival at day 30. The impact of sow catabolism during a lactational oestrus induction protocol on embryo survival may therefore need to be investigated. The effect of induction protocols involving piglet separation on weaner growth and mortality as well as the effect of all induction protocols on the next litter size may also need to be examined before these protocols are accepted by the pig industry.

Acknowledgements

Tables and Figures

Nutrient	Gestation Feed	Lactation Feed	Creep Feed
Metabolisable Energy (MJ ME/kg)	13.3	13.3	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

Table 1. Nutrient composition of gestation, lactation and creep diets.
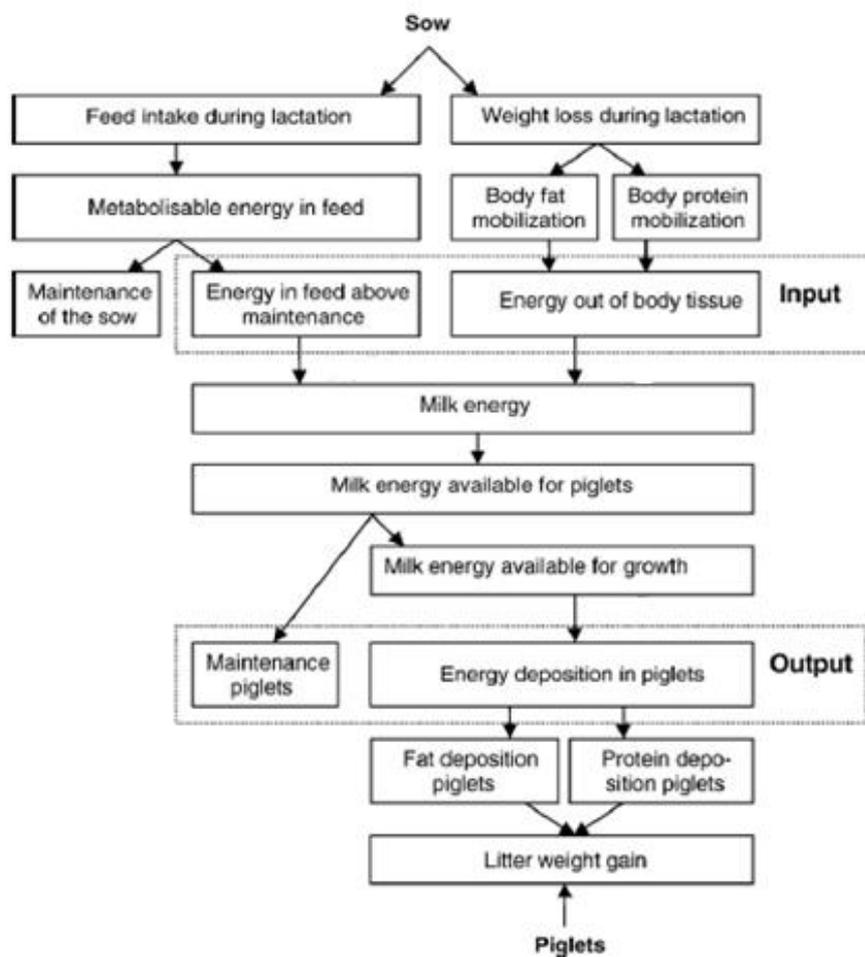
Figure 1. Energy flow of sow inputs and outputs during lactation (taken from Bergsma et al. 2009).
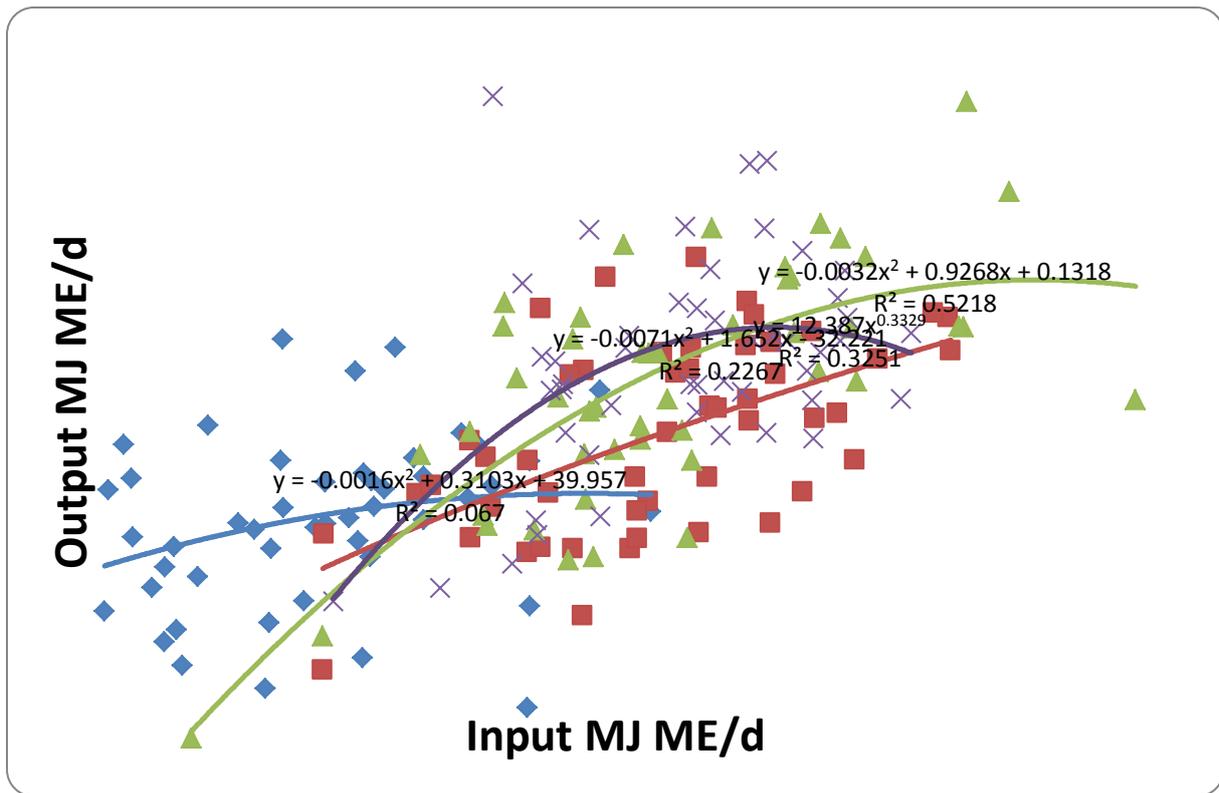
$y = -0.0032x^2 + 0.9268x + 0.1318$
$R^2 = 0.5218$

$y = 12.387x^{0.3329}$
$R^2 = 0.3251$

$y = -0.0071x^2 + 1.652x - 32.221$
$R^2 = 0.2267$

$y = -0.0016x^2 + 0.3103x + 39.957$
$R^2 = 0.067$

Output MJ ME/d

Input MJ ME/d

Figure 2. Relationship between sow energy input MJ ME/d and energy output MJ ME/d. ◆Control (y = -0.0016x^2 + 0.3103x + 39.957, r = 0.26, n = 47), ■Piglet Separation 16 h/d (y = 12.387$x^{0.3329}$, r = 0.57, n = 50), ▲ Piglet Separation 8 h/d (y = -0.0032x^2 + 0.9268x + 0.1318, r = 0.72, n = 47), ✕ Full Boar Exposure (y = -0.0071x^2 + 1.652x – 32.221, r = 0.48, n = 48).

	Control	Piglet Separation 16 h/d (SEP 16)	Piglet Separation 8 h/d (SEP 8)	Full Boar Exposure (BOAR)	All Sows	SED	P value
Number of Sows Treated	47	50	47	48	192	-	-
Mating Rate	44/47[a] (93.6%)	41/50[ab] (82%)	25/47[c] (53.2%)	36/48[bc] (75%)	146/192 (76%)	0.63	P = 0.002
Day at First Mating (mean ± SE)	4.3 ± 0.2[a]	5.5 ± 0.2[b]	5.0 ± 0.3[ab]	5.1 ± 0.3[ab]	5.0 ± 0.1	0.39	P = 0.01
Pregnancy Rate	34/41 (83%)	36/39 (92.3%)	16/24 (66.7%)	24/36 (66.7%)	110/140 (78.6%)	0.75	P = 0.16

Table 2 - Reproductive performance of sows following oestrus induction using piglet separation and boar exposure starting on day 21 of lactation. Values with different superscripts within a row are significantly different. Significance was determined at P < 0.05.

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Appendices

Appendix 1 - Equations

1. Energy of feed (MJ ME) = (feed offered – residue) × (15.304222*0.96)

2. Protein (kg) = 11.90 + 0.1711 × Body weight (kg) + 1.904 × Backfat (mm)

3. Fat (kg) = -11.58 + 0.1027 × Body weight (kg) + 1.904 × Backfat (mm)

4. Sow Maintenance (MJ ME) = (0.440 × (average weight (kg))$^{0.75}$) × days of lactation

5. Average piglet daily gain (kg) = ((weaning weight - birth weight)/days of lactation) × 1000)/weaned litter number

6. Piglet fat mass (kg) = (birth weight × 0.014) + (weaning weight – birth weight) × (0.135 + 0.00014 × average daily gain)

7. Piglet protein mass (kg) = (birth weight × 0.116) + (weaning weight – birth weight) × 0.16

8. Total weight foetuses (g) = $e^{(8.72962 - 4.07466 \times e\wedge(-0.03318 \times (\text{days of pregnancy} - 45)) + 0.000154 \times \text{daily energy intake during gestation (MJ ME/d)} \times \text{days of pregnancy} + 0.06774 \times \text{number of foetuses})}$

9. Weight of placentas (g) = $e^{(7.02746 - 0.95164 \times e\wedge(-0.06879 \times (\text{days of pregnancy} - 45)) + 0.000085 \times \text{daily energy intake during gestation (MJ ME/d)} \times \text{days of pregnancy} + 0.09335 \times \text{number of foetuses})}$

10. Weight of intra-uterine fluid (g) = $e^{(-0.2636 + 0.18805 \times \text{days of pregnancy} - 0.001189 \times \text{days of pregnancy}\wedge2 + 0.13194 \times \text{number of foetuses})}$

11. Piglet maintenance (MJ ME) = (0.485 × (average weight (kg))$^{0.75}$) × days of lactation

	Control	Piglet Separation 16 h/d (SEP 16)	Piglet Separation 8 h/d (SEP 8)	Full Boar Exposure (BOAR)	Total	P value
Number of Sows Treated	47	50	47	48	192	-
Litter Size at Weaning (mean ± SE)	9.3 ± 0.2	9.0 ± 0.2	9.1 ± 0.3	9.4 ± 0.2	9.2 ± 0.1	P = 0.62
Parity (mean ± SE)	3.8 ± 0.2	3.5 ± 0.2	3.4 ± 0.2	3.3 ± 0.2	3.5 ± 0.1	P = 0.46
Weight at Entry (mean ± SE) (kg)	310.5 ± 5.1	299.4 ± 5.2	305.6 ± 5.1	298.9 ± 5.1	303.6 ± 2.6	P = 0.42
Backfat at Entry (mean ± SE) (mm)	28.3 ± 1.0	26.7 ± 1.0	26.6 ± 0.7	25.8 ± 0.8	26.8 ± 0.4	P = 0.27

Table 3 - Descriptive statistics of experimental sows treated for oestrus induction using piglet separation and boar exposure at day 21 of lactation. Significance was determined at $P < 0.05$.