REPRODUCTIVE PERFORMANCE OF SOWS SUPPLEMENTED WITH AN OIL HIGH IN ESSENTIAL FATTY ACIDS DURING EARLY GESTATION

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By

Nadine Funk

In Partial Fulfillment of the

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Reproductive Performance of Sows Supplemented with an Oil High in Essential Fatty Acids During Early Gestation

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements of the degree of Master of Science

ABSTRACT

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Linoleic and linolenic acids are involved in both implantation and central nervous system development of the embryos. By supplementing gestation diets with these essential fatty acids (FAs), it may be possible to enhance embryo survival, litter size and piglet survivability. Approximately 60 sows and gilts were used for each of 3 trials. Animals were housed on straw in groups of 14 to 16 and were fed once daily in individual feeding stalls. On day of breeding (d0) animals were randomly assigned within pen to 1 of 3 treatments; diet 1 (T1 – control (commercial dry sow), diet 2 (T2) – starch (equal energy intake to diet 3, but no supplemental fatty acids), diet 3 (T3) – oil (supplemented with flax seed oil to bring linoleic acid content to 2%). Animals were formula-fed according to body weight (BW) during gestation (1%BW + 0.7kg). The test diets were fed until day 40 of gestation, after which all animals returned to the commercial gestation ration (control). In trial 1, the younger growing animals were weaned in relatively poor body condition and older mature animals tended to be over-conditioned. For trials 2 and 3, the feeding formula was adjusted to account for body condition as well as body weight. Sow body weights, backfat thickness and body condition scores (BCS) were recorded on days 0, 30, 40, 60, 90, 109, and 113 of gestation; days 4 and 14 of lactation and at weaning (d28). Blood samples for progesterone and estradiol analysis were taken from sows on days 0, 30, 40, 60, 90 of gestation, day 14 of lactation and at weaning.

Treatment had no effect in terms of litter characteristics, or the sow's weaning to estrus interval. Supplemental essential fatty acids did not affect body weight or BCS of the animals. Backfat levels were influenced by treatment. The mean separation tests used were unable to determine specific differences. However, it appears that flaxseed oil supplementation and potentially starch supplementation increased backfat throughout both gestation and lactation, relative to the control fed animals. For day 0 all treatments had a mean backfat measure between 12 and 12.5 mm, reaching a maximum by day 113, 15.83 + 0.213, 16.79 + 0.199, 17.20 + 0.193 for trials 1, 2 and 3 respectively. Progesterone was affected by treatment, but again specific differences were undetectable. The most obvious difference occurred at weaning when T2 and T3 had mean concentrations of approximately 4 ng/ml while T1 had non-identifiable. Supplementation with an oil rich in essential fatty acids at the levels and the duration used in this study did not improve reproductive performance of sows. In this study the supplemental energy (T2 and T3) fed during early gestation did not have any detrimental effects on litter size. The formula used for gestation feeding in this trial did not maintain all animals equally. The younger growing animals were unable to meet the demands placed on them, resulting in very thin animals at weaning; while the older heavier sows tended to gain too much body condition and entered into lactation with very high levels of backfat. Adjusting the formula to account for body condition for trials 2 and 3, seemed to help maintain more consistent body condition scores (BCS) overall; suggesting that BCS could in fact serve as a useful tool for producers when evaluation gestational feeding programs.

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List of Abbreviations

ad lib	Ad libitum
BCS	Body condition score
BW	Body weight
cp	Crude protein
d	day
DE	Digestible energy
E_2	Estradiol
FSH	Follicle stimulating hormone
GE	Gross energy
GH	Growth Hormone
GnRH	Gonadotrophin releasing hormone
IGF1	insulin-like growth factor 1
kcal	Kilocalories
kg	Kilogram
LH	Luteinizing hormone
MCT	Medium chain triglycerides
MJ	Megajoules
ml	Millilitres
µl	Microliters
mm	Millimeters
ng	Nanograms
NPD	Non-productive days
°C	degrees centigrade
p	Probability
P_4	Progesterone
pg	Picograms
pp	Post-partum
PUFA	Polyunsaturated fatty acids
RIA	Radio immunoassay
RPM	Revolutions per minute
SEM	Standard error of the mean
SEW	Segregated early weaning
T1	Treatment 1
T2	Treatment 2
T3	Treatment 3
MEI	Mean to estrus interval

Chapter 1

Introduction

Viability of intensive livestock production depends on optimizing financial and biological efficiency. While it is often difficult to directly control biological efficiency it is possible to influence measurable production efficiency through a variety of mechanisms. One of the areas of primary concern is reproductive efficiency.

Sow biological performance and litter/piglet performance influence reproductive efficiency of the sow herd. In terms of sow reproduction the main measure is pigs/sow/year. Four main criteria dictate the number of litters a sow can produce per year: gestation length, lactation length, wean to estrus interval (WEI), and number of non-productive days (NPD). Gestation length is a set biological entity and essentially cannot be altered. Lactation length, while it can be altered, is generally pre-determined by the system within which a production unit exists. The WEI can be influenced by several factors: lactation length, metabolic/nutritional status of the sow, and by basic husbandry practices including housing. The number of NPD are those spent neither pregnant nor nursing. The WEI, returns to estrus and any day that gilts are in the barn before they first conceive all contribute to the NPDs for the herd. The number of live born pigs per litter is another indicator of sow performance, and can be influenced by a sow's nutritional and metabolic state before breeding and during gestation (Foxcroft et al, 1995; Ashworth, 1994).

Reproductive performance is also gauged by several piglet and litter parameters. Dam nutritional state and metabolic status are especially influential on the number of embryos during the early gestation period.

Piglet viability is another key aspect of reproductive success. As the majority of all pre-weaning deaths occur in the first 72 hours after birth (Bishop et al. 1985), one method of measuring viability is through an assessment of litter size and weight at birth compared to those found at weaning. Piglet viability may be linked to dam nutrition during gestation (Bishop et al 1985) via body composition differences at birth and milk composition differences.

Reproduction is a cyclical event. The nutritional plane and metabolic status of the sow during each stage of the reproductive cycle contributes to subsequent reproductive success or failure (Einarsson and Rojikittikhun, 1993; Aherne and Kirkwood, 1985). Recent studies have begun to delineate the importance of the early gestation period on overall reproductive performance (Einarsson and Rojikittikhun, 1993; Aherne and Kirkwood, 1985). Feeding strategies and diet composition are two areas that have been investigated (Aherne and Kirkwood, 1985). The effects of key nutrients and their role in specific reproductive processes, such as implantation and early embryonic development have been investigated (Baidoo et al, 1993). Essential fatty acids, namely linoleic and linolenic acids, are thought to be involved in these critical processes. Current trends seem to indicate that sow diets may be lacking sufficient quantity of these nutrients to achieve maximum production levels (Baidoo et al, 1993). It may be possible to improve reproductive performance

by better defining sow and conceptus requirements for individual nutrients (Perez Rigau et al. 1995). By supplementing sow diets during early gestation with essential fatty acids, it may be possible to improve early embryonic development particularly of the nervous system and increase embryo survival, resulting in more uniform and viable litters at birth.

It may be that there is an inadequate supply of these essential fatty acids during early gestation. By increasing the amount of EFA's available for the sow during early gestation, it may be possible to improve both implantation and CNS development of the embryos. Improving these processes could potentially lead to the production of larger larger which are both more uniform and more viable at birth. This study was designed to see if supplementing sows with an oil high in essential fatty acids during early gestation would influence litter size at birth, piglet birth weights or piglet viability at birth.

Chapter 2

Review of Literature

The economic importance of sow reproductive efficiency has made it a major focus of current research. The objective of this review is to understand how gestational diets influence reproductive performance, as measured in terms of pigs pigs weaned/sow/year. The number of litters produced each year, and the size of each litter ultimately impact on annual piglet production.

Sow feeding during both gestation and lactation influences ovulation rate, embryo/piglet survival, and overall sow performance. This review will focus primarily on the importance of the early gestation period on overall reproduction.

Nutritional Influences on Reproductive Performance

Of utmost importance when considering the nutrient requirements of a sow herd is the fact that nutrient requirements cannot be stated in fixed terms. Nutrients are required at levels to satisfy a targeted response in the animal, consistent with the animal's genetic potential and its environment (Aherne and Kirkwood, 1985). Through the various stages of pregnancy, the maintenance requirements of the sow change very little (Cole, 1990). During lactation, minimizing weight and fat loss can maximize long-term sow reproduction (Einarsson and Rojkittikhun, 1993). This makes the primary objective when feeding lactating sows to maximize feed intake. Several conditions should be maintained to help maximize lactational intake; gestation feed level must be low,

moderate environmental temperatures maintained, body fat level at farrowing controlled, and high density diets fed to lactating sows (Einarsson and Rojkittikhun, 1993).

Gestation Feeding

Feeding a low protein diet during gestation leads to a greatly reduced feed intake during lactation and consequent compromised reproduction (Cole, 1990).

In addition to controlling protein level in gestation diets, it is important to recognize that sows with high levels of body fat reserves prior to farrowing tend to have a lower voluntary feed intake during lactation (Einarsson and Rojkittikhun, 1993; Young *et al.* 1990). Therefore, animals with high body weight and back fat thickness tend to lose more body tissue during lactation than animals of leaner condition (Einarsson and Rojkittikhun, 1993). This tissue loss occurs to the greatest extent during the first week of lactation (Einarsson and Rojkittikhun, 1993). As tissue loss during lactation tends to compromise over all reproductive efficiency, the gestational feeding regimen then should ensure that sows do not become over-conditioned prior to farrowing.

Lactation Feeding

Ovarian follicular development and future reproductive performance of a sow is influenced to a large extent by her nutritional status and piglet suckling intensity (Foxcroft *et al.* 1995). In a study comparing *ad libitum* and restrict-fed gilts from farrowing to day 14 of lactation, the *ad libitum* fed gilts displayed substantial follicular development, while the restrict fed animals had essentially no follicles

over 3 mm in diameter (Foxcroft *et al*, 1995). The lack of follicular development seen in these feed restricted gilts/sows may arise from an altered LH profile and atypical plasma insulin concentrations during early lactation (Einarsson and Rojkittikhun, 1993). It is important to note that while maximal feed intake is imperative to reaching reproductive potential, sows are not physically prepared to begin ad lib feeding immediately post-farrowing. It is recommended that feeding level be increased gradually over the first 2-3 days of lactation to bring animals up to full feed intake (Einarsson and Rojkittikhun, 1993). Increasing feed allowances by small increments helps to reduce the incidence of sow constipation, agalactia, congested mammary glands, reduced appetite, or piglet scours (Aherne and Williams, 1992).

Body Condition

Minimizing body weight and body condition (degree of fat cover) fluctuations during the reproductive cycle can optimize the long-term reproduction of sows. Each phase of the reproductive cycle is influenced by the nutritional and metabolic state of the animal in the previous stage (Aherne and Kirkwood, 1985). For example, feed intake and changes in both weight and body composition during lactation influence post-weaning performance (return to estrus and ovulation rate) as well as subsequent early gestation (conception rate) performance (Aherne and Kirkwood, 1985).

The wean to estrus interval (WEI) in primiparous sows increases with increased lactational back fat loss. Sows with relatively low lactation feed intake lose large quantities of weight and backfat, and have a higher incidence of delayed

estrus (Young *et al*. 1990). Foxcroft et al, 1995, suggested that it is the primiparous sow's limited appetite that results in tissue catabolism during lactation, while multi-parous sows are better able to meet lactation demands through adequate intake (Foxcroft *et al*. 1995). Furthermore, evidence has been found suggesting there is a certain physiological threshold beyond which sows cannot begin normal cyclic activity (Einarsson and Rojkittikhun, 1993). Young *et al* (1990) found that sows fed a low level of energy (22.2 MJ DE/d) during gestation able to perform satisfactorily to the end of parity 2. Beyond parity 2, however, a large number of sows could no longer maintain satisfactory performance (removed from experiment for reproductive failure, death, lameness, <7mm backfat) ; parity 1 – 63 litters, parity 2 – 54 litters, parity 3 – 34 litters, and parity 4 – 27 litters. The medium level of energy (29.2 MJ DE/d) had the lowest attrition rate over the four parities, starting with parity 1 with 63 animals and finishing parity 4 with 48 animals. This may have been because the animals utilized their existing body reserves and increased their lactation feed intake in order to meet the demands of lactation. However, there are biological limits. A number of sows that did not complete four parities had P2 backfat measures of $\leq$ 10mm. There may be a critical level of backfat below which reproduction cannot be maintained and sow attrition rates may increase rapidly (Young *et al*. 1990).

Metabolic Influences on Sow Reproductive Performance

Possible predictors of sow reproductive performance, include: body weight, fat and protein loss during lactation; body composition at farrowing and at weaning; as well as minimum live weight of the sow at weaning (Foxcroft et al, 1995). These measures are likely to be accurate so long as they represent the metabolic state of the animal (Foxcroft *et al*, 1995). However; Foxcroft *et al* (1995) hypothesized that it is more likely the energetic or protein changes at the cellular level, which reflect metabolic status of the sow that will provide the functional link to reproductive performance. Though at present accurate measure of these indicators is not routinely done.

It has been established that changes in both energy status and protein metabolism signal the reproductive axis. Metabolic responses to available nutrients and energy fluctuate as the lean tissue deposition associated with development changes. In light of these facts, Foxcroft et al (1995) concluded that the dynamics of protein metabolism might play a central role in regulating sow fertility.

Rate of fat mobilization of sows during lactation is influenced by body weight; back fat thickness at farrowing, litter size, litter demand for milk and sow feeding during lactation (Einarsson and Rojkittikhun, 1993). It is inherent that differences may exist in energy metabolism between equally nourished sows with the same lactation milk output. This supports the idea that nutrient requirements should not be stated in fixed terms but considered in conjunction with the genetic potential and environment of the animal (Aherne and Kirkwood, 1985).

While the stage of the reproductive cycle is important in determining the level of requirement of the sow, the anabolic or catabolic status of the animal will modify the way in which these requirements are met (Cole, 1990). Animals may enter a catabolic state in late pregnancy when fetal demands are the highest, depending on energy and nutrient supply (Cole, 1990). This catabolic state may persist through the weaning to estrus period (Cole, 1990). It is the failure of an animal to revert to an anabolic state at weaning that has been implicated as a possible cause of both delayed return to estrus after weaning (Kirkwood et al, 1990) and small litter problems in the subsequent farrowing (Cole, 1990).

Nutritional Effects on the Litter

The nutritional status of the dam also influences litter size and piglets weight. Approximately 70% of all pre-weaning mortalities occur in the first 72h post-farrowing (Bishop *et al*, 1985). These deaths are most commonly attributed to energy deprivation resulting from the new born pigs limited energy reserves, the inability of newborn pigs to efficiently utilize these body reserves to remain homeostatic, and the inability of the sow to supply sufficient nutrients via colostrum (Bishop *et al*, 1985). Heavier pigs at birth have more vigor, consume more milk and have higher weaning weights (Bishop *et al*, 1985). Piglet survival, weaning weight and days to market are all significantly influenced by birth weight. Most stillborns and post-farrowing losses are the result of physiological immaturity and a

lack of stored energy in the piglet leading to an overall lack of vigor and inability to survive (Azain, 1993).

Litter Size

Litter size is one of the key measures of reproductive performance within a herd. Two determinants of the number of piglets are ovulation rate and embryo survival (Aherne and Kirkwood, 1985) Nutrition plays a role in controlling both of these factors.

Ovulation Rate

Ovulation rate can be influenced nutritionally by changing the size of the ovarian follicle pool available for recruitment. Both the nutritional and metabolic status of the sow influence ovarian sensitivity to gonadotrophins, as a way of mediating follicular development and subsequent ovulation rate (Foxcroft et al. 1995). Intermediary metabolism and related hormones affect follicular function. Nutritionally mediated differences in insulin secretion during lactation are associated with subsequent fertility. These differences in insulin secretion are involved in both direct ovarian effects and indirect central effects on luteinizing hormone (Foxcroft *et al.* 1995). Increased insulin levels can help to rescue mature follicles that are about to begin degenerating; thereby increasing the number of ovulations in the following estrus period (Hughes and Pearce, 1989). Levels of insulin may influence the release of gonadotrophin-releasing hormone (GnRH) from the hypothalamus (Cosgrove et al, 1997). Elevated insulin levels also lead to increased insulin-like growth factor 1 (IGF1) and increased growth hormone (GH).

IGF1 and GH work with insulin in creating a synergy with follicle-stimulating hormone (FSH), which results in enhanced gonadotrophin receptor development and increased steiodogenesis in the developing follicle. Hormone treatment can be used to mimic these effects. Insulin administration during lactation has been shown to have beneficial effects on the subsequent ovulation (Foxcroft *et al*, 1995). Nutrition directly influences both the seratonin and acetylcholine neurotransmitter systems, both of which are known to be involved in the regulation of gonadotrophin secretion (Booth, 1990). Increasing the feed intake of sows prior to mating (ie flushing) may lead to reduced levels of circulating steroid hormones. A decrease in the steroid hormone levels (ie progesterone) will reduce the negative feedback on the hypothalamus and pituitary and lead to increased levels of gonadotrophins being released. The increased gonadotrophin level may lead to an increased number of ova shed (Ashworth, 1994). Feeding at a high nutritional level prior to mating to increase ovulation rate is referred to as "flushing".

Embryo Survival

Plasma progesterone concentration immediately following ovulation has been shown to be positively correlated with embryo survival and inversely related to variance in embryo survival (Einarsson and Rojkittikhun, 1993). These researchers proposed that changes in plasma progesterone immediately following ovulation may be more important in determining embryo survival than are progesterone levels later in gestation. Supplementing diets with energy lead to decreased plasma progesterone concentrations and embryo survival (Einarsson and Rojkittikhun, 1993). One proposed explanation for the decreased progesterone levels seen is that increased energy causes increased hepatic blood flow, resulting

in an increased rate of clearance of the steroid hormones. Data from a study conducted by Symonds and Prime (1988) with ovariectomized, non-pregnant gilts showed that the portal blood flow and metabolic clearance rate of progesterone increased significantly when the feed intake was increased, supporting the proposed theory.

Body Composition of Piglets

Tissues and organs must form properly in-utero if a fetus is to survive outside the womb. Researchers have investigated the effects of changes in the sow's diet on piglet body composition and resulting viability at birth (Farnworth and Kramer, 1988). One area of research that has received significant attention is the supplementation of sow diets with various fats and energy sources to determine whether any changes would occur in piglet body composition: piglet survivability and its' various influencing parameters (Friend, 1974; Pettigrew, 1981; Farnworth and Kramer, 1988; Farnworth and Kramer, 1989; Azain, 1993, Fritsche *et al*, 1993).

Many studies have investigated the effects of dietary intervention during late gestation. Intervention at this point generally seems to have little effect on birth weights, overall body composition and the survival of the pigs in the first days of life (Farnworth and Kramer, 1988). It is important to note, however, that while altering sow diets does not change fetal body composition, fetal organs do contain large quantities of linoleic acid (18:2) and linolenic acid (18:3), which cannot be synthesized by the embryo. Therefore, these fatty acids must have come from the mother, demonstrating that both maternal and fetal systems contribute nutrients for internal organ development (Farnworth and Kramer, 1989).

Feeding fish oil to sows leads to the enrichment of piglets with omega-3 polyunsaturated fatty acids (PUFA). Some transfer of PUFAs occur in-utero, but most occurs through milk (Fritsche *et al.* 1993). Bishop *et al* (1985) found an increase in carcass fat content of newborns from sows receiving additional fat, compared to those receiving starch. Several other researchers found similar results. However, Friend (1974) found no increase in fat content of piglets. Fetal pigs show little change in percent of total body lipid during gestation (Farnworth and Kramer, 1988). Altering the level or type of fat in a sow's diet from as early as mid-gestation does not influence in-utero tissue development or its gross composition (Farnworth and Kramer, 1988). Increased birth weights and a reduced percentage of pigs with birth weights of 1.0 kg or less have been found when feeding low protein low lysine diets during gestation (Aherne, 1996). Despite this fact, this may not be an efficient method of improving reproductive performance, as low protein gestation diets lead to decreased lactation feed intake (Cole, 1990), thereby compromising overall reproduction.

Perinatal and Preweaning Survival

Feeding fat or increasing energy level later in gestation, though it does not alter litter size, can have positive effects on perinatal piglet survival. Piglet birth weights may increase when gestation diet energy levels are increased to a maximum of 25 MJ DE/ day; beyond this level, no significant effect was found (Aherne and Kirkwood, 1985). Supplemental fat in late gestation also increases the fat content of colostrum, which may also improve the survivability of neonatal pigs (Bishop *et al*, 1985).

Feeding fish oil to sows leads to the transfer of some PUFAs in-utero, but the piglet receives most of the PUFA enrichment through the milk (Fritsche *et al*, 1993). It was proposed that enrichment of suckling pigs with omega-3 PUFA might alter immune function and incidence of inflammatory disease.

Feeding sows medium chain triglycerides (MCT) for the last 3 weeks of gestation decreased pre-weaning mortality (Azain, 1993). This study showed that supplementing sow diets with MCT improved litter size by 1 pig at weaning and doubled the survival rate of light birth weight pigs (<900g) relative to sows fed a control diet. Azain (1993) hypothesized that in this instance it was most likely a dietary effect on the fetus, rather than an alteration in the milk composition that was responsible for the improved survival rates seen. Azain (1993) concluded this based on the decrease in overall milk lipid concentration seen, with only a slightly modified fatty acid profile in the milk from sows receiving the MCT supplemented diet, while the piglets from sows receiving the MCT supplemented diet were found to have elevated levels of blood glucose relative to the control animals. An additional consideration in dealing with light birth weight pigs is the fact that they are more likely to have poor colostrum intakes resulting in low antibody levels. This is of particular importance for segregated early weaning (SEW) and multi-site production systems, where these piglets will thus enter the nursery with low disease resistance (Aherne, 1996).

Bishop *et al* (1985) found that while dietary supplementation of sows with triamcinolone (a synthetic glucocorticoid) and soybean oil both lead to increased colostral fat levels, supplementation with triamcinolone showed a much greater

increase. He hypothesized that this may have been a result of the effect of the gluccocorticoids on fatty acid mobilization in the adipose tissue of sows, since fatty acids from adipose tissue are readily incorporated into milk fat. Triamcinolone supplemented sows also had piglets of higher weights at birth and at day 14 as compared to their control-fed counterparts.

Evidence is conflicting on the benefits of diet supplementation for sows in terms of piglet survivability for light birth weight pigs (Bishop *et al.* 1985). Pettigrew (1981) in a review of available literature reported that the addition of fat to sow diets during late gestation and lactation improved pre-weaning survival by 2.3% units.

It is unclear whether the addition of fat in late gestation increases piglet carcass fat, piglet glycogen stores, milk/colostrum fat levels, milk production, or alters piglet blood parameters (Farnworth and Kramer, 1988). Independently these changes may not bear any statistical significance, but their combined effect may result in a more viable piglet (Farnworth and Kramer, 1988).

Embryonic Mortality

Success of reproduction depends on the sequential occurrence of a series of events transpiring at the right time and in the correct place along the reproductive tract (Ulberg and Rampacek, 1974). An embryo, like all stages of young life, relies on maternal nurturing for survival. Obviously, this nurturing must occur within the confines of the uterus in the case of the blastocyst. The uterus must provide a permissive environment that is both biochemically and

endocrinologically appropriate for embryonic development. As previously discussed, nutrition of the dam can alter the uterine environment. Normal embryonic development depends on the uterine environment supplying a supportive environment appropriate for the stage of development. Both the profile of the uterine hormones and secretory proteins are critical factors determining the degree of embryonic/maternal harmony (Ulberg and Rampacek, 1974; Wilmut and Ashworth, 1985; Roberts *et al*, 1993).

In swine, the majority (30%) of embryonic mortality occurs during early gestation (< 40 days) (Pope and First, 1985). Work done thus far has indicated that embryos recovered at day 7 or earlier are generally viable and very negligible loss has occurred by this day, even when a fertilization rate of 100% is assumed (Pope and First, 1985). The focus area for embryonic mortality thus becomes the period between day 7 and day 40 of gestation.

It is known that progesterone and estrogen are integral for the establishment and maintenance of pregnancies (Wilmut and Ashworth, 1985; Archibong *et al*, 1987; Roberts *et al*, 1993). Consequently, both hormones have been studied to determine their possible role in embryonic mortality. The roles that uterine secretory proteins and genetics may play in embryonic mortality have also been investigated.

Progesterone in Early Gestation

Progesterone is the primary hormone associated with pregnancy. Generally, progesterone levels during early gestation and litter size are positively correlated. Progesterone level peaks by day 12 of gestation and gradually decreases after this

(Hafez, 1993). In comparing gilts bred at first and third estrus, Archibong *et al* (1987) found that although the first estrus bred gilts had higher embryonic mortality than third estrus bred gilts, there were no significant differences in progesterone levels at day 3 or 30 of gestation between the two groups. In light of these results, Archibong and associates (1987) suggested that the cause of increased embryonic mortality in the first estrus bred gilts is not failure of the gravid uterus to be exposed to adequate levels of progesterone. Rather, they suggested that inadequate priming of the uterus by progesterone prior to mating as a result of the low systemic levels of progesterone found in prepubertal animals might have caused the increased embryonic mortality seen in the first estrus-bred gilts. The authors suggested that the uterus may require exposure to a certain level of progesterone prior to mating, in short, a priming effect, in order to achieve low embryonic mortality rates.

Estrogen in Early Gestation

As well as progesterone, estrogen is associated with pregnancy. In pigs, the conceptus begins to secrete estrogen as it begins to elongate at day 9 or 10 of gestation. Conceptus estrogen in pigs is thought to have a luteotrophic or antiluteolytic effect. Injection of exogenous estrogen on day 9, prior to secretion of estrogen by the concepti causes the uterine environment to change (Stroband and Van der Lende, 1990). It appears likely that estrogen can regulate the secretory actions of the uterus (Morgan et al, 1987). Estrogen treatment of sows at day 9-10 lead to reduced numbers of polypeptides being secreted by the uterus (Gries et al, 1988), thus it is possible to postulate that estrogen secreted by conepti may have a

similar effect. These polypeptides may be integral in blastocyst expansion. The less developed embryos that have not expanded fully yet, may die because of a lack of these essential polypeptides (Stroband and Van der Lende, 1990).

Additionally there has been some evidence to show that estrogens are involved in the actual implantation process by stimulating the release of plasmin inhibitor from the endometrium (Stroband and Van der Lende, 1990). The further advanced embryos that are secreting more estrogen induce calcium, prostaglandin and protein sequestering within the uterus earlier than their less advanced counterparts (Pope and First, 1985). This change in uterine milieu may be fatal for the less advanced embryos. In his 1987 study, Archibong *et al* found that there was no difference in plasma estrogen levels in the first estrus versus third estrus bred gilts at day 3 of gestation, but plasma estrogen levels were significantly higher at day 30 in the gilts bred at third estrus. Whether the increased level of estrogen on day 30 in the gilts bred at third estrus was a cause or effect of the lower embryonic mortality seen in this trial has not yet been determined (Archibong *et al*, 1987). It is possible to speculate that the increased estrogen level is simply a function of the lower embryonic mortality seen, i.e. more estrogen-secreting concepti present. From these results, it is also possible to suggest that while the actual level of each of these steroid hormones may not be critical, it is the ratio of progesterone: estrogen that is important when considering embryonic survival. Archibong *et al* (1987) cautions that it is not clear whether this phenomenon is a cause or an effect of embryonic mortality.

Uterine Secretory Proteins in Early Gestation

The uterus secretes many proteins during gestation which facilitate a wide variety of processes required for successful reproduction. While many of these proteins are of blood serum origin, a significant portion of porcine uterine luminal protein is uterine synthesized (Fisher and Beier, 1986). The types of protein secreted by the uterus change throughout gestation. It is not clear whether the changes in the uterine secretions instill embryonic changes, or whether the conceptus instigates changes in the uterine environment. If there is great variation in the stage of development of a litter, then the uterine environment may be altered to suit the requirements of the more advanced embryos, leaving the less advanced embryos to perish in a "hostile" environment. Embryonic asynchrony can be caused by a prolonged ovulation interval, where the later shed ova lead to less developed embryos (Roberts et al, 1993).

Role of Genetics in Embryonic Mortality

Clearly, the above discussion reveals that the uterine milieu of hormones and other secretory products is very influential on embryonic development. There is a close association between stage of embryonic development and uterine environment. Genetics also plays a role in the rate of development of an embryo (Roberts *et al*, 1993). Embryos may be genetically programmed to develop at different rates (Roberts *et al*, 1993). Similar to prolonged ovulation periods, different rates of embryonic development lead to asynchrony within a litter and may result in slower developing embryos having limited chances of survival.

Embryo transfer work has shown that synchronous transfer (same day embryos and recipient) yields the highest number of viable embryos. Interestingly, it has been shown that embryo mortality is lower when embryos are transplanted into a uterine environment that is less advanced than themselves, relative to embryos that were transplanted into a more advanced uterine environment (Pope and First, 1985). This further supports the idea that the products of conception are influenced by the uterine environment in which they develop and that asynchrony within a litter, regardless of whether it be due to prolonged ovulation intervals, or embryos that are genetically programmed to develop at different rates leads to increased embryonic mortality.

Fatty Acids and Reproduction

With advances in research technologies, it has been possible to learn much more detail about physiological and metabolic processes. Additionally many more research projects have been done investigating multiple areas, including the influence of nutrition on reproduction. From this work, knowledge has been gained relating to the influences of specific nutrients on reproduction. One area that has begun to capture the interest of researchers is the role of specific fatty acids on reproduction.

Linoleic and linolenic acid are both precursors for the prostaglandins involved in the implantation process (Baidoo *et al*, 1993). These essential fatty acids are also involved in the formation of the central nervous system (Perez Rigau *et al*, 1995). It may be possible to improve embryo survival, as well as both

embryo and piglet viability, by enhancing either of these processes through the supplementation of these essential fatty acids.

Conclusions

This review has focused on factors affecting reproductive performance in a pork production unit. Particular emphasis was placed on illustrating the importance of the early gestation period on reproductive performance and how dam nutrition during this time seems to play a key role in determining litter size, piglet viability and sow performance in subsequent cycles.

In short, from a sow performance perspective, it is paramount that lactation feed intake be maximized in order to capitalize on the reproductive potential of the herd. As gestation feeding directly influences lactation feed intake and consequently performance during that time, it becomes a critical factor in the equation when trying to maximize herd efficiency. While it is important not to over-feed animals during gestation so that they will rely on appetite, rather than body reserves to meet the demands of lactation, it is equally important that the gestation diet adequately meets the demands of the sow and the developing litter. To this end, researchers have begun to investigate the requirements for specific nutrients throughout gestation. One area that has shown potential for improving reproductive performance is the role of essential fatty acids during early gestation.

Chapter 3

Materials and Methods

Animals

For each of 3 trials Cotswold gilts and sows were housed on straw in four groups of 14 - 16, according to parity and body weight. Animals were individually fed once a day in feed stalls adjacent to their group pen. Water was available free choice in the group pen area. All animal handling, housing and care was in compliance with the guidelines of the Canadian Council of Animal Care (1993). During gestation sows were housed under 12 hours of light, and in the farrowing barn lights were on for 8 hours except during summer when room temperatures were elevated, lights were shut off when staff were not working in the barn.

Sow Management

Heat checks were performed once daily in the morning. Gilts and sows were inseminated naturally between 8:00 – 11:00 of first day of standing estrus, then artificially about 24 hours later on the first estrus following weaning or the first estrus exhibited by new gilts during the breeding period.

Gilts and sows were formula fed according to body weight (BW) (1% BW + 0.7kg) one of the three treatment rations in mash form from day 0 to day 40. During the test period, animals were fed a barley-based commercial gestation diet in mash form. From day 40 until crate entry (d 109) test animals were

formula fed the same commercial gestation diet, but in pelleted form (see figure 1 for time line).

On d109 (+/-3 days) pregnant animals were moved to one of two farrowing barns: one with conventional farrowing crates (7'5" * 5'6.5" * 1'8.5" – sow area - 2'2"wide at bottom 1'6" wide at top) and one with a convert-a-pen system (7'10.5" * 6' * 3'3.5" – sow area width – 1'5.5" top – 2' at bottom). Assignment to farrowing barn was balanced for: gestation housing pen, treatment, parity and day of mating to eliminate any farrowing barn or room effect. A barley-based commercial lactation diet formulated to have a DE 3280 kcal, and a cp of 17% was fed from entry into the farrowing barn until weaning. Sows were fed to appetite during lactation using 0.5 kg increments to increase them to a maximum daily intake of 10 kg for younger sows and 9.0 kg for older sows (>5 parity), provided they were meeting the demands of lactation without sacrificing body condition (body condition score (BCS) <3.0).

On day of weaning sows were moved back to the gestation barn to be rebred. During the rebreeding period, sows and gilts were fed a daily allowance (approx 2 kg) of the commercial gestation diet in mash form.

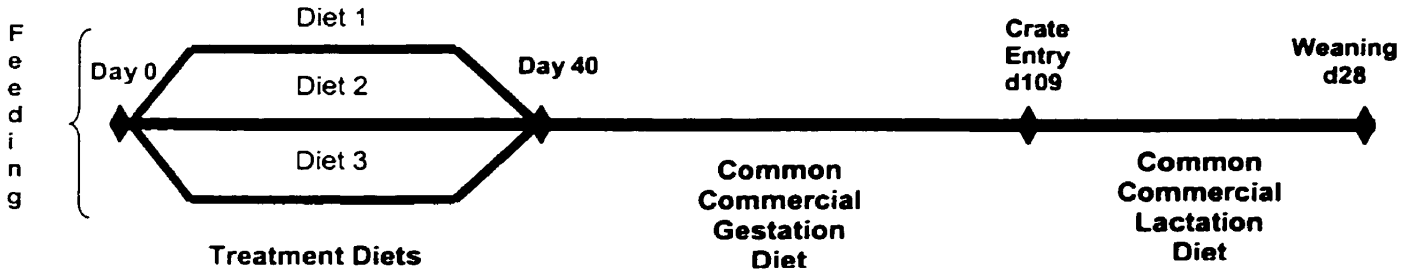

Figure 1: Schematic of feeding schedule (diet changes) including treatment period

Litter Management

Piglet weights were recorded at birth, days 3 and 14 pp and at weaning (d 28 pp). Piglet deaths, fosters and removals were recorded during the trial. Piglets had free access to water and were offered creep feed from day 14 pp to weaning. The standard operating procedures of the production unit for piglet processing and care were followed (Connor, 1993).

Diets

Sows and gilts were assigned to one of 3 treatments on day of first mating (day 0 gestation): treatment 1 (T1) – control (basal diet), treatment 2 (T2) – basal diet plus corn starch), treatment 3 (T3) (basal and flax seed oil). For each of trial animals were assigned so there was equal representation of each parity group in

each treatment group. Sows were fed an amount of basal diet according to a formula based on body weight for the first 40 days of gestation. The main ingredients of the basal gestation diets were ground barley (55%), wheat middlings (25%), canola meal (8.5%), soybean meal (6.0%), and tallow (1%). For ease of handling and accuracy reasons, the starch and oil were blended right into the basal diet at the campus mill; consequently, feed allowances for T2 and T3 were calculated so that the starch and oil were supplemental over the daily allotment of basal diet. All treatment diets were in mash form. After the treatment period, all sows were fed the straight basal diet (pelleted) according to body weight.

Following trial one, gilts and some sows were in sufficiently poor body condition that it was apparent that the formula being used for gestation feeding was not adequately meeting animals' needs. For trials 2 and 3, the formula was used to calculate the basic amount, and then BCS was used to alter that level as recommended by Patience *et al* (1995) if the animals were above or below a BCS of 3.0. The addition or reduction in the daily feeding allowance was done according to a schedule recommended by Patience et al (1995) (see appendix 2).

Table 1: Diet composition of basal gestation ration

Nutrient	Calculated level	Nutrient	Calculated level
DE	3180 (3166**)	Protein	15.0 (15.6)
Fiber %	6.75	Lysine	0.68
Fat %	4.0	Threonine	0.55
Phosphorous	0.85 (1.05)	Methionine and Cystine	0.55
Calcium	1.0 (1.08)		

(*) values from proximate analysis
(**) DE was calculated as .83 (Patience et al, 1995) of GE value analyzed in lab
Vitamins and minerals were added according to NRC (1988) requirements

Diet Mixing

The basal diet was milled commercially and delivered in mash form. Flax seed oil was analyzed for fatty acid content. Oil was added to the basal diet so as to make the total concentration of linoleic acid 2% (average 7.0% of diet). The energy concentration of T3 was calculated and starch was supplemented to T2 at a level (average 14.4%) to make it isocaloric with T3. The addition of starch or oil added approximately 530 kcal/kg of basal diet. The oil had a mean linolenic acid content of 55%, so T3 contained about 3.8% add linolenic acid. Due to the volatile nature of the flaxseed oil, T3 was mixed in small batches that lasted no more than 14 days.

Trials

For this study three repetitions of the trial were conducted. For trial 1 animals were bred in October/November of 1996, for trial 2 in March/April 1997, and for trial 3 in August/September 1997. The same core breeding group was used for all trials. Replacements were made to ensure the use of 1 pen (about 16) gilts at breeding for each trial, and culling was done in accordance with standard operating procedures of the barn. Animals were randomly assigned to treatment on day 0 of each trial.

Parity Distribution and Grouping

For this study animals were divided into 2 parity groups; sows (parity 2+ at time of breeding) and gilts (parity 1 or less at breeding). In total 111 gilts and 66 sows were used; trial 1 had 43 gilts and 18 sows, trial 2 had 39 gilts and 18

sows, and trial 3 had 30 gilts and 29 sows. Because of the natural variation in the traits being measured, for statistical analysis it was necessary to make only 2 parity groups. Grouping gilts and 1st parity sows together was done due to the extra demands both groups experience during gestation and lactation for growth (Dourmad et al., 1994). Beyond parity 2, sows growth rate slows and they seem better equipped to meet the demands of gestation and lactation.

Sow Data

Pregnancy was confirmed by ultrasound (Renco Corporation PREG-TONE model) at 30 days after mating. Bodyweight and back-fat measurements and BCS were taken at d0 (estrus), day 30, day 40, day 60, day 90, day 112 of gestation and on day 3 postpartum (pp), day 14 pp, and at weaning (day 28). Backfat measures were taken in 2 spots; 2 inches behind the last rib and 1 inch of the mid line and 2 inches ahead of the pin bones and 1 inch off the midline. The Krautkramer-Branson USK6 ultrasound probe machine was used to determine backfat depth. The front measure is most similar to the P2 measure commonly cited in other literature and will be reported in this paper. BCS were taken according to a scale of 5 points, where 1 represents poorly conditioned (very thin) animals and 5 represents over conditioned (fat) animals. BCS is done by looking at the animal and feeling the degree of fat cover of the hips and backbone (Patience *et al.* 1995). A detailed description of the body scores is shown in Appendix 1.

Blood Sampling

Sows were single sampled via jugular venipuncture on days 0, 30, 40, 60, and 90 of gestation, and days 3, and 14 of lactation and at weaning. Animals were restrained using a wire nose snare, and samples were collected using a 20-gauge 1.5 inch single sample needle and a 10 ml vacutainer tube for serum collection (Vacutainer, Becton Dickinson and Company, Franklin Lakes, NJ). Samples were cooled at 4°C until the next day. Sera were obtained by centrifugation (CR3000, Jouran Inc., Winchester VA) at 2500 rpm for 30 minutes. Sera were decanted and stored at -20°C until assayed for progesterone, and estradiol content. Progesterone and estradiol assays were run on all samples. Some preliminary fatty acid analysis on the serum was done, but the results were not considered to be meaningful or reliable, so were discarded.

Progesterone

Serum progesterone (P_4) was assayed using a commercial kit (Coat-A-Count, Diagnostics Products Corporation, Los Angelels, CA, USA) for solid-phase radioimmunoassay (RIA). The standard curve range was 0.1 to 40 ng ml^{-1}. The method required that 100 µl of standard or serum be aliquoted into anti-P_4 coated tubes, followed by the addition of tracer (^{125}I-labelled progesterone) (1 ml). Following an incubation period of 1 hour in a water bath at 37° C, tubes were decanted to isolate the antibody-bound P_4. A gamma counter (LKB Wallac 1282 CompuGamma Universal Gamma Counter) was used to read the radioactivity in tubes.

Estradiol

Serum estradiol (E_2) was analyzed using a commercial RIA kit (DSL-4800 Ultra Sensitive. Diagnostics Systems Laboratories Inc., Webster, Texas, USA). The procedure required that 200 µl of the standard or serum be pipetted into test tubes (12X75 mm) followed by 100 µl of the estradiol antiserum. All tubes were then vortexed, covered and incubated at room temperature for 1 hour. After incubation 100 µl of the tracer (Estradiol (I-125) Reagent) was added and the tubes were vortexed again and covered to incubate for 2 hours at room temperature. Following this incubation, the 1 ml of the precipitating reagent was added and tubes were vortexed and allowed to sit at room temperature for 15-20 minutes. All tubes were then centrifuged for 15-20 minutes at 1500 X g and decanted. Radioactivity levels were read in a gamma counter (LKB Wallac 1282 CompuGamma Universal Gamma Counter).

Statistical Analysis

These trials were similar in terms of animal management, parity grouping, and dietary treatments that were applied. The basic experimental design was considered to be a randomized complete block design with trials as block effects. Within each block there was a 3*2 factorial arrangement of dietary treatment and parity effects. Data was analyzed using the General Linear Model of the Statistical Analysis System (1986).

The statistical model used to analyze variables measured once on each animal (WEI and litter data) was:

$y_{ijk} = \mu + b_i + t_j + p_k + btp_{ijk} + s_{l(ijk)}$ with y_{ijk} an observation on WEI or litter characters

b_i = block or trial effects (three trials)

t_j = dietary treatment (three treatments)

p_k = parity group (two parity groups)

tp_{jk} = treatment*parity interactions

btp_{ijk} = block*treatment*parity interactions, used as the error effect for testing the factors above

$s_{l(ijk)}$ = effect of the l^{th} sow in the i^{th} block, j^{th} treatment and k^{th} parity

In the model shown above, blocks, block*treatment*parity interactions and sow effects were considered as random effects. Standard errors of treatment, parity and their interactions used the mean square for btp_{ijk}. The trials were repeated at different times, which lends confidence as to the repeatability of the treatment effects. For analysis of variables measured repeatedly on the animals (weight, backfat, BCS, and blood parameters) the basic design and model used above was expanded as a split-plot (or repeated measures) design with time period as the factor to represent repetition. The model was:

$y_{ijklm} = \mu + b_i + t_j + p_k + btp_{ijk} + s_{l(ijk)} + d_m + td_{jm} + pd_{km} + tpd_{jkm} + e_{ijklm}$:

where y_{ijklm} is an observation on weight, backfat, BCS, or a blood parameter on the l^{th} sow in the k^{th} parity j^{th} treatment, i^{th} trial measured on the i^{th} day.

b, t, p_k, btp_{jk}, btp_{ijk}, $s_{l(k)}$ are as described above

d_m is the effect of time on the m^{th} day of measurement

td, pd_{km}, tpd_{jkm} are interaction of treatment and parity with day

e_{ijklm} is the sub-plot error term representing sow variability across days

In this model, block, block*treatment*parity, sow effect and sub-plot error terms were considered random. For testing main plot effects (block, treatment, parity and treatment*parity interaction), the block*treatment*parity interaction term was used. Sub-plot effects (day and interactions with day) were tested against the sub-plot error term.

Chapter 4

Results

Body Weights

Body weights were not affected by the supplementation of oil or starch during the early part of gestation. Figure 2 shows the difference in body weight response by parity group over time ($p<0.01$). Body weights increased significantly through out gestation except between days 30 and 40 for both the sows and gilts and between day 109 and 113 for sows only. While there was no significant weight loss from day 3 to 14 of lactation for either group, both groups did show a significant decrease in body weight by weaning (d 28). There was a three-way interaction of treatment*group*trial, but investigation of the interaction means did not reveal a meaningful pattern. This interaction may simply have been an artifact of the unequal parity distribution from trial to trial.

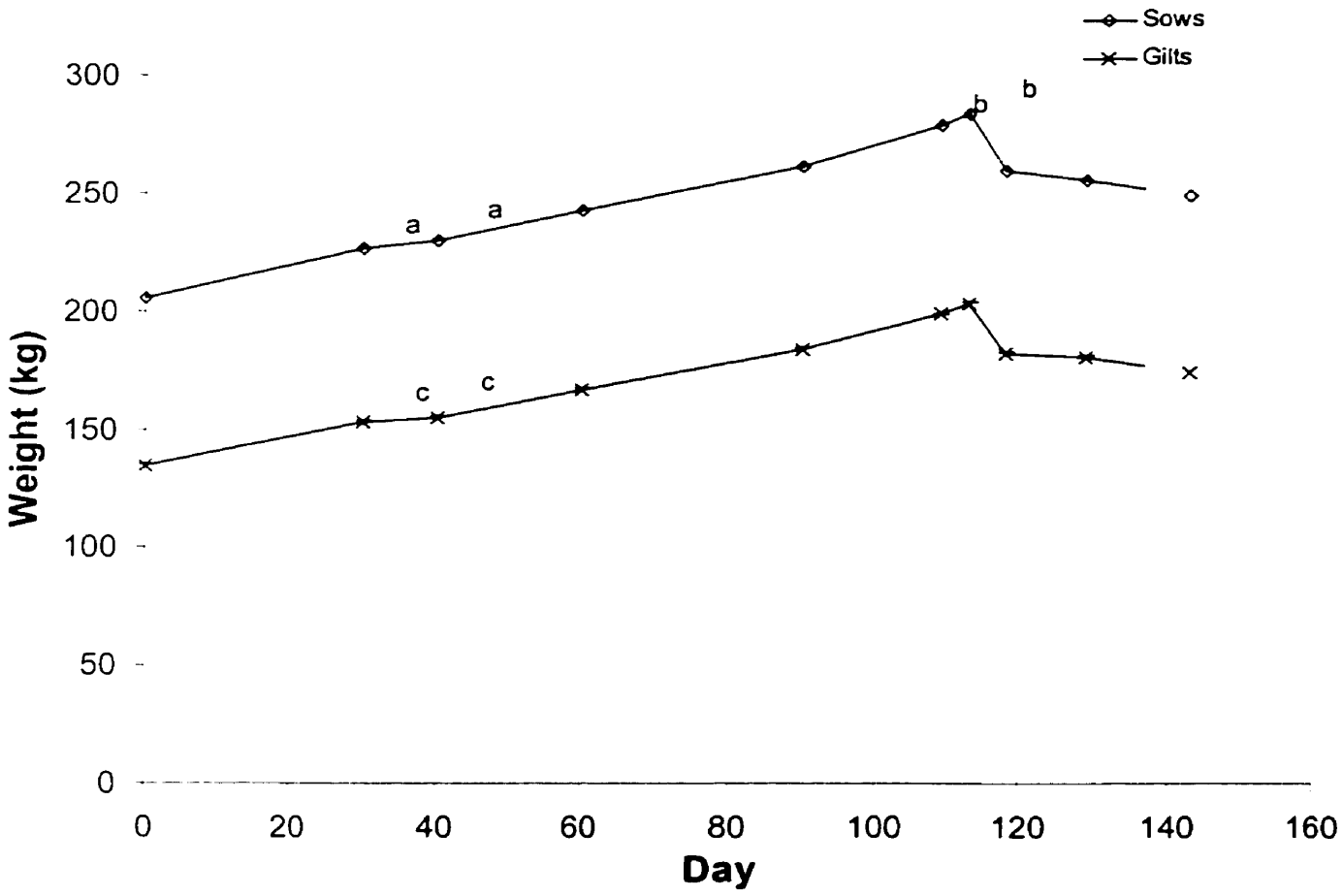

Figure 2: Mean body weight for sows (parity ≥ 2) and gilts (parity < 2) for all trials.
a a – represent values that are not significantly different from one another
Range of SEM Gilts – 0.726 – 0.811 Sows – 0.968 – 1.216

Back fat

Sows fed either supplemental energy source (T2 and T3) during early gestation had higher back fat measures during gestation and lactation than their control fed counterparts (T1) ($p<0.01$). Figure 3 demonstrates the effect of treatment over time for all sows and gilts. The Bonferroni test performed could not distinguish specific differences. As shown in figure 4, the response of parity groups differed over time ($p<0.01$). Initial front back fat measurements differed by less than 1mm for the front probe: (11.86 $\pm$ 0.12 for gilts vs. 12.71 $\pm$ 0.164 sows) between parity groups. Although a similar pattern of backfat changes occurred, sows deposited more backfat. By day 113 the sows had higher back fat than the gilts (18.03 $\pm$ 0.19 vs. 15.18 $\pm$ 0.13 for sows and gilts respectively). Backfat losses were simlar throughout lactation so that sows at weaning had a n average of 14.94 $\pm$ 0.21 mm of back fat while gilts had only 11.42 $\pm$ 0.14 mm of back fat. Mean back fat measures also differed by trial as shown in table 2.

Table 2: Mean front backfat for each trial

Trial	Back fat (mm)	Comparison of Mean Values
1	15.36 $\pm$ 0.209	a
2	14.34 $\pm$ 0.237	b
3	14.80 $\pm$ 0.283	ab

All values are LS means $\pm$ SEM
a,b - means with different characters are significantly different

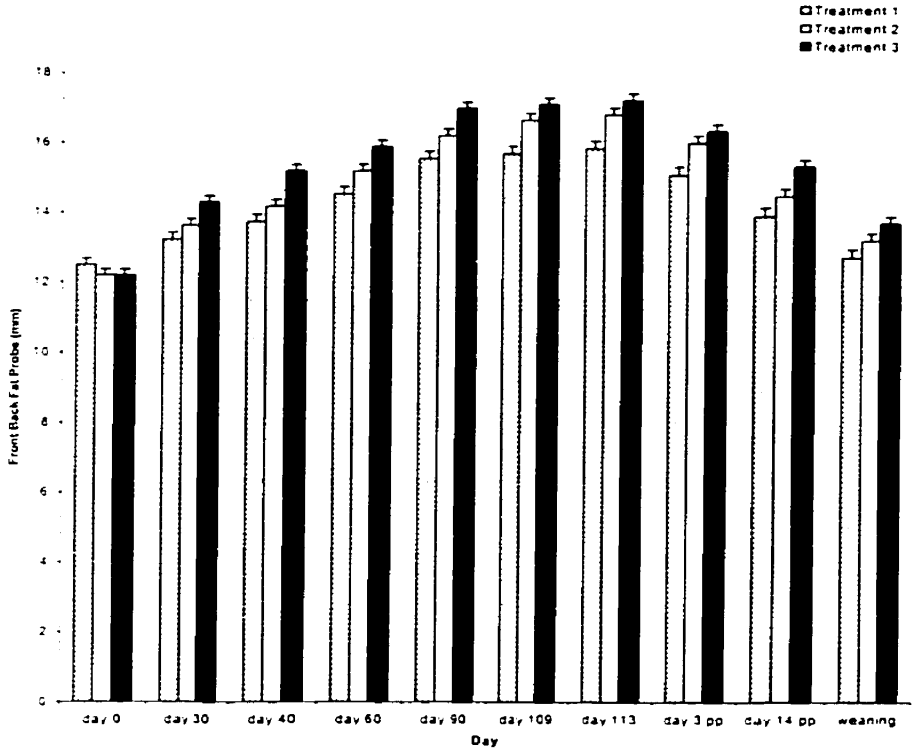

Figure 3. Front back fat probes for each treatment throughout gestation and lactation for all trials (LS Mean ± SEM).

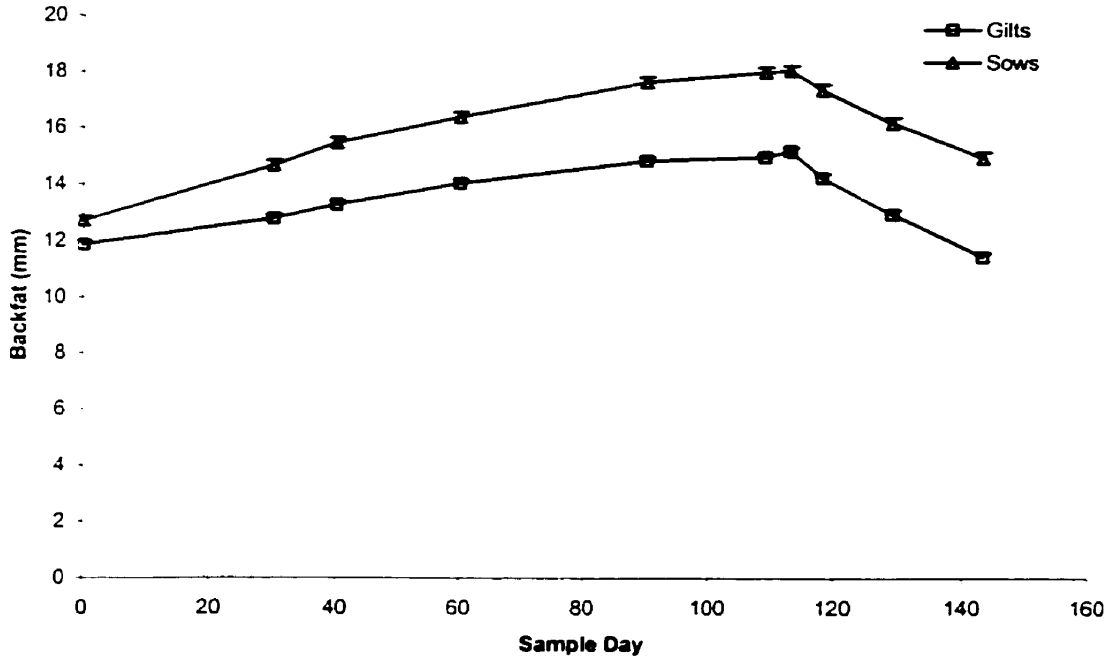

Figure 4: Front backfat (mm) (measured 5 cm behind the last rib) for each parity group on each sample day (LS Means ± SEM)
Range of SEM: Gilts – 0.124 – 0.140 Sows – 0.164 – 0.206

Body Condition Scores

Supplementation of the early gestation diet with flaxseed oil or starch had no significant effect on body condition scores (BCS). However, BCS for all treatments did change significantly over time ($P \leq 0.01$). BCS increased from day 0 (2.96) to day 30 (3.03) of gestation; remained similar on day 30 through 60; increased ($p<0.01$) by day 90 (3.19); then remained similar until day 3pp. The BCS then decreased significantly during lactation to reach scores similar to those of early to mid gestation by day 14 pp. before declining further ($p<0.01$) by weaning (2.86) at 28 days. There was a significant interaction of parity group with day ($p<0.01$). As shown in figure 5, the sows that were parity 2 or higher had similar BCS to gilts at day 0, but increased to a higher maximum BCS ($p<0.01$) and had a higher BCS at weaning (day 28) than the gilts. BCS was also influenced by trial ($p<0.01$), as shown in table 3.

Table 3: Comparison of mean BCS for all animals for each trial ($p<0.05$)

Trial	Mean BCS	Comparison of Mean Values
1	3.22 ± 0.012	a
2	2.97 ± 0.014	b
3	3.04 ± 0.017	c

All values are LS mean ± SEM
a,b,c indicate values that are significantly different
See Appendix 1 for BCS scale

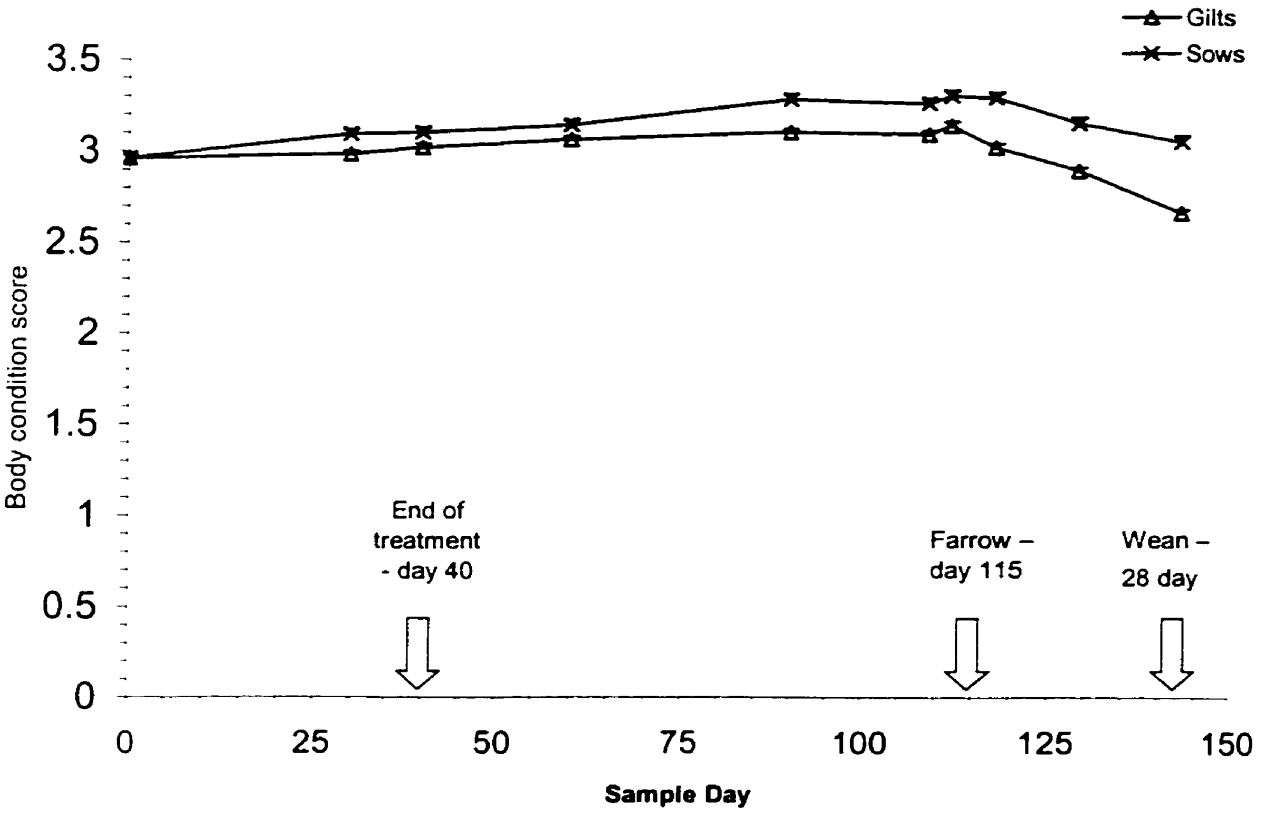

Figure 5: Body condition score on each sample day for sows (parity ≥ 2) and gilts (parity < 2) for all trials (LS Means ± SEM). Range of SEM: for gilts (0.017 – 0.019) and for sows (0.023 – 0.029). Average gestation was 115.3 ± 0.2 days for gilts; 115.1±0.2 days for sows

Progesterone Data

Treatment had no significant effect on progesterone level ($p>0.05$). However, there was a significant interaction of treatment with day ($p<0.05$). Figure 6 illustrates how the response to day differed with treatment. The progesterone levels were similar across treatments throughout gestation; rising dramatically from day 0 to day 30 and remaining elevated for the duration of gestation. At day 14 pp there was no detectable progesterone for any of the treatment groups. However, supplemental energy (T2 and T3) resulted in higher progesterone levels at weaning than for sows with no supplemental energy (T1). Table 4 shows the difference in progesterone levels by trial ($p<0.05$).

Table 4: P4 Concentration for each trial

Trial	P4 Concentration (ng/ml)	Comparison of Mean Values $p<0.05$
1	12.95 ± 0.567	a
2	12.01 ± 0.483	a
3	10.30 ± 0.466	b

All values are LS mean ± SEM

a,b represent values that are significantly different ($p<0.05$)

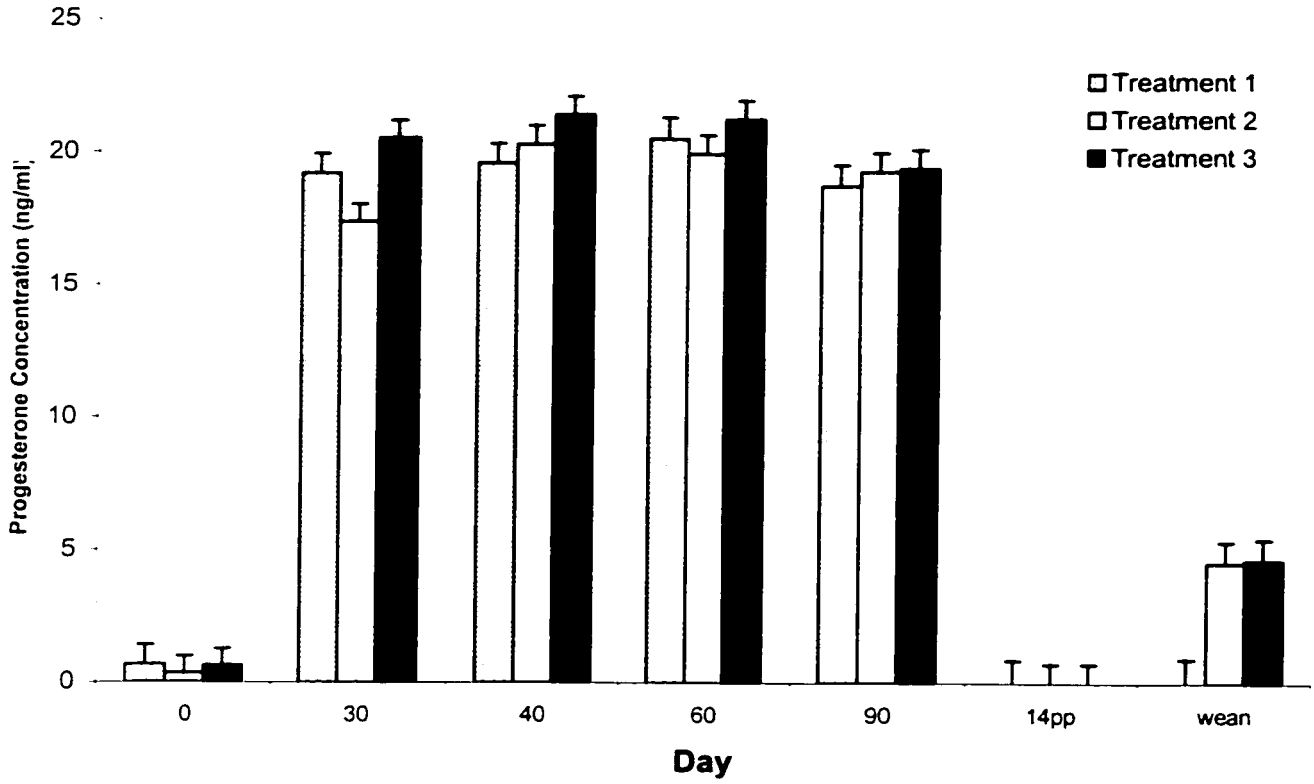

Figure 6: Progesterone concentrations on each sample day by treatment for all trials (LS Means + SEM)

Estrogen

Estrogen concentrations were similar across treatments ($p>0.05$). Estrogen levels did differ between the parity groups ($p<0.05$), with the gilts having a mean estrogen concentration of 29.31 $\pm$ 0.87 pg/mL compared to that of the sows with a mean concentration of 25.52 $\pm$ 1.47 pg/mL. The response of group differed over time ($p<0.01$) as shown in figure 7. Estrogen levels tended to be low at breeding (6.93 $\pm$ 2.07 pg/mL for gilts and 9.84 $\pm$ 3.12 for sows pg/mL), increased by day 30 (23.62 + 2.14 and 18.33 + 3.25 pg/mL for gilts and sows respectively), and dropped back to levels similar to those found at breeding until day 90 when maximum levels of 149.17 +2.25 pg/ml for gilts and 122.01 + 3.72 pg/ml for sows were detected. During lactation (day 14pp and at weaning) estrogen levels returned to levels similar to those found at breeding.

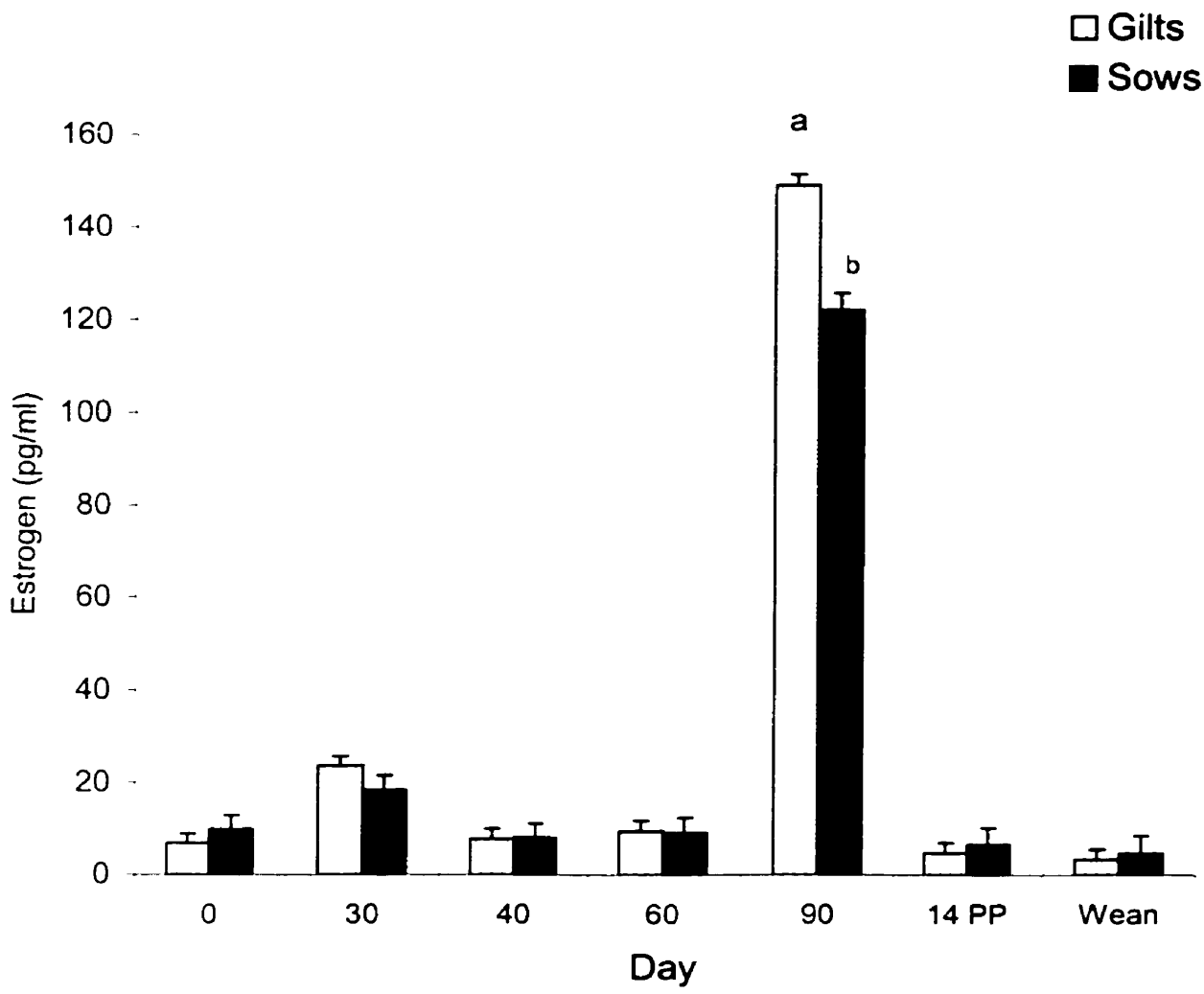

Figure 7: Estrogen concentration for each parity group throughout trial (LS Means + SEM)
a,b – represent values that differ for that sample day ($p<0.05$)

Wean to Estrus Interval (WEI)

There was no difference ($p>0.05$) in WEI between trials (Table 5) or treatments (Table 6).

Table 5: Wean to Estrus Interval (days) for each trial.

Trial	WEI (days)		
1	6.8	±	0.89
2	4.5	±	1.05
3	5.4	±	1.17

All values are LS mean ± SEM

Table 6: Wean to Estrus Interval (days) for each treatment.

Trt	WEI (days)		
1	4.7	±	1.05
2	6.2	±	1.05
3	5.8	±	1.02

All values are LS mean ± SEM

Similarly, WEIs were not different between sows (5.04 ± 1.13 days) and the gilts (6.11 ± 0.43 days) ($p>0.05$).

Conception and Farrowing Rates

For this study, a total of 177 animals were bred. The day 30 pregnancy rate was 92.6% (13 open). The average farrowing rate for this study was 89.3% (158 litters from 177 breedings). Not all of the litters produced were included in the data analysis because some had pigs removed early for use in other trials being conducted.

Piglet Data

Supplemental energy fed to sows/gilts during early gestation did not influence mean litter size or mean pig weights for any of the sample days in the trial (birth, d3pp, d14pp and weaning (d28)) ($p>0.05$). Litter size at birth varied with trial ($p<0.05$). Trial 1 had more (12.27 + 0.343) pigs than either trial 2 (10.66 + 0.300) or trial 3 (10.94 + 0.298). Mean pig numbers on each of the sample days was also influenced by trial. Litter sizes were consistently larger in trial 1 than trial 3 while litter size in trial 2 was intermediate. Parity also influenced litters sizes at birth, day 3, day 3 adjusted ($p<0.01$), and at day 14 pp ($p<0.05$), with sows having larger litters than gilts. The day 3 adjusted number of piglets was calculated as (n born alive – n fostered in + n fostered out). This number was considered to represent piglet viability. Mean birth weight was also influenced by trial ($p<0.05$). Trial 1 had lighter birth weight pigs (1.45 + 0.051 kg) than trial 2 (1.65 + 0.045 kg), while trial 3 had a mean birth weight (1.48 + 0.044 kg), which was similar to both trial 1 and trial 2. Mean pig weights differed

with trial on each of the sample days, though there was no consistent pattern of variation from one sample day to the next. The mean number of deaths within the first 72-h post-farrowing also differed by trial ($p<0.05$). Trials 1 and 3 had similar mean deaths (1.06 + 0.19 and 1.13 + 0.16 respectively), while trial 2 had fewer deaths than both trial 1 and 3 (0.29 + 0.17). For detailed trial and parity differences please refer to Appendices 3 and 4. Tables 7 and 8 show the litter data by group for each treatment. Table 7 is reflective of the gestation performance of the dam. Table 8, which focuses on the day 3 PP to weaning data, can be considered representative of lactation performance of the dams.

Table 7: Average litter size and pig weight at birth and number of pigs surviving to day 3*

		Born Alive			Day 3 Adjusted**	
Treatment	Group	N	# of pigs/litter	pig wt (kg)	N	# of pigs/litter
1	Gilts	35	10.1±0.4	1.51 ±0.05	35	9.5±0.3
1	Sows	14	12.6±0.6	1.51±0.08	13	11.6±0.6
2	Gilts	32	10.7±0.4	1.54±0.06	32	10.2±0.4
2	Sows	18	11.4±0.5	1.62±0.07	18	10.7±0.5
3	Gilts	33	10.9±0.4	1.51±0.05	33	9.7±0.4
3	Sows	19	12.3±0.5	1.48±0.07	19	11.2±0.5

*LS Mean value for mean values ± SEM
** - Day 3 adjusted = # born alive – fosters in +fosters out (i.e. -- piglet viability by birth dam)

Table 8: Litter data during lactation

		Day 4			Day 14			Weaning (day 28)		
Treatment	Group	N	# of pigs/litter	pig wt (kg)	N	# of pigs/litter	pig wt (kg)	N	# of pigs/litter	pig wt (kg)
1	Gilts	35	10.0±0.2	2.03±0.05	35	9.8±0.2	4.9±0.11	35	9.7±0.3	8.79±0.23
1	Sows	13	11.0±0.4	1.84±0.09	13	10.3±0.4	4.70±0.19	13	10.2±0.5	8.72±0.39
2	Gilts	32	10.1±0.2	1.93±0.05	32	9.9±0.2	4.95±0.12	32	9.9±0.3	9.08±0.24
2	Sows	18	11.0±0.3	2.07±0.08	18	10.8±0.3	4.98±0.17	18	10.1±0.4	8.36±0.33
3	Gilts	33	9.9±0.2	1.97±0.05	33	9.6±0.2	4.94±0.12	33	9.6±0.3	8.87±0.24
3	Sows	19	10.5±0.3	1.95±0.08	19	9.9±0.3	4.92±0.16	19	9.8±0.4	8.66±0.32

All values are LS Means ± the SEM

Values represent mean number of pigs nursing the sow on the sample day

Chapter 5

Discussion

There have been a number of reports dealing with nutrition during mid-gestation, late gestation, the combination of those phases, or the entire gestation period (Hoppe et al. 1990; Coffey et al. 1987; Young et al. 1990) focusing on the lactation performance of the sows and the piglets. The early gestation period alone, however, has not received much research focus. The events of early gestation are crucial for ensuring reproductive success. After the ova are shed, fertilization must occur and viable embryos must develop and implant successfully in the uterus, if pregnancy is to be established and maintained (Ulberg and Rampacek, 1974). There are many factors that can influence the success of these processes, including the nutrition of the dam during this key time of the pregnancy. The critical role that essential fatty acids, particularly linoleic and linolenic acid, may play in maximizing performance in terms of litter size, piglet viability and the success of the subsequent mating period warrants further investigation (Perez Rigau et al. 1995; Baidoo et al. 1993). Linoleic and linolenic acids are precursors for the F-prostaglandins involved in implantation, and may play a key role in reproductive success (Fengler et al. 1990). This study was designed to see if supplementation of sow diets with essential fatty acids during the first trimester of gestation could improve litter size and viability or sow performance.

The results from this study did not indicate that there was any influence of essential fatty acids on body weight, BCS, WEI, or estrogen levels. Similarly,

treatment did not affect litter size at birth, piglet birth weights, early piglet survival or litter size at weaning. The interaction of treatment with day did affect backfat; while detection of specific differences was not possible, it would seem that sows both T2 and T3 tended to gain more backfat over T1 during gestation, and maintained this difference through to weaning. Similarly there was a treatment by day interaction for progesterone concentration in this study. Again, the specific difference were unable to be detected, but the largest differences seems to occur at weaning, when both T2 and T3 have a higher mean concentration of P_4 relative to T1. This could be indicating earlier jollicular development and ovulation in these sows. While no affect of EFAs on sow performance or litter size was found, it did seem that supplemental energy during early gestation could potentially have some benefit in terms of sow performance and litter traits.

Body weights were not affected by supplemental energy offered during the first 40 days of gestation. As the energy gain during the first third of pregnancy is normally low, increasing in the latter portion of gestation as the demands of the developing litter increase (Noblet et al, 1997), this is not a surprising result. The oil supplement provided approximately 530 kcal kg^{-1} of energy.

Supplemental energy, whether in the form of starch or flaxseed oil, did increase back fat levels in the treatment animals. As with body weight both parity groups followed similar patterns of change for back fat; with the older, more mature animals achieving higher maximum fat depths and maintaining a higher degree of fat cover through to the end of lactation. Previous studies have shown that the modern gilts and first parity sow represent a special case for optimizing

reproduction. The modern gilt, selected for leanness, rapid growth, increased milk production and earlier onset of puberty often has a reduced appetite (Aherne and Williams, 1992). These young fast growing animals also tend to have insufficient body reserves with which to meet the increased demands of modern production (Rozeboom et al. 1996). Foxcroft et al (1995) presented unpublished data suggesting that the primiparous animal may not have an adequate appetite to effectively meet the metabolic demands of lactation and therefore, generally become catabolic during lactation. This theory may explain the difference seen in this trial between sows and gilts in terms of lactation back fat loss. Cole (1990) suggested that one of the reasons to focus on feeding to BCS was the priority of tissue deposition that occurs naturally. In short, it is the inherent nature of an animal to preserve both the individual and the species, thus meeting the needs of the dam's brain and CNS and the demands of the developing litter are of key importance. To this end, fat has low priority in terms of tissue deposition. Correspondingly, feed restriction during early gestation must be severe in order to decrease embryo survival, because the embryo is given such high priority in nutrient supply (Aherne and Williams, 1992). This theory also supports our findings that the animals receiving supplemental energy tend to have increased backfat levels relative to their control fed counter parts, ie the energy in T1 was put into litter development with less spared for fat deposition than in the higher energy treatments. Additionally, this would support the idea that younger growing animals would tend to lose more fat than the older fully-grown animals during the high demand period of lactation. The gilts went from a maximum back fat measure of

15.19 mm at 3 days pre-farrowing to 11.45 mm at weaning, while the sows went from a maximum measure of 18.03 mm on day 113 of gestation to 14.94 mm at weaning.

Body condition score increased throughout gestation and decreased throughout lactation. Similar to back fat, BCS increased more in the higher parity animals during gestation and decreased to a lesser extent during lactation than it did for gilts and primiparous animals. Again, this would be the expected pattern of change, considering the physiological changes the animals are undergoing during gestation and lactation. Similarly, if the gilts entered lactation with lower back fat than their older counterparts, and were weaned with considerably lower back fat, it is logical that BCS would follow a similar pattern, as BCS is a subjective measure of backfat levels. A trial difference was also detected, with trial 1 having the highest mean BCS, trial 2 having the lowest BCS, and trial 3 having an intermediary value. It is possible to speculate that these differences may be partially accounted for by the deviation that was made in the feeding protocol following the first trial. The animals were formula fed during the first gestation period; some of these animals had BCS that were too low (>2.75) at the end of the lactation period. This occurred more commonly with the gilts and primiparous animals. This problem, did mean some of the animals started trial 2 with a lower BCS than for trial 1, and were left trying to regain that fat cover, grow, and meet the demands of the developing litter simultaneously. It is unlikely that these animals were able to meet all these demands to the same degree the initial batch of animals were, so it is reasonable to speculate that some residual effects from this initial difficulty would still be seen in

the third trial. This fact is a likely cause for the lower BCS seen in trial 2, and the intermediate mean BCS seen in trial 3.

Progesterone values were not influenced by treatment in this study. The effect of treatment was influenced by day. While the specific differences could not be detected, it appears as if the major treatment*day effect occurs at weaning when T1 had essentially no detectable P4 while T2 and T3 have a mean P4 of approximately 4 ng/mL. Further examination of the data showed that in T1, 5 (10%) of the sampled animals had P4 values over 1 ng/mL at weaning, while in T2 and T3 there were 14 (31%) and 11 (26.8%) animals respectively with P4 concentrations >1 ng/mL. These values would suggest that perhaps these animals had come into heat in the crates and were in fact in the mid-luteal phase of the estrous cycle. Of the T1 animals displaying an elevated P4 value, 4 had WEI recorded, and the average WEI for these 4 animals was 11.3 days. For T2, 8 of the animals had WEI recorded and the mean WEI was 12.6 days, while for T3 there were 6 with a recorded WEI, and the mean WEI was 14.5 days. The other animals with elevated P4 levels did not have a WEI recorded, because they were removed from the breeding group. These average values for the WEI suggest that in fact these animals were in mid-cycle and must have cycled while in the farrowing crates. It is possible to speculate that animals on T2 and T3 would be better prepared to cycle quickly (< 7 days after weaning) if weaning were to occur earlier (ie. 18 – 21 d).

The wean to estrus intervals in this trial were not significantly influenced by treatment. The wean to first service estrus interval cited in the herd summary published by the Prairie Swine Center as 6.0 days for the upper 25% of

farms, which is similar to the WEIs found for each of the trials (6.83 ± 0.89, 4.52 ± 1.05, and 5.37 ± 1.17 days).

While there was no direct link between EFA supplementation and the parameters measured, when all the parameters are considered together, there were some interesting results. Increased energy intake during early gestation should lead to increased back fat and BCS values at farrowing, which in theory should lead to decreased lactation feed intake. Appetite or intake suppression during lactation leads to a higher degree of tissue catabolism, which in turn has been shown to cause an increase in the WEI and a reduction in subsequent litter size (Aherne and Williams, 1992). In this trial, there was no evidence that the increased energy caused any adverse affects on the time it took for the animals to return to estrus.

Additionally, these animals were fed according to an industry-accepted formula. The formula did not adequately meet the needs of the animals in trial 1 and was amended for very thin (BCS < 2.75; especially prevalent in the younger animals) and fat (BCS > 3.75; seen mostly in mature animals). This is an interesting observation. It is interesting to note that these animals were group housed. The group housing allowed for free movement, and in fact required movement as these animals had to walk for water and to the feeding stalls. The extra movement and freedom takes energy, which of course means that these animals have increased energy requirements. Western Canadian pork production systems mainly employ a stall-based gestation housing system. Animals housed in stalls thus have lower energy requirements relative to loose-housed sows. Much of

the research available at this time is based on data collected from facilities using gestation stalls. This is one variation that perhaps should have been accounted for in the methodology. Noblet (1997) suggested that because physical activity can vary greatly between housing systems and between sows (activity, including stereotypy behavior) variability in energy requirements between herds and/or sows will occur. Having said that, it is still interesting to speculate further about formula feeding. One of the major problems facing the pork production industry is the poor performance of primiparous animals and the poor longevity of many of the breeding animals (Rozeboom *et al.* 1996; Caroll *et al.* 1996). Indicators like backfat or BCS for animals may serve as practical tools for evaluating the effectiveness of the feeding regime on an individual animal basis. One could speculate that in fact the modern feed restrictions placed on young animals during gestation are hindering long-term productivity.

Supplemental energy fed to sows during early gestation did not alter litter size at birth, day 3 pp, day 14pp or at weaning. Many studies have shown that increased energy during early gestation results in increased embryonic mortality (Einarsson and Rojkittikhun, 1993; Jindal et al., 1996, and Jindal et al., 1997). Any effect that supplemental energy may have had on embryo survival in this study did not manifest itself as a difference in litter size. Therefore, supplemental energy in early gestation may not negatively impact litter size. There were trial differences in litter size at birth. Two influencing factors may have played a role in these differences, the first and most obvious is the difference in parity distribution amongst the trials. Generally, gilts and early parity sows tend to have smaller

litters, than mature animals (≥ parity 3; Douramd et al, 1994). The reduction in performance, in terms of litter size at birth, seen among trials may also have been in part due to the low body condition of sows exiting the crates from trial 1, which as previously discussed has been linked with reduced subsequent litter sizes. A breeding herd summary from the PigChamp program of 282 Canadian farm had the upper 25% of farms having an average of 10.7 pigs born alive (Prairie Swine Center, 2000) to which the current results compare favorably (12.27 ± 0.3, 10.86 ± 0.3; and 10.94 ± 0.3). The number weaned for each of the 3 trials (10.61 ± 0.27, 9.74 ± 024, and 9.38 ± 0.24 respectively) was comparable to the upper 35% of the summary herds, even though the average weaning for those herds was 17.7 days (Prairie Swine Center, 2000). With the high levels of production seen in this trial any benefit in terms of litter numbers and size, may have been unnoticeable. It is possible to speculate in a herd with average, or below average production that the benefits of essential fatty acid supplementation may be more visible.

Sow body weight and BCS were not affected by supplemental energy in this study. Supplemental energy during early gestation did, however, lead to increased backfat reserves during lactation and gestation. Estrogen and progesterone levels were not affected by treatment; however, there was a treatment*day interaction for progesterone. The most obvious difference here being that at weaning the animals that received the supplemental energy had higher progesterone concentrations. When the WEI for the animals with elevate P4 values were investigated, it would seem likely that these animals had perhaps cycled in the crates and were in the mid-luteal phase of their cycle at time of weaning. No effect of supplemental

energy on the WEI was found during this study. Additionally, supplementing the early gestation diet with energy, regardless of source (corn starch or flax seed oil) did not affect litter size or piglet viability. At the level of supplementation used in this study, it would seem that there is no benefit in terms of reproduction, litter size, piglet viability, and sow WEI.

Chapter 6

Conclusions

During pregnancy feed supply must be adapted to the specific requirements of pregnancy so that body reserves can be replenished for growth so physical maturity can be met. Such a strategy would minimize changes in body reserves and limit reproductive problems. Deficiencies in nutrition may explain most of the differences between potential and actual performance of sows (Noblet et al, 1997). Supplementing the early gestation diet with flax seed oil to bring the linoleic acid content of the diet to 2% showed no reproductive improvements, but did seem to increase backfat reserves, as did supplementation with corn starch (an energy source with no essential fatty acids). Perhaps supplementation at a higher level would demonstrate a difference in reproductive traits like number of live born pigs, piglet viability and WEI for sows. While there were no differences found in BCS for the energy supplemented animals, relative to their control fed counterparts, it is interesting to note that BCS and backfat followed very similar patterns over time. This would seem to indicate that within a herd, BCS may serve as a useful tool for assessing gestation feeding regimens.

Further investigation is required to establish the linoleic and linolenic acid requirement of the gestating sows.

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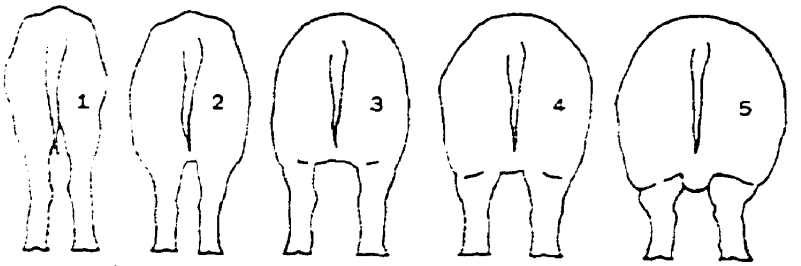
Appendix 1

FIGURE 8: THE FIVE CONDITION SCORE RATINGS FOR SOWS IN MID-LACTATION



Poor or emaciated—hips and backbone prominent—score=1.
Moderate thin—hips & backbone easily felt without palm pressure—score=2.
Ideal—hips & backbone only felt with firm palm pressure—score=3.
Over conditioned—hips and backbone cannot be felt—score=4.
Fat or obese—hips and backbone heavily covered—score=5.

Vido,1996

Pictures taken from Elanco Animal Health

Appendix 2

Table A2.1: Changes in daily feed allotment for gestating sows to account for BCS (used for trials 2 and 3 only)

Condition Score	Change in feed (kg)
1.0	+0.6
1.5	+0.4
2.0	+0.3
2.5	+0.2
3.0	0.0
3.5	-0.2
4.0	-0.3
4.5	-0.4
5.0	-0.6

Patience *et al*,1995

Appendix 3

Table A3.1: Comparison of number born alive for each trial (p<0.05)

Trial	Born Alive			Comparisons
1	12.27	±	0.343	a
2	10.86	±	0.300	b
3	10.94	±	0.298	b

*All values are LS Means ± SEM

a,b represent values that are significantly different

Table A3.2: Comparison of piglet birth weight for each trial (p<0.05)

Trial	Piglet birth weight			Comparisons
1	1.45	±	0.051	a
2	1.65	±	0.045	b
3	1.48	±	0.044	ab

*All values are LS Means ± SEM

a,b represent values that are significantly different

Table A3.3: Comparison of adjusted** number of pigs on day 3 (p<0.05)

Trial	Day 3 Adjusted			Comparisons
1	11.21	±	0.342	a
2	10.47	±	0.305	ab
3	9.81	±	0.298	b

*All values are LS Means ± SEM

**Adjusted number represents the number of birth pigs alive on day 3 (represents piglet viability by birth dam)

Day 3 Adjusted = # born alive – fosters in + fosters out

a,b represent values that are significantly different

Table A3.4: Comparison of number of deaths by day 3 ($p<0.05$)

Trial	Deaths by day 3			Comparisons
1	1.06	±	0.19	a
2	0.29	±	0.17	b
3	1.13	±	0.16	b

*All values are LS Means ± SEM

**Represents the number of birth pigs that died by day 3

Deaths by day 3 = day 3 adjusted – born alive

a,b represent values that are significantly different

Table A3.5: Comparison of number of piglets on day 3 for each trial ($p<0.05$)

Trial	Day 3 Numbers			Comparisons
1	10.99	±	0.219	a
2	10.55	±	0.196	a
3	9.70	±	0.190	b

*All values are LS Means ± SEM

a,b represent values that are significantly different

Table A3.6: Comparison of day 3 piglet weights ($p<0.05$)

Trial	Day 3 weights			Comparisons
1	1.88	±	0.059	a
2	2.06	±	0.052	a
3	2.02	±	0.051	a

*All values are LS Means ± SEM

a,b represent values that are significantly different

Table A3.7: Comparison of number of piglets on day 14 ($p<0.05$)

Trial	Day 14 numbers			Comparisons
1	10.69	±	0.21	a
2	9.97	±	0.19	ab
3	9.53	±	0.18	b

*All values are LS Means ± SEM

a,b represent values that are significantly different

Table A3.8: Comparison of day 14 piglets weights (p<0.05)

Trial	Day 14 weights			Comparisons
1	4.72	±	0.11	a
2	4.81	±	0.10	ab
3	5.17	±	0.10	b

*All values are LS Means ± SEM

a,b represent values that are significantly different

Table A3.9: Comparison of number weaned for each trial (p<0.05)

Trial	Number Weaned			Comparisons
1	10.61	±	0.273	a
2	9.74	±	0.239	ab
3	9.38	±	0.237	b

*All values are LS Means ± SEM

a,b represent values that are significantly different

Table A3.10: Comparison of weaning weights for each trial (p<0.05)

Trial	Weaning Weights			Comparisons
1	8.50	±	0.23	a
2	8.28	±	0.20	a
3	9.46	±	0.20	b

*All values are LS Means ± SEM

a,b represent values that are significantly different

Appendix 4

Table A4.1: Comparison of number born alive for gilts and sows ($p<0.05$)

Parity Group	Born Alive			Comparisons
Gilts	10.595	±	0.206	a
Sows	12.119	±	0.299	b

*All values are LS Means ± SEM

a,b represent values that are significantly different

Table A4.2: Comparison of adjusted** number of piglets on day 3 for gilts and sows ($p<0.05$)

Parity Group	Day 3 Adjusted			Comparisons
Gilts	9.805	±	0.205	a
Sows	11.186	±	0.301	b

*All values are LS Means ± SEM

**Adjusted number represents the number of birth pigs alive on day 3 (represents piglet viability by birth dam)

Day 3 Adjusted = # born alive – fosters in + fosters out

a,b represent values that are significantly different

Table A4.3: Comparison of number of piglets on day 3 for gilts and sows ($p<0.05$)

Parity Group	Day 3 Numbers			Comparisons
Gilts	10.009	±	0.131	a
Sows	10.815	±	0.193	b

*All values are LS Means ± SEM

a,b represent values that are significantly different

Table A4.4: Comparison of number piglets on day 14 for gilts and sows ($p<0.05$)

Parity Group	Day 14 Numbers			Comparisons
Gilts	9.789	±	0.127	a
Sows	10.342	±	0.186	b

*All values are LS Means ± SEM

a,b represent values that are significantly different