Summary of current knowledge on sow nutrition in the Scientific literature

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Executive Summary

Our sow herd is now capable of giving birth to over 15 piglets per litter. Whilst his has been a dramatic change, sow nutrition has not changed so dramatically but yet we need the sows to rear these piglets as well as when fewer were born. This review summaries our current knowledge, from scientific literature on what works to promote sow productivity.

Good sow productivity begins with good gilt management. It is recommended that gilts should be served when they have 16-18mm of back fat, are between 220-230 days old, weigh between 130 and 140kg and have reached second or third oestrus. A special gilt diet from approximately 50kg is usually required to achieve these weight and back fat targets. It is also good practice to flush gilts for at least two weeks prior to insemination to increase ovulation rate.

Feeding sows during gestation can involve increased feeding during early and late pregnancy. Indeed, increasing feed allowances (over 3kg) in early gestation can have a beneficial effect on litter sizes. However, it may also have a negative effect on individual piglet growth post birth. Overall, evidence is contradictory on the effect of feed allowance in early gestation, furthermore genetics has largely solved the issue of increasing litter size at this stage. It is recommended that feeding 2.4kg during mid-gestation is sufficient for piglet development and high rates of feeding can actually reduce performance. In theory, feeding 2.5kg is sufficient in late gestation as well and many studies have found no positive impact on litter weight and performance at higher feeding levels.

Adding supplementary fat to sows gestation diets can increase the sow's energy intake, but there is no consistent effect of additional fat to sow diets on piglet performance. It may however, improve piglet survival, but this may be due to increased gestation length and improved colostrum quality.

Protein content is important in gestation diets as most of *in utero* piglet growth and mammary development is protein. Crude protein should be between 15 and 17% in late gestation to cover the sow's protein needs for piglet and mammary growth. Lysine levels for gilts should be at least 0.7% in a 2.5kg/day feed allocation and lysine levels for sows should be at least 0.5% in a 3kg/day feed allocation. Supplemental arginine and carnitine (both amino acids) can also improve sow and piglet performance.

Colostrum quality in sows is of utmost importance as colostrum intake is directly correlated to piglet survival. Supplementary fat offered in late gestation may increase fat (energy) content of colostrum, and certain fatty acids (such as supplementary CLA) may also increase immunoglobulins which transfer immunity from the sow to the piglet.

During lactation, sows with high feeding levels are able to produce more milk which leads to greater piglet growth and reduces sow body loss. Lactation feed intake is extremely important as intake drives milk yield. To improve intake, the farrowing room temperature needs to accommodate the needs of the sow to stay cool and the needs of the piglet to stay warm. Practical ways to achieve this include directing air flow onto sows, wetting or misting the sows to aid evaporation and using creep-boxes (a covered area for piglets) so that the farrowing house temperature can be reduced. Also, a sow will drink more than 40 liters a day; to help her maintain this, drinkers should have a flow rate of over 2 liters per minute. Lastly, ensure troughs are cleaned thoroughly on a daily basis as mouldy, rancid feed will depress intake.

Adding fat to the lactation diet can reduce mortality and increase growth rate of piglets; however, this can be at the expense of sow body weight. Conjugated Linolenic acid (CLA) at low doses can reduce piglet birth weight, but at 1% inclusion CLA can increase weaning weight. Protein restriction during lactation reduces sow and piglet performance**.** Studies have found that protein and lysine levels higher than BSAS recommendations (17% and 1% respectively) can improve litter performance and reduce sow weight loss.

In conclusion, a sow can rear 12+ piglets to a good weaning weight if she is given the right fuel (feed!).

1. Introduction

There has been large genetic progress in prolificacy and growth rates in the pork industry over the last 20 years. The average number of finished pigs/sow/year (p/s/y) has increased in the EU from 16.2 in 1990 to 23.3 in 2013 (BPEX, 2014). It is expected that improvement will continue as producers begin to target 30 pigs/sow/year (the top 10% of EU herds already wean 27.9 p/s/y – BPEX, 2014). The number of live-born piglets per litter, piglet survival, average daily gain (ADG), feed conversion ratio (FCR) and lean meat percentage are the most important traits for economic efficiency (Heyer and Lebret, 2007). These traits can be influenced by maternal nutrition (Brameld et al., 1998; Rehfeldt et al., 2011a, 2011b). Therefore, emphasis has turned to redefining nutrient requirements for modern, highly prolific sows.

2. Gilt management

To increase sow longevity and the number of piglets produced per sow per lifetime, the first consideration is the nutrition and management of the replacement gilt.

2.1. Gilt selection and body condition

Using gilts with an average litter size of 12.5, Amaral Filha *et al.* (2010) determined that gilts with a backfat depth of 16-17 mm had the greatest first litter size. They also found that gilts with an average daily gain (ADG) of 701-771g/day from birth until first mating had the largest first litter size. Those with lower ADG had reduced litter size and those with higher ADG had increased stillbirths and greater variability in birth weights. Reviews by Close and Cole (2000) and Whittemore (2006) also conclude that the body condition of the gilt at first mating has an effect on lifetime performance.

However, the body condition recommendations suggested (16-18mm of backfat) are unlikely to be achieved by feeding finisher diets, which are formulated for maximum lean growth of slaughter pigs, to gilts. It is recommended to use gilt developer diets which promote greater fat deposition and increase bone strength.

Achieving high backfat depths prior to mating is also difficult in genetically lean gilts (Whittemore, 2006). Hence, much research has focused on restricting lean gain to maximize fat gain (i.e. altering the energy:lysine ratio of the diets). However, increasing fat deposition to an extent that protein becomes limiting (restricting liveweight gain), can impair metabolic status and compromise ovulation rates and reproductive performance (Sinclair et al., 2001; van Wettere, 2011). Furthermore, Mejia-Guadarrama *et al.* (2002) actually recommends that gilts have high protein reserves prior to farrowing to buffer the effects of insufficient protein intake during lactation on milk composition.

Therefore, at this crucial stage, it is important to find a balance between lean and fat gain. Close and Cole (2000) suggest selecting breeding stock at approximately 60kg body weight (about 12-15 weeks of age) and feeding a 13.5 MJ DE, 8g/kg lysine diet at a rate of between 2.5-4.0 kg/day until they reach 130kg. The diet should then be offered *ad libitum* for two weeks before service to flush the gilts.

2.2. When to serve gilts

It is recommended that gilts should not be served at their first heat. Work by Archibong *et al.* (1987) found that gilts had a significantly lower ovulation rate on their first heat compared to those on their third heat (12.2 vs 14.5; $P < 0.05$).

Recent work at AFBI, Hillsborough demonstrated that there was no effect of oestrus number (1-5) at first service on first litter performance (number of piglets born alive and average birth weight). However, gilts served on their third oestrus had the greatest number of piglets born alive and weaned ($P < 0.001$) over their life time, but gilts served on oestrus 4 and 5 had fewer numbers of piglets born alive and weaned ($P < 0.001$). (Cottney et al., 2012a). Therefore serving gilts on their third oestrus led to improved live time performance.

2.3. Feeding Gilts at Service

Reviews by Anderson and Melampy (1972) and den Hartog and van Kempen (1980) indicate that flush feeding (high plane feeding) pre-mating increases ovulation rate. Embryo survival rate also increases from 68% to over 80% when gilts are fed on a high plane of nutrition for at least 2 weeks before mating (Almeida et al., 2000). The positive effect of high plane feeding is thought to be due to changes in insulin and IGF plasma concentrations which increase the secretion of Luteinising Hormone, which stimulates follicular growth (Close and Cole, 2000).

Results from studies examining the effect of offering gilts a high plane of nutrition post-insemination are inconsistent. Some studies have found that continuing high plane feeding regimes after mating leads to increased embryo mortality (Ashworth, 1999; Xu *et al.*, 2010) and Cottney et al., (2012b) found that as the period of high plan feeding increased, the farrowing rate of the gilts decreased. However, other studies find no such effect (Prunier *et al.*, 1999; Quesnel *et al.*, 2010; Langendijk, 2012; Hughes and van Wettere, 2014). Overall it is suggested that high plane feeding should be avoided post service.

*2.4. Conclusion***:**

Gilts should be served when they:

- have 16-18mm of back fat,
- are between 220-230 days old,
- weigh between 130 and 140kg
- have reached second or third oestrus

- have been flushed for at least two weeks
- Flush feeding should cease after service

3. Sow Management

The effects of poor body condition on the reproductive performance of sows are well documented. Whittemore (2006) reported that for every 1% of body fat lost from sows during lactation, there will be 0.1 fewer piglets born in the next litter. As litter size increases, backfat and bodyweight decrease, the period from weaning to oestrus increases and the number of pigs in the next litter decreases (Morrow *et al.*, 1992; Touchette *et al.*, 1998a; Eissen *et al.*, 2003). This effect is most pronounced in gilts having nursed large litters due to low body reserves, lower daily feed intakes and the need for additional energy for growth compared to multiparous sows.

Eissen *et al.* (2000) reported that an increase in average daily feed intake led to reduced backfat losses, increased litter weight gain and reduced the probability of a prolonged weaning to oestrus interval in primiparous sows. However, as numbers of pigs in the litter increased from 10 to 14, there was a greater backfat loss but no significant increase in feed intake.

Eissen *et al.* (2000) also found that the increasing weaning to oestrus interval associated with larger litter sizes could be attributed to bodyweight losses, and especially body protein losses. As litter size increased above 9.9 piglets, there was a corresponding decrease in the size of the second litter, and each extra piglet in the litter increased the risk of a prolonged interval between weaning and oestrus by 23%. Therefore, it is vitally important that sows, and especially primiparous sows, receive adequate nutrition during lactation. However, the variation in lactation feed intake between sows can be large and sows may not be able to physically eat enough during lactation to fulfill the nutritional demands placed upon them especially in the second and third weeks of lactation (Revell and Williams, 1993).

4. Gilt and Sow Nutrition in Gestation

During gestation, a sow usually needs to replenish her body reserves after the previous lactation, but not become excessively fat. This generally means that a restrictive feeding regime should be applied. Overfeeding during gestation can lead to the sow becoming excessively fat (>3.5 BSC), which reduces appetite during lactation and leads to the mobilisation of body reserves and the loss of body condition (Young *et al.*, 2004). Overfeeding in gestation can also have a negative impact on mammary development due to excessive fat deposition (Farmer and Sorensen, 2001). On the other hand, sows that are very lean at farrowing (<2.5 BSC) have been found to lose more body condition during lactation, and as a result take longer to return to oestrus after weaning. They are also much more likely to suffer from reproductive failure and greater levels of lameness (Gill, 2007).

The most common method of feeding gestating gilts and sows is to feed each animal according to their visual body condition score with the aim of achieving a score of 3 at farrowing (Whittemore, 2006). This method is easy and quick to use. However, it has the limitations that body condition and backfat are poorly linked (Young *et al.*, 2001), and subjective.

4.1. Early Gestation Feeding (day 0-50)

Studies have investigated additional feeding in early gestation with beneficial (Hoving *et al.*, 2010), detrimental (McNamara et al., 2011) or no effect (Heyer, 2007) on reproductive performance. For example, Hoving *et al.* (2010) found that offering multiparous sows 3.25 kg/day vs. 2.5 kg/day during the first 28 days of pregnancy increased litter size (15.2 piglets v. 13.2 piglets, P <0.05).

However, Bee (2004) fed multiparous sows low (40% less) or high (40% more) food allowance during the first 50 days of gestation. Piglets born to high-energy sows were lighter at birth, grew slower and had lower FCR and higher percentages of adipose tissue. Therefore increased energy intake during early pregnancy may have a negative effect on individual piglet performance even if litter size is increased.

4.2. Mid Gestation Feeding (day 25-80)

Nissen et al. (2003) found a negative effect of *ad lib* feeding of pregnant sows from days 25-50 on ADG and muscle deposition rate of piglets especially the smaller littermates. Similarly, there was no improvement in growth performance, ADG, FCR or pig slaughter weight of pigs when sows were fed at 200% of requirements between days 25-50 or days 50-80. These results have been confirmed by Cerisuelo et al. (2009).

Increasing energy allowance between days 50-80 of gestation actually increased the number of stillborn piglets per litter (Lawlor and Lynch, 2005; Lawlor et al., 2007; McNamara et al., 2008). Samuel *et al.* (2007) recommended that feeding sows at a rate of 2.4kg/day (13MJ DE/kg, 0.65% lysine, 15% CP) throughout early and mid-gestation gestation was sufficient.

4.3. Late Gestation (Day 80-112)

Although it is common practice to increase feed during late pregnancy, most studies show no improvement on litter performance (Lawlor and Lynch, 2005; Lawlor and Lynch 2007; Lingendijk, 2011 and Cottney et al., 2012c) However, Shelton *et al.* (2009) found that an increased allowance of feed (extra 0.91kg) between day 90 of gestation and farrowing over two parities increased weight gain of both the sows and gilts. Samuel *et al.* (2007) suggested that during late gestation, sows require at least 32.76 MJ/day (2.5kg of a 13MJ DE diet).

4.4 Entire Gestation

Heyer et al. (2007) offered sows differing levels (2.3kg, 3.1kg, 3.9kg and 4.6kg) of the same diet (12.3DE; 15.3% CP; 0.7% lysine) throughout gestation. The lowest feed supply (2.3kgs) produced 3 piglets less per litter compared to the other treatments. Overall, birth weight, variation in birth weight and mortality was not affected by maternal nutrition. Weight loss of sows during lactation was greater with increased feed supply, but ADG of the piglets during the suckling period was not significantly influenced. Increasing the feed allowance above 3.1kg/day had no further effect.

4.5. Conclusion

- Increasing feed allowances (over 3kg) in early gestation can have a beneficial effect on litter sizes. However, it may have a negative effect on individual piglet growth.
- Feeding 2.4kg during mid-gestation is sufficient and high rates of feeding can reduce performance.
- Feeding 2.5kg is sufficient in late gestation and there may be no positive impact on litter weight and performance at higher levels.

5. Energy in Gestation Diets

5.1 Additional fat

The effects of providing additional fat to the gestation diet are inconsistent in the literature. Fat supplementation of sow diets during late gestation can improve growth performance and survival of piglets, especially small piglets (Rooke et al., 2001; Averette et al., 1999). Fat supplementation may also increase colostrum quality (see Section 7 about Colostrum). However, Laws et al. (2007; 2009) found that providing sows with extra meal improved piglet birth weight and milk yield compared with supplementing the diet with extra fat. Pastorelli *et al.* (2009) also found no effect on piglet characteristics or on piglet energy reserves when additional fat was incorporated into gestation diets.

Rooke et al. (1998) demonstrated that piglets had a higher viability score when they were born to sows fed a diet supplemented with soybean oil (no polyunsaturated long-chain fatty acids) than with tuna oil (contains polyunsaturated long-chain fatty acids) during gestation. The authors credited this to an increased gestation length as discussed by Edwards and Pike (1997). Rooke et al. (2001) also noted that salmon oil (added at 16.5kg/t) increased gestation length and reduced pre-weaning mortality.
However, other research has found that additional fat during gestation may have detrimental effects. A study by van der Peet-Schwering *et al.* (2004) found that feeding a top dressing of 164g/d of fat (soya oil) compared to a control diet from day 85 of gestation until parturition led to fewer piglets born and more stillborn piglets.

Sows fed the additional fat were heavier and fatter than the control group of sows. Furthermore, sows offered higher fat diets had reduced intakes, which defeated the purpose of providing extra energy in the diet.

Therefore, it appears that providing additional fat during gestation may not directly benefit piglet performance but instead is deposited as maternal body reserves. A possible reason for the lack of effect of feeding additional dietary fat to sows on piglet birth weight is that the majority of foetal body tissues are composed of protein. Hence, this may explain why the studies with additional feed (and therefore protein) (Laws *et al.*, 2007; 2009) were successful at increasing piglet birth weight. Excessive fat gain during gestation can also have serious detrimental effects during lactation.

5.2 Linseed

Vonnahme et al. (2010) found an increase in litter size when feeding linseed meal (LSM). Sows received a 12.5% LSM diet throughout gestation or from day 1-15 of gestation. The number of fully formed piglets was increased (P=0.05) in sows fed LSM at the beginning of gestation compared with sows fed through the whole of gestation. Therefore, feeding LSM during the first 2 weeks after breeding may enhance litter size. However, there was no increase in piglet birth weight.

5.3 Conclusion

- There is no consistent effect of additional fat to sow diets on piglet performance
- Fat may improve survival of piglets, but this may be due to increased gestation length and improved colostrum quality

6. Protein

A foetus gains 17.5g of protein from day 0-70 (0.25g of protein/d) and 203.7g of protein from day 70-114 (4.63g of protein/d). So, if a sow has 14 foetuses, she requires 3.5 and 64.8g/d of protein for foetal growth in early and late gestation, respectively. This is a 61.3-g/d difference or an 18.5-fold increase in the rate of tissue protein gain between early and late gestation (McPherson et al., 2004).

An individual mammary gland gains 11.2g of protein from day 0-80 (0.14g of protein/d) and 115.9g of protein from day 80-114 (3.41g of protein/d). If a sow has 16 mammary glands, she requires 2.2 and 54.6g/d of protein gain for mammary growth early and late gestation, respectively. This is a 52.3g difference or a 24.4-fold increase for the rate of tissue gain between early and late gestation (Ji et al., 2006).

Therefore, not counting maintenance, a sow requires 5.7 and 119g/d of protein in early and late gestation respectively. Protein restriction in gestation has been found to have a negative effect on foetal growth and birth weight (Davis et al., 1997; Scoknecht et al., 1994; Pond et al., 1991). However current sow gestation diets tend to be around 14% CP which is adequate for protein requirements in late gestation.

Tydlitat et al. (2007 and 2008) investigated the impact of feed containing 13%, 15%, 18% and 21% crude protein (CP) in late pregnancy. They found that high intake of CP (18 or 21%) in sows before parturition prolonged delivery and increased the number of stillborn piglets demonstrating a negative impact of high CP intake in last stage of pregnancy. However, Cooper et al. (2001) found no difference in reproductive or piglet performance when increasing lysine levels form 8.3d/day (BSAS 2003 recommendation) to 10.3g/day.

6.1. Amino Acids

There is limited up-to-date information on amino acid (AA) requirements and ideal ratios of dietary AA for sows. This is due to the complexity of requirements associated with foetal growth combined with mammary growth, milk production, and maternal nutrient mobilization during gestation and lactation, as well as contradictory conclusions in the published literature (Kim et al, 2009).

AA requirements of gestating sows vary with each gestational stage (McPherson et al., 2004; Kim et al., 2009; Wu et al., 1999). Feeding a single amount of AA throughout gestation results in overfeeding AA in early gestation and underfeeding AA in late gestation (Srichana, 2007; Kim et al., 2009; Samuel et al., 2010). Overfeeding AA increases feed costs and environmental contamination through excretion of excess nitrogen (Adeola, 1999), whereas underfeeding AA during pregnancy causes excess breakdown of maternal tissue to support foetal growth and milk production (Clowes et al., 2003).

Wu et al. (1999); Kim et al. (2001); McPherson et al. (2004) and Ji et al. (2005) concluded that digestible lysine requirements for gestating gilts to support the needs for maintenance, maternal, foetal, and mammary tissue gains are: 5.57 and 8.78g/d for day 0-60 and day 60-114 of gestation, respectively. This is lower than the BSAS recommendation of 8.5 – 14.8g/d for gilts.

Based on relative ratio to Lysine, sows in early gestation (day 0-60) require increased amounts of Threonine, whereas sows in late gestation (day 60-114) require increased amounts of Arginine and Leucine (Wu et al., 1999; Kim et al., 2001a,b; McPherson et al.,2004; Ji et al., 2005). See Table 1 for summary of recommendations.

Table 1: AA requirements in ratio to lysine for gestating sows

	BSAS Recommendations (2003)	Recommendations from Studies* Early Gestation	Recommendations from Studies* Late Gestation
Lysine	**1**	**1**	**1**
Threonine	**0.71**	**0.79**	**0.71**
Arginine	**-**	**0.89**	**0.98**
Leucine	**1**	**0.88**	**0.95**

Wu et al., 1999; Kim et al., 2001; McPherson et al.,2004; Ji et al., 2005

A study conducted by Kim et al. (2009), tested the use of the AA balance recommended by several studies (Outlined in Table 1) on sow performance during gestation and lactation. Body weight gain of the ideal protein group was greater (P<0.01) than for the control group which lost more backfat (P<0.05). There were no changes in birth weights and litter size at birth, but litter birth weight variation was smaller by 14.4% (P<0.05) for the ideal protein group. These results indicate that when pregnant gilts receive a diet with ideally balanced AA, they can conserve dietary AA for maternal tissue gain and for reducing foetal weight variation (Kim et al., 2009).

BSAS (2003) recommends 8-12.7kg of digestible lysine per day for average weight mid-parity sows. However, increasing dietary lysine intake above BSAS recommendations (8g/kg instead of 6g/kg) in late gestation increased total solid and protein contents of colostrum (Heo et al., 2008; Yang et al., 2008).

A. Carnitine

The supplementation of gestating sows with L-carnitine can increase the number of pigs born alive by an average among studies of 3.9 pigs (Waylan et al., 2005; Ramanau et al., 2004), increase birth weight by about 8% (Eder et al., 2001; Ramanau et al., 2002) and reduced intra-litter weight variation (Birkenfield et al., 2006). Sows supplemented with L-carnitine also produce more milk (Ramanau et al., 2004, 2005) as carnitine plays an important role in energy production immediately after birth (Birkenfield et al., 2006).

Milk production of sows is also strongly influenced by litter size, piglet weights and suckling intervals. If piglets suckle more frequently or for a prolonged period, they will cause milk production to rise (King et al. 1997; Spinka et al., 1997; Birkenfeild et al., 2006; Auldist et al. 2000). The authors suspected that piglets of sows supplemented with L-carnitine are more vigorous and were able to stimulate a greater milk flow in the sows than piglets of control sows (Birkenfeild et al., 2006).

Musser et al. (1999) suggested that the L-carnitine supplementation of sows increases the intrauterine nutrition and development of the foetuses as piglets had more muscle fibres, a greater loin depth, a higher percentage of lean and less backfat than the piglets of control sows. It is possible that improved foetal development led to increased piglet vitality at birth, which could be associated with increased persistence of suckling (Birkenfield et al., 2006).

B. Arginine

Arginine regulates embryonic and foetal muscle growth and development (Wu et al.,2010). There is evidence that the arginine family of amino acids (arginine, glutamine, glutamate, proline, aspartate, asparagines) have an important role in placental, embryonic and foetal development (Ramaekers et al., 2006; Wu et al., 2007; Wu et al., 2010; Berard and Bee, 2010; Gao et al., 2012; Che et al., 2013). Arginine supplementation can increase litter size and birth weight, and its combination with glutamine, leucine and proline can reduce variation in birth weight (Wu et al., 2010).

In early gestation, Berard and Bee (2010) and Ramaekers et al. (2006) found positive results of arginine supplementation. In gilts receiving 26g L-arginine per day from days 14-28 of gestation, the number of viable foetuses and total weight was greater ($P<0.04$) at day 75. This suggests that L-arginine supplementation during early gestation enhances foetal survival. A higher number of live piglets have also been observed in sows supplemented with 25 g L-arginine per day from 14-28 days of gestation, without affecting the average birth weight (Ramaekers et al., 2006).

Che et al., (2013), found that sows supplemented with 1% Arginine from day 30-114 or day 30-90 had fewer dead piglets ($P<0.05$) than control sows. Sows supplemented from day 30-114 had higher total and live litter weight. These finding are consistent with the results of Gao et al. (2012), who reported that dietary Arginine supplementation from day 30-114 of gestation increased live-born pigs by 2 pigs per litter, likely due to improved uterine capacity (Wu et al., 2006).

6.2 Conclusions:

- Crude protein above 14% in late gestation should be sufficient to cover the sows protein needs.
- Lysine levels for gilts should be at least 0.7% in a 2.5kg/day feed allocation.
- Lysine levels for sows should be at least 0.5% in a 3kg/day feed allocation.
- Supplemental arginine and carnitine can improve sow and piglet performance. However, these supplements are currently expensive and the economic return is questionable.

7. Colostrum

A low intake of colostrum is a key factor of pre weaning mortality (Edwards, 2002; Le Dividich et al., 2005; Quesnel, 2011). Colostrum provides essential energy and passive immunity (Rooke and Bland, 2002; Le Dividich, et al., 2005). Therefore, early and increased intake of colostrum is of vital importance for piglets. The last week of gestation is important for colostrum production (Hansen et al., 2012; Flummer and Theil, 2012).

7.1 Colostrum yield

Production of colostrum and milk are separate processes (Quesnel, 2011; Flummer and Theil, 2012). There is a slight influence of parity on colostrum yield, with a tendency for a greater production in second- and third-parity sows (Devillers et al., 2007). However, unlike milk, colostrum yield is only slightly influenced by litter weight, vitality at birth (Devillers et al., 2007) and litter size (Quesnel, 2011). In the first few hours after farrowing, colostrum is continually available (de Passille and Rushen, 1989; Fraser and Rushen, 1992), thus, colostrum intake per piglet is lower when litter size increases (Le Dividich et al., 2005; Devillers et al., 2007). Fraser and Rushen (1992) noted that piglets added to the litter during the last hour obtained less colostrum than those added in the middle of parturition. Devillers et al. (2007) suggested that the amount of colostrum available per piglet decreases by 22-42g per each additional piglet born. Devillers et al., (2007) and Quesnel (2011) found that colostrum intake per piglet increased with piglet weight and decreased when within-litter variation of birth weight increased. In practice this means that small piglets may be less vigorous and less able to compete with littermates for teat access leading to poorer growth and a higher mortality (Quiniou et al., 2002).

The induction of premature parturition via injection of prostaglandin on day 112 of gestation decreases colostral fat concentration therefore, the addition of fat to the sow diet in late gestation can maintain the colostral energy level (Jackson et al., 1995). Fat supplementation during late pregnancy also increases total lipids (Jackson et al., 1995; Heo et al., 2008) and lactose content (Heo et al., 2008) in colostrum.

7.2 Transfer of Immunity

Neonatal survival is dependent on sufficient colostrum for humoral immunity until their own immune systems mature which begins about 14 days of age (Rooke and Bland, 2002). An inadequate transfer of maternal immunoglobulins increases susceptibility to infection, not only in the postnatal period (Drew and Owens, 1988), but also after weaning (Krakowski et al., 2002). Concentrations of IgG are lower in colostrum of first to third parity sows and greater in older sows so it may be useful to put weak piglets on to older sows to nurse (Quesnel, 2011). The concentration of immunoglobulins is greater in colostrum compared to milk with a dramatic decline between days 0-3 of lactation (Laws et al., 2009).

Fat supplementation in gestation can increase concentration of IgG in colostrum (Laws et al., 2009); this effect was greatest in sows fed palm oil in late pregnancy or those fed sunflower oil in early pregnancy ($P<0.01$). This may be due to beta-carotene (via palm oil; Lietz et al., 2001) and vitamin E (via sunflower; Duran, 2002). The type of fat supplementation the sow receives also alters IgA and IgM concentrations. Feeding palm oil or fish oil in early gestation and sunflower oil and fish oil in late gestation increases the IgA secreted in colostrum ($P<0.05$), and sunflower supplementation in early gestation and palm oil in late gestation increases IgM in colostrum ($P>0.05$) (Laws et al., 2009). The enhanced serum concentration of IgG in piglets, due to maternal fat supplementation, can continue up to weaning (Rooke et al., 2003; Corino et al., 2009).

Supplementing sows with 0.5-1% Conjugated linolenic acid (CLA) isomers can also increase colostral IgG, IgA, and IgM ($P<0.05$) (Corino et al., 2002; Bontempo et al., 2004; Corino et al., 2009). Dietary CLA isomers at doses of 0.5 to 1% increased piglet serum concentrations of IgG, IgA, and IgM (Corino et al., 2002).

Newborn piglets also depend on the transfer of vitamins and minerals via colostrum (Farmer and Quesnel, 2009). Vitamin E storage in the adipose tissue of the sow has a great influence on its concentration in colostrum (Hakansson et al., 2001). It is possible to increase Vitamin E concentrations in colostrum by increasing dietary supply during gestation (Bland et al., 2001; Pinelli-Saavedra et al., 2008), or by injections of Vitamin E on day 100 and 107 of pregnancy (Chung and Mahan, 1995). Similarly, supplementing the sow diet with Vitamin A in late gestation increased colostral content (Bland et al., 2001). However, supplementation of Vitamin C in late gestation had no effect on its concentration in colostrum (Mahan and Vallet, 1997). Increases in Vitamin content of the gestating sow diet can improve the IgG status of piglets (Pinelli-Saavedra et al., 2001; Rooke and Bland, 2002), through increased efficiency of IgG absorption by the piglets.

7.3 Conclusions:

- Colostrum intake is of utmost importance for piglet survival
- Additional fat in late gestation may increase fat (energy) content of colostrum
- Certain fats may also increase immunoglobulins which transfer immunity from the sow to the piglet

8. Lactation Feeding

Modern sows can produce up to 3 gallons (11.36 litres) of milk per day (Whiney et al., 2012). Relative to body weight, this is similar to a high-producing dairy cow. Therefore, the nutrient requirement of sows increases dramatically during lactation. It is estimated that a 225kg sow requires a 3-fold increase in energy during lactation compared with gestation (BSAS, 2003).

8.1 Feed intake

Voluntary feed intake during lactation is often not high enough to sustain milk production needed (Eissen, 2000) and sows mobilize body fat and protein to meet the needs of lactation (Pettigrew et al., 1992a,b). The extent of weight loss varies among sows (Mullan and Williams, 1990). A small amount of fat mobilization is not a problem, but excessive fat mobilization or mobilization of protein can cause fertility problems in the next farrowing cycle (Clowes et al., 2003).

There are a number of factors that can influence the appetite of sows during lactation. Younger sows and extremely fat sows (with a body condition score of 5) are known to have smaller appetites than older parity sows or sows with a condition score of 3 (Eissen *et al.*, 2000). Temperature also has a large effect on feed intake.

Temperature is the single most important environmental factor influencing voluntary feed intake during lactation (Close and Cole, 2000). A sow responds to a change in temperature by changing her rate of heat production. When this heat production is minimal, it is termed the thermo-neutral zone. Below this zone, the sow responds by consuming more feed to meet her increased energy requirements, and above this zone feed intake is depressed. For example, sows reduced feed intake by 25% when the temperature of the farrowing house was increased from 16 to 27 ^{o}C. Messias de Bragananca *et al.* (1998) found that lactation feed intake decreased by 40 and 43% when the temperature was raised from 18 to 28^{o}C and 20 to 30^{o}C, respectively.

The upper level that the sow can tolerate is no higher than 15-20^{o}C (Black et al., 1993). However, piglets need temperatures as high as 30^{o}C, so the farrowing room needs to accommodate both needs. Practical ways to achieve this include:

- Directing air flow onto sows to aid cooling
- Wetting or misting the sows to aid evaporation
- Placing metal slats under the farrowing crate for the sow, surrounded by plastic slats for the piglet
- Using creep-boxes (a covered area for piglets) so that the farrowing house temperature can be reduced

Temperature is not the only factor to consider when trying to improve intakes. Other practical solutions include:

- The sow needs to be healthy – careful stockmanship should notice signs of mastitis etc.
- Feeding twice or even three times a day will encourage higher intakes
- Water intake drives feed intake. A sow will drink more than 40 liters a day. To help her maintain this, drinkers should have a flow rate of over 2 liters per minute.
- Ensure troughs are clean. Mouldy, rancid feed will depress intake.
- Target a score 3 for body condition at farrowing. Overfat sows (>3 BSC) will also have depressed lactation intake.
- Intakes will also be reduced if the sow is suffering from constipation. Management to avoid this include:
    - Adding fiber (at least 3.2% of lactation diet) to lactation diets

- Ensuring good water intake
- Reduce feed allowance for a few days pre-farrowing
- Step up feed allowance slowly (around 0.5kg/day)

When it is not possible to increase feed intake through better management, it may be possible to offer sows a more nutrient dense diet to provide the required levels of nutrients in a smaller quantity of feed. A number of studies have focused on increasing the energy and protein composition of the diets. Tritton *et al.* (1996) increased lysine levels (6.2, 8.4, 10.6, 13.1 and 15.1 g/kg) with a digestible energy of 14.3 MJ/kg, or digestible energy levels (12.6, 13.2, 13.8, 14.4, 15.1 MJ/kg) with a lysine:DE ratio of 0.88. Piglet growth was unaffected by digestible energy content but increased with increasing dietary lysine (with a lysine level of 13.1g/kg giving the greatest litter growth rate of 2.12kg/day). Sow body weight loss was unaffected by dietary lysine but declined with increasing DE content up to 13.8MJ/kg.

Increasing the proportion of energy supplied by fat in the lactation diet is associated with a higher dietary net energy intake, but feed intake is reduced (van den Brand et al., 2000, Quiniou et al., 2008; Park et al., 2008).

8.2 Energy

Piglets have low fat reserves at birth (20g/kg) and hence a limited ‘internal’ energy supply. This predisposes them to heat loss due to cold or inadequate consumption of milk, which weakens them or causes death (Gu and Li, 2003; Cordero et al., 2011). Addition of fat to the diet of sows during late gestation and lactation increases milk production and fat content (van den Brand et al., 2000; Lauridsen and Danielsen, 2004; Park et al., 2008; Quiniou et al., 2008; Laws et al., 2009).

Energy supply as fat should begin at least 5 days before farrowing so that fatty acids can be transferred to the mammary glands (Pettigrew, 1981). Some results of fat supplementation indicate improved survival of piglets (Pettigrew, 1981; Rooke et al., 2001), improvement in ADG (Lauridsen and Danielson, 2004) and increased lipid content in piglet muscle (Gerfault, 2000). However, not all studies agree (van den Brand et al., 2000). Other studies suggest starch is superior to fat as an energy source in sow lactation diets (Van den Brand et al., 2000; Jones et al., 2002). Discrepancies may be due to the variations in length of feeding supplemental fat, percentage of fat, the fat source, and initial inclusion time.

8.2.1 . Energy Source

Quiniou et al., (2008) compared the effect of starch versus fat energy by adding equal amounts of energy (13.6MJ DE)to lactation diets through addition of either 5% soybean oil, (‘Fat’ diets), or 11.3% cornstarch, (‘Starch’ diets). There was no difference in piglet birth weight, but postnatal mortality tended to be lower in the fat than in the starch sows (P=0.05). Litters from sows fed ‘fat’ diets also had a higher ADG (P<0.05) and tended to be 0.5kg heavier at weaning. Backfat loss was higher in fat-fed sows (P<0.01) due to a deteriorated energy balance from reduced feed intake. This indicates that extra energy intake supplied by lipids is transferred to the mammary glands and incorporated into milk (Jones et al., 2002). The authors feared that an increase in body fatness would result. However, pigs studied up to slaughter showed no effect of energy source provided to the sow either on growth performance or carcass composition (Quiniou et al., 2008).

Van den Brand et al. (2000) examined the combined effect of energy source and energy density. Sows were offered High or Low nutrient density diet with two sources of energy during lactation: Fat (tallow) or Starch. The High feeding level resulted in higher milk production (P=0.02) and by day 20, piglet weight from sows at the High feeding level was greater (P=0.03), due to higher ADG (P=0.005). At the Low feeding level, no effect of energy composition was found, but at the High feeding level, sows fed the Fat-rich diet produced milk with a higher fat and energy concentration than sows fed the Starch-rich diet. Therefore, energy as dietary fat fed at a high feeding level for lactating sows is preferentially secreted as milk fat. This resulted in a higher milk energy output and higher energy retention in the piglets, but a more-negative energy balance for the fat-fed sows due to higher weight loss (P=0.05) (van den Brand et al., 2000).

Park et al. (2008) also investigated the combined effects of energy density and energy source. During lactation, sows fed a high energy diet (14.7 MJ DE) exhibited faster litter ADG (+0.5kg/day) and improved litter weaning weight (+14.5kg) than the low energy diet (14.2 MJ DE), in agreement with previous studies (van den Brand et al., 2000; Quiniou et al., 2008). Improved litter performance may be due to improved milk composition and increased fat content of colostrum of sows fed high energy or high fat diets compared to low energy or low fat diets (van den Brand, 2000; Park et al. 2008; Yang et al., 2008; Laws et al., 2009).

8.2.2. Fat Source

Lauridsen and Danielson (2004) offered various fat sources from 108 days of gestation until weaning. Diets were formulated with 8% of: animal fat, rapeseed oil, fish oil, coconut oil, palm oil, or sunflower oil, respectively. Addition of 8% fat (excepting fish oil and rapeseed oil) to lactation diets increased the ADG from birth to weaning compared to the control diet due to increased fat and energy content of the milk. As digestibility of sow's milk is high, this rise in sow milk fat was effectively turned to gain by the piglets (Lauidsen and Danielson, 2004).

Supplementation of fat also increased the concentration of total fatty acids, Vitamin E, and Vitamin A in the milk compared to the control diet. ADG of the piglets from sows fed fish oil was lower than the other fat treatments (Lauridsen and Danielson, 2004). When using 10% fish oil in diets for lactating sows, Danielson and Lauridsen (2001) (as quoted by Lauridsen and Danielson, 2004) also observed a significantly lower number of piglets at weaning and decreased milk production.

8.2.3. Fatty Acids

The fatty acid (FA) profile of milk can be altered by the FA profile of sow diets (Rooke et al., 2001; Laws et al., 2009). The FA profile of the diet also affects the FA composition of the piglets' tissues (Rooke et al., 2001; Cordero et al., 2011).

One FA of particular interest is CLA (Conjugated linoleic acid). Dietary CLA can enhance IgG in piglets and decrease the negative effects of inflammatory response (Corino et al., 2002). CLA is secreted in colostrum and milk of sows (Bontempo et al., 2004), with an estimated transfer efficiency ranging from 53-63% and 55-69%, respectively (Bee, 2000). CLA has also been shown to reduce fat deposition and backfat thickness, and increase intramuscular fat content in growing-finishing pigs in some studies (Dugan et al., 1997, 1999; Wiegand et al., 2001, 2002), but not in others (D'Souza and Mullan, 2002; Tischendorf et al., 2002).

However, the literature is not consistent with regard to the effect of CLA administration to sows on piglet weight at weaning. Poulos et al. (2004) and Bontempo et al. (2004) reported no effect of dietary sow CLA treatment, while Patterson et al. (2007) observed that weaned piglets from sows fed diets supplemented with 20g/kg CLA from day 85 of pregnancy were lighter than piglets from control sows. Park et al. (2005) also reported lower birth weight in piglets from sows fed a CLA-enriched diet.

However, Corino et al., (2009) observed sows offered control or 0.5% CLA supplementation beginning 7 days pre-farrowing. No differences were detected for sow body weight, body weight loss and feed intake or number of piglets born, born alive, and weaned. The weight of piglets at birth ($P<0.05$) and weaning ($P<0.001$) was greater for those receiving CLA.

Peng et al. (2010) fed sow diets containing 0, 0.5, or 1.0% CLA during the last 50 days of gestation and throughout lactation. Supplementation with CLA tended to linearly increase the number of piglets born alive and weaned per litter. Birth weight was unaffected by CLA supplementation, but weaning weight tended to increase linearly as a result of CLA supplementation.

8.3. Protein

Maternal protein mobilization can respond to changes in dietary protein supply to keep milk production stable. However, severe protein restriction during lactation will decrease milk production (Knabe et al., 1996; Jones and Stahly, 1999). Increased dietary lysine level during lactation can maximize litter gain through better milk quality and reduce the wean-to-oestrus interval (Wilson et al., 1996). High protein levels can also improve the second litter size in primiparous sows (Tritton et al., 1996).

McNamara and Pettigrew (2002) profiled protein intake at two levels. Sows consuming the highest protein (863g CP/day: 59g Lysine/day) lost least weight. Sows consuming the lowest protein (678g CP/day: 47g lysine/day) tended to produce lower litter gain, which was most evident in the last week of lactation. This decreased piglet growth by 2kg per litter in the last 3 days of lactation compared with the high protein and control diets.

8.4 Amino Acids

For sows with a low feed intake and substantial tissue mobilization during lactation (usually first and second parity sows), Threonine is a critical limiting AA. For sows with a high feed intake and limited tissue mobilization, Valine appears to become increasingly important during lactation (Kim et al., 2001). A study by Soltwedel et al. (2006) indicates that the ideal ratio of Thr:Lys is 0.63 and the ideal ratio of Val:Lys is 0.81 for lactating sows. These values confirm the BSAS Nutrient Standards (2003).

Ideally, lactation diets could be designed for sows based on their expected levels of tissue mobilization during lactation, which is related to their parity (Kim et al., 2001). A parity split feeding system could be a way of applying dynamic ideal protein concept in feeding lactating sows for maximum performance (Kim et al, 2009). However, practical application of a phase feeding and a parity-split feeding is challenging. Multiple feeding lines and feed storage bins would be required, and most farms are not ready to handle these yet. Top-dressing of AA is an alternative way to cope with parity-split feeding. Specific parity groups can be top-dressed for deficient nutrients, which can be done manually, eliminating the needs of additional feeding lines. However, the economic value of these slight improvements remains to be seen.

8.4.1. Lysine.

Kim et al. (2001) and Soltwedel et al. (2006) concluded that Lysine is the primary limiting AA in sows. Tritton et al. (1996) suggest that, for first litter sows during lactation, a daily lysine intake of 55g/day is required, however Yang et al. (2009) suggests that gilts require up to 84g lysine/day during lactation, both of which exceed the BSAS (2003) recommendations (33.1 – 53.3g/d). Yang also found that, higher lysine levels (83.7 vs. 64.4 g lysine/day) increased the concentrations of total solids, protein and non-fat solids in colostrum and milk. The number of piglets at weaning was also greater and litter wean weight increased by 8.5%.

When lysine intake is inadequate, sows mobilize body protein and fat to support foetal development, milk production and litter growth. Yang et al., (2009) used sow diets with a low lysine (0.6%) or high lysine (0.8%) content from day 80 of gestation followed by two lactation diets: low (1%) and high (1.3%) lysine. The low lysine levels were similar to BSAS Nutrient Standards (2003). The increase in dietary lysine levels during gestation and lactation reduced weight and backfat loss consistent with previous work (Mejia-Guadarrama et al. 2002; McNamara and Pettigrew, 2002). The total number of pigs born did not differ among treatments, but the average birth weight was greater in sows fed higher lysine diets during gestation (Yang et al., 2009). The number of piglets at weaning was greater in sows fed higher lysine diets during lactation. These piglets also grew faster, which resulted in an 8.5% greater litter weight at weaning (Yang et al., 2009).

8.4.2. Arginine

Young animals have a high requirement for Arginine (Li et al., 2007). However, Arginine intake from sow's milk is low relative to piglet requirement (Kim et al., 2007). Estimates based on Arginine supply from sow's milk and requirement of piglets, shows that sow's milk provides less than 40% of the daily requirement in 7 day old suckling pigs (Wu and Knabe, 1995; Wu et al., 2004) indicating that Arginine deficiency is a factor limiting maximal weight gain of milk-fed piglets (Wu et al., 2004; Kim et al., 2007). Therefore, increasing milk Arginine production could enhance piglet growth.

Mateo et al. (2008) supplemented pregnant gilts with 1% L-ArginineHCl from day 30 of gestation to weaning. Litter size, sow body weight, backfat thickness and feed intake during lactation did not differ among treatment groups. Piglet weights from sows fed the Arginine-supplemented diets during lactation were greater throughout lactation compared with piglets from control-fed sows. On average, piglets from Arginine-supplemented sows gained 20g more per day, or 420g more during the 21 day lactation, compared with the piglets from sows in the control groups. As litter weight gain is correlated with milk production or nutrient concentrations in milk, increased piglet or litter weight gain in Arginine-supplemented sows may indicate increased milk production or increased nutrient concentrations in milk. Indeed, total AA content in milk was greater ($P<0.05$) for sows fed the Arginine-supplemented diets particularly in the first week of lactation corresponding with increased weight gain of piglets. This improved the overall piglet growth performance during the entire lactation period (Mateo et al., 2008).

8.5. *Conclusion*

- At high feeding levels sows are able to produce more milk which leads to greater piglet growth and reduces sow body loss. Temperature is a key driver of sow intake during lactation.
- Adding fat to the lactation diet can reduce mortality and increase growth rate of piglets; however, this can be at the expense of sow body weight.
- CLA at low doses can reduce piglet body weight, but at 1% inclusion CLA can increase birth and weaning weight and increase litter size.
- Protein restriction reduces sow and piglet performance
- Protein and lysine levels higher than BSAS recommendations can improve litter performance and reduce sow weight loss.

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