Nutritional Strategies for the Sow to Cope with an Increase in Litter Size

B.P. Mullan[1], R.H. King[2] and J.C. Kim[1]

[1]Department of Agriculture and Food, South Perth, WA 6151. [2]RHK Consulting, Essendon, VIC 3040.

Introduction

Increasing the number of pigs sold per sow per year is a key component of profitability in commercial pig production. Assuming that we can make significant increases in the number of piglets born alive through genetic selection and improved reproductive technologies, the real challenge is to then rear all of these without any detrimental effect on the sow. We also can't afford to be just interested in piglet survival, because we know that what happens pre-weaning has a large influence on performance thereafter, which in turn can have a big impact on cost of production and hence profitability. The weight of the piglet at birth and the quality of the piglet at weaning are thus important considerations, and strategies involved in maximising survival may not be the same as those required to also optimise piglet quality or long-term performance.

If the sow has the same number of functional teats as there are piglets born alive, then it is theoretically possible for the sow to rear all of those piglets through to weaning. However, some form of artificial rearing of piglets will be necessary as part of any overall strategy because of the likelihood of there not being sufficient lactation capacity available at all times.

It is also difficult to consider nutritional strategies in isolation from other husbandry and management issues. For example, only small gains can be made in increasing nutrient intake during lactation by changing the nutrient content of the diet if there is a limitation on feed intake related to environmental factors. Therefore attention to detail in all areas is required if we are to fully capitalise on the genetic gains that are possible, and many of these come under the banner of management. The aim of this paper is to consider those factors, from a nutritional perspective, that are important if we are to benefit from the increased number of piglets to be born through improvements in genetic and reproductive technologies.

The quality piglet - setting our goal

The weight of the pig at weaning, and indeed at birth, bears a strong positive relationship to subsequent growth and the weight at some time in the future (King, 2003). Hence weaning weight has to be a key performance target in pork production because of the overall influence that it has on growth in the growing and finishing stages. In addition, processes occurring before and after weaning may influence carcase quality of pigs at slaughter (105 kg live weight; Pluske *et al.*, 2005). In the case of large litters, are we prepared to sacrifice some of the benefits of weight at weaning in return for increased numbers?

If we accept that we are not just interested in the number of piglets that survive through to weaning but also on how well these pigs grow thereafter, then we need to define what we mean by a quality piglet. One definition might be an animal that has the capability to withstand the stress of weaning without the need for routine medication and specialist care, and that it grows to its potential from weaning through to slaughter. In simple terms, it is an 'easy to care for' animal. It is relatively easy to set a target weight at weaning, adjusted according to the age at weaning, but a useful target should also take into account a measure of variability. Even though we may be happy if we reach our target average weaning weight, we haven't been successful if the lightest 25 percent of pigs that are weaned subsequently negate the gains that we have made in increased numbers by requiring extra resources (eg. feed, housing, management) through to sale. Payne *et al.* (1999) discussed the impact of variation on long term performance and profitability, and it is already a major problem faced by the pork industry. Having to deal with an increase in variation is a real risk if we increase litter size substantially.

How can we monitor how successful we have been at producing quality piglets? At present it is primarily based on live weight at weaning, but perhaps we need to start taking a more novel approach. For example, it might include the percentage of pigs requiring treatment during a set period or, more likely, the proportion of pigs reaching a target live weight at a set age (eg. 10 weeks). With the likely introduction of technologies that will allow us to individually identify pigs, perhaps automatically monitor their body temperature and obtain regular estimates of their weight and possibly feed intake, it may become relatively easy to monitor performance of individual pigs in a group situation. This in turn will allow us to better measure how successful our management has been and to thus make changes to deal with the consequences of larger litters. With an increasing proportion of pigs now being grown out on contract, those with responsibility for the rearing of weaner pigs will also want to know more about what has happened to that piglet pre-weaning since it has such a big effect on how that animal performs thereafter.

The sow

How and what we feed the sow from the time of selection as a breeder throughout the breeding cycle will have an important bearing on our capacity to rear as many piglets as possible from large litters. This starts with maximising piglet birth weight, but then must include aspects of quality and quantity of colostrum and milk through to subsequent effects on reproductive performance of the sow.

Birth weight

Much of the published work on the response of birth weight to maternal feed intake was conducted with older genotypes between the mid 1960s and the mid 1980s. Pluske *et al.* (1995) reviewed this work and concluded that the relationship between maternal energy intake and birth weight was linear for sows but curvilinear for first-litter sows. In other words, with young sows there is an increase in birth weight as energy intake of the sow increases to a point at which the sow directs a greater proportion of that additional energy into building up her own body reserves rather than continue to increase birth weight. Data presented by Foxcroft *et al.* (2006) demonstrates the impact of increased litter size on both average birth weight and the proportion of piglets born in the various weight categories (Table 1). This group argue that the introduction of hyperprolific females into the breeding herd needs careful consideration in the context of the overall efficiency of pork production. In other words, it is not just the number of piglets produced that is important, but also the quality.

While the sow is very good at buffering the developing foetus against nutritional inadequacies during pregnancy, it is generally recommended that feeding level is increased during the last three to four weeks of gestation to coincide with the increased demand for nutrients. With the introduction of group housing systems it is going to become more difficult in many situations to guarantee that the nutrient requirements of the sow, and hence birth weight of piglets, is optimised. Of course if we could identify those gilts and sows that we knew were going to have a large litter and feed them accordingly then that would greatly improve the efficiency with which we use feed in the breeding herd. There have been efforts in the past to relate litter size to blood parameters such as oestrone sulphate at about four weeks into gestation (Moenter *et al.*, 1992). While these measures may not be able to accurately quantify subsequent litter size, they may be used to discriminate between low, medium and high litter sizes and may offer the opportunity to manage differently those sows that are likely to have much larger litter sizes.

Table 1. *Effect of litter size at birth on the average birth weight of pigs born to hyperprolific sows in commercial production in France (Foxcroft* et al.*, 2006).*

		Percentage of pigs within specific weight ranges			
Total pigs born	Average birth weight (kg)	<1.0 kg	1.0 to 1.5 kg	1.5 to 2.0 kg	> 2.0 kg
12.6	1.49	7	37	43	13
17.4	1.27	15	57	26	2

Colostrum

Colostrum is the first secretion of the mammary gland. The two major roles of colostrum are to provide the piglet with energy for heat production and metabolism, and with passive immunity to prevent infections (Le Dividich, 2006). Ensuring piglets receive sufficient colostrum is essential regardless of litter size, but obviously as litter size increases the likelihood of some piglets not receiving sufficient colostrum also increases. Le Dividich *et al.* (2005) have extensively reviewed the role of colostrum and its production by the sow. The most important constituents of colostrum are the immunoglobulins (Ig), which are initially high but drop rapidly during the first 24 h of secretion. The concentration of IgG is halved within six hours after the first piglet is born, and so with an increase in litter size it therefore becomes more important to use management techniques to ensure all piglets have equal access to colostrum.

There is a large variation in colostrum yield among sows, but litter size, which is known to have a strong influence on milk production, does not affect colostrum yield (Devillers *et al.*, 2007). While weight of the sow, parity, duration of gestation and induction of farrowing were all characteristics of sows that contributed to variation in colostrum yield, no single factor had a clear effect. It is therefore difficult to see how feeding strategies of sows in gestation could be used to have a significant impact on colostrum production. Production of colostrum by the sow and its consumption by the piglet result from a close interaction between the sow and her litter because both are dependent on the sow's ability to produce colostrum, and on that of the piglets to reach and extract colostrum from the udder (Le Dividich, 2006).

An increase in litter size makes it all the more important to find ways to stimulate the production of components of colostrum, such as the immunoglobulins, through what we feed the sow pre-farrowing. For example, Funderburke (2002) fed sows mannan oligosaccharides for the three weeks pre-farrowing, and some of the improvement in piglet weight at weaning and reduction in pre-weaning mortality was attributed to a significant improvement in the immunoglobulin concentration in colostrum. Given the importance of colostrum to piglet health and subsequent performance, identifying ways to manipulate its production and composition is clearly an important area of research. Some sows have characteristics of colostrum production that are better suited to rearing a large litter than others, but of course, unless we have a simple marker to identify these animals then we can't use this in a practical sense. To what extent the ability of the sow to produce colostrum has increased in the more prolific genotypes is unknown (Le Dividich., 2006).

Milk yield and composition

Piglet growth can be increased either by increasing the quantity of sow's milk produced or by increasing its concentration of protein (Williams, 1995). Several studies have been conducted to attempt to change the protein and amino acid content of sow's milk. For example, King *et al.* (1993) compared diets containing between six and 24 percent crude protein, and found a small, non significant increase in milk protein (from 53 to 59 g/kg). Other studies (see review by Williams, 1995) have been extended to the level of amino acids, and even then the amino acid profile of the sows' milk was relatively constant with minimal variation between the various estimates.

Even when the body protein content of gilts was manipulated such that amino acids for milk production were supplied by either endogenous or exogenous sources at high or low levels, the proportion of protein in milk was hardly changed (Revell *et al.*, 1998). The sow is thus well able to buffer milk production during lactation by mobilisation of body reserves to cover any shortfall. Although the composition of milk, particularly its protein content, remains fairly constant the total output of milk can vary substantially depending on a number of factors; the protein and energy supply in the diet and the endogenous supply of precursors or the body reserves of animals (Williams, 1995).

Milk production in the sow is largely a factor of stage of lactation and litter size, reaching a maximum during the third to fourth week of lactation and increasing linearly with litter size (Auldist and King, 1995). Estimates of milk yield as measured by dilution techniques by King *et al.* (1989) and Auldist *et al.* (1994) suggested that a sow with a litter of 10 would be producing approximately 10 kg/d, somewhat more than was estimated in an earlier study by Elsley (1971; Figure 1). Furthermore, sows suckling 14 piglets were capable of producing in excess of 15 litres of milk/d in early lactation (Auldist *et al.*, 1994). Thus it seems that the lactating sow can provide more milk if there are greater numbers and heavier pigs, particularly in early lactation, and only in later lactation, milk yield of sows may be limiting in larger litters. A more recent study by Miller (unpublished) recorded milk yields of 13.7 kg/d for primiparous sows and 19.6 kg/d for multiparous sows on d 21 of lactation in an Australian commercial piggery, suggesting that perhaps milk yield has increased substantially during the last 10 to 20 years. However, since there hasn't been a dramatic shift in either litter size or weaning weights during this same period then it seems unlikely that there has been such a big change in milk production of sows. Perhaps it is appropriate to repeat studies like that of Auldist *et al.* (1994) to look at the relationship between litter size and milk production of current genotypes and with litter sizes beyond the 14 used in that study. This would then enable calculations to be done to more accurately predict the nutrient requirements for sows nursing large litters, although reasonable estimates may be made from average litter growth rates between birth and weaning, assuming a relatively stable conversion of nutrients from milk into tissue gain.

A number of cross-fostering experiments have clearly demonstrated that piglet weight is an important controlling factor in determining milk intake and consequently sows' milk production (Auldist and King, 1995). The results support the general hypothesis that sows' milk yield is primarily affected by the demand for milk by piglets during early lactation. As lactation proceeds the supply of substrates, governed by nutrient intake of the sow and the availability of body reserves, becomes increasingly important in determining milk production. This suggests therefore that maximising nutrient intake of the sow during lactation, certainly after the first week, is of high priority.

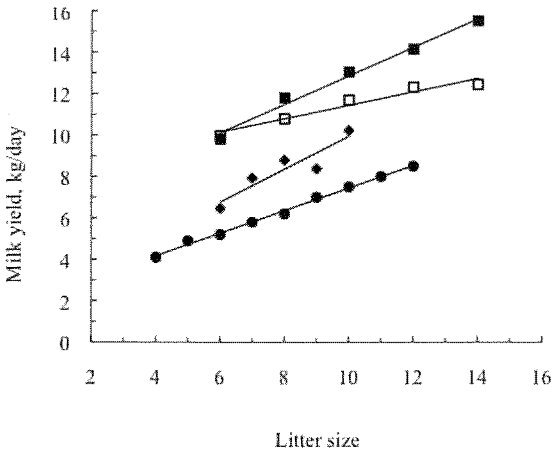

Figure 1. *Comparison of the relationship between milk yield and litter size. (■, Auldist* et al., *1998), early lactation; (□, Auldist* et al., *1998), late lactation (●, Elsley, 1971; ◆, King* et al., *1989).*

Nutrient intake of the sow

Feed intake

Many sows fail to eat sufficient amounts of feed to meet the demands of lactation. The most recent measure of feed intake by sows during lactation was by Jones and Hermesch (2007) who studied the effect of both season and parity on the feed intake of sows during a 21 d lactation in a commercial piggery in south eastern Queensland. Mean feed intake was 5.11 kg/d and the difference in intake between summer and winter months was approximately 1.0 kg/d (5 versus 6 kg/d), and there was a similar magnitude of difference between primiparous and multiparous sows. This result is similar to an earlier study on five commercial farms by Handley *et al.* (1995) in which average intake of first litter sows was 5.46 kg/d and for older sows 6.19 kg/d. Despite estimates that 20 percent of first and 30 percent of second parity sows having reduced lifetime performance due to low feed intake in lactation (Hermesch and Jones, 2007), feed intake is rarely measured and in most cases the amount of feed consumed is over estimated during this critical phase of production.

In a study involving over 19,000 litters, Koketsu *et al.* (1996) examined the relationship between litter size and feed intake of sows during lactation (Figure 2). As litter size increased from 3 to 13 piglets, average feed intake of the sow increased from 4.4 to 5.0 kg/d, but as litter size increased further there was no further increase in feed intake. A similar response is clear from the results of O'Grady *et al.* (1985) and Auldist *et al.* (1998), suggesting that voluntary feed intake of lactating sows nursing relatively small litters increases with increasing litter size, but that at higher litter sizes other factors begin to limit intake.

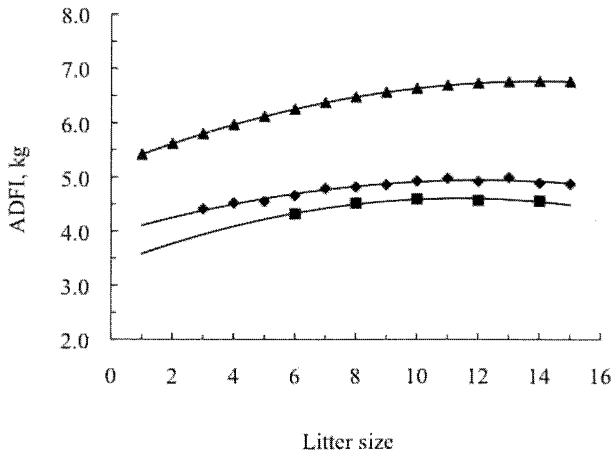

Figure 2. *Effect of litter size on voluntary feed intake of lactating sows. (■, Auldist* et al., *1998; ◆, KoKetsu* et al., *1996; ▲, O'Grady* et al., *1985).*

Fortunately, the sow is able to mobilise her own body reserves to supply the nutrients required for milk production, rather than conserving these reserves to ensure a prompt start to the next reproductive cycle (Mullan and Williams, 1989). This means that a hidden cost of increasing litter size could be a reduction in subsequent reproductive performance (eg. weaning to oestrus interval, subsequent litter size). If this happens, then while we have sows with the genetic potential for large litter size, their lifetime productivity may not be substantially better than what it is at present.

There are numerous factors that influence feed intake of the lactating sow and these have been well documented (Eissen *et al.*, 2000; King, 2003; Bunter *et al.*, 2007). Feed management factors such as *ad libitum* versus frequent feeding, wet versus dry feeding etc., may affect voluntary feed intake but will not be discussed in detail in this paper. One of the major factors, however, that does warrant some discussion is ambient temperature because it is probably the factor having greatest impact in Australian pork production, yet is one which is relatively easy, even though perhaps expensive, to correct.

The ideal temperature for lactating sows is approximately 20°C, whereas that for piglets is closer to 30°C. Numerous studies have been conducted to examine the response of the sow to high ambient temperatures, and the primary response is a decline in feed intake during lactation, an increase in the loss of body reserves as the sow attempts to maintain milk production, and eventually a reduction in piglet growth rates (eg. Black *et al.*, 1993). When multiparous sows were exposed to a high ambient temperature (27-30°C), daily feed intake was decreased by 28 percent compared to sows within the zone of thermal comfort (18-20 °C; Prunier *et al.*, 1997). More importantly was the observation that primiparous sows exposed to high ambient temperature could not effectively mobilise body reserves for milk production as compared to those housed in their thermal comfort zone. High temperatures reduce milk yield indirectly by reducing feed intake, but also have an adverse direct effect on milk yield. Mullan *et al.* (1992) found that sows housed at higher temperatures produced less milk than those kept under thermoneutral conditions, despite receiving the same amount of feed during lactation. Black *et al.* (1993) suggested that exposure to high ambient temperatures may redirect blood flow to the skin and away from other tissues such as mammary glands and hence reduce milk production. This notion was supported by the study of Renaudeau *et al.* (2003) who demonstrated that the amount of blood (measured at the pudic mammary artery) required to produce 1 kg of milk by the mammary gland was higher at 28°C than at 20°C (482 versus 452 L/kg, respectively). This finding indicates that under heat stress sows use a greater proportion of blood flow to irrigate capillaries in the skin.

Options to minimise the effect of heat stress on reproductive performance and weaner performance include early weaning (Spencer *et al.*, 2003), providing creep feed (Renaudeau and Noblet, 2001) and supplying milk replacer during lactation (Spencer *et al.*, 2003). Of these, supplying milk replacer has the greatest potential for meeting the demands of a larger litter provided systems are in place to allow it to be done with minimal human intervention. Cooling systems may also have a role in maintaining the lactation performance of sows. A recent study applied a floor cooling system to sows exposed to ambient temperatures of 21.5 to 29.5°C and found that floor cooling decreased sow body weight loss during lactation, increased feed intake and milk production, and decreased weaning-to-oestrous interval (Silva *et al.*, 2009). While not a nutritional strategy *per se*, control of ambient temperature does have a large bearing on the capacity to optimise nutrient intake of the sow during lactation and it would seem that in most cases an investment of capital into appropriate farrowing accommodation is required if we are to meet the needs of large litters. Ensuring the dietary electrolyte balance was above 300 mEq/kg rather than at either 120 or 200 mEq/kg was also found to be beneficial to piglet growth rates and sow performance during summer months (Lizardo *et al.*, 2009), but like most studies this research was done with a relatively modest litter size as compared to what we are considering might be the norm.

Composition of sow diets

Dietary energy

Allowing for maintenance and milk production, the requirement for digestible energy (DE) can be calculated. For example, a sow with a body weight of 200 kg and rearing 12 piglets would require an average intake of 100 MJ DE/ during a 28 d lactation (Close and Cole, 2000). As suggested already in this paper, records of voluntary feed intake by sows in commercial piggeries indicates an average intake close to 6 kg/d, in which case the diet fed during lactation would need to contain 16.7 MJ DE/kg to meet the energy requirements of the lactating sow. Lactation diets in commercial piggeries would commonly contain between 14.0 and 14.5 MJ DE/kg, and given that the calculated requirement by Close and Cole (2000) was for a litter of 12 then it is hardly surprising that there is concern about the sow's capacity to consume sufficient energy to meet the requirements of milk production with a large litter without losing considerable body reserves.

Meeting the nutrients required for milk production is a combination of that supplied in the diet and that available from the sows' own body reserves. A good example of how the sow mobilises her own body reserves to meet the demands of lactation is in the study of Mullan and Williams (1989). When the energy intake of lactating sows was restricted to around 24 MJ/d, piglets nursed from sows with low body reserves at farrowing grew less than piglets suckling from sows with higher levels of body reserves at farrowing (167 versus 200 g/d, respectively). Modern genotypes would have a far greater proportion of body protein and less body fat than those animals used in this experiment, but there is no reason to believe why the same principles of using body reserves would not apply.

A number of studies (see review by Williams, 1995) have been conducted to examine the relationship between maternal energy intake and litter growth rate, although few of these included any measure of milk yield. These results show that the response of milk output to energy intake is variable reflecting indirect measures of milk output (measured by piglet growth) and factors such as weight of sows, their parity and body reserves, and the protein content of the diets fed during lactation. Williams (1995) makes the point that *ad libitum* intake in these studies, at least for gilts, was generally below 70 MJ of metabolisable energy (ME)/d. To override the normal mechanisms that limit food intake, Pluske *et al.* (1995) fed gilts through a stomach cannula and was able to achieve intakes of 42, 75 or 104 MJ ME/d. A limit to milk production was demonstrated since there was no response in piglet growth beyond an intake of 75 MJ ME/d. The extra energy that the super-alimented gilts received went not into milk but into body reserves. A similar study, this time with sows, by Matzat *et al.* (1990) showed a linear response between milk output and maternal energy intake. Thus it seems that daily energy intakes above about 70 MJ DE may not result in increased milk yield in first litter sows, but older sows may respond to increased feed intake and energy supply above these levels during lactation. Williams (1995) concluded that these results might mean that gilts and sows partition energy differently during lactation as a way of protecting the maternal growth processes in gilts, but the other conclusion was that the ceiling in milk output reflects nothing more complex than a shortage of secretory cells in the mammary tissue of gilts.

The effects of changes in the energy concentration of lactating sows diets has received some attention in recent years in attempts to improve voluntary energy intake and lactation performance. In a recent study Smits *et al.* (2007) tested the hypothesis that litter weight gain would be increased with dietary energy levels of lactation diets offered to genetically lean first-litter sows during summer. Despite a large difference in the DE content of lactation diets (13.0 to 15.3 MJ DE/kg), there was no significant effect on feed intake of the sow or piglet growth rates during a 27 d lactation with litters of 10.5 (Table 2). Maximum energy intake was still around 70 MJ DE/d, and while the higher energy diets did reduce weight loss during lactation there was no effect on piglet growth rates. There may have been a difference in piglet growth rates if litter size was greater, but this result also supports the general philosophy that the sow, particularly the first litter sow, is not as interested in maximising milk production as we might be, but is more concerned about conservation of her own body reserves during the lactation period when they are still capable of depositing appreciable amounts of lean tissue. Therefore, especially with primiparous sows, an increase in litter size may be offset by a decline in weaning weights, because of an intrinsic limit to milk production.

Table 2. *The effect of dietary digestible energy (DE) level on the performance of first-litter sows (Smits* et al.*, 2007).*

Dietary energy level (MJ DE/kg)	13.0	13.6	14.2	14.7	15.3	P value
Sow intake (kg/d)	4.7	4.7	4.6	4.7	4.7	NS
Energy intake (MJ DE/d)	61	64	65	69	71	
Litter growth rate (kg/d)	1.79	1.64	1.84	1.78	1.79	NS
Piglet growth rate (g/d)	201	192	209	205	209	NS
Piglet weaning weight (kg)	6.9	6.7	7.1	7.0	7.1	NS
Sow weight loss (kg)	18.6	12.5	15.4	12.4	10.2	$P<0.01$
Sow P2 loss (mm)	3.5	3.3	3.4	2.7	2.8	NS

NS, not significant.

Dietary protein

A number of studies have been conducted to examine the relationship between protein intake of the sow during lactation and litter growth rate and/or milk production (King *et al.*, 1993; Tritton *et al.*, 1996; Jones and Stahly, 1999; Yang *et al.*, 2008). For example, King *et al.* (1993) fed first-litter sows diets that ranged in protein content between 6.3 and 23.8 percent during a 24 d lactation with a litter size of nine (Table 3). There was a significant linear response in growth rate of piglets and in milk yield, with the effect on yield being greater in late lactation than in early lactation. The conclusion from this study was that primiparous sows required a diet containing 200 g crude protein/kg or 12.8

g lysine/kg to maximise nitrogen balance during lactation, whereas only 130 g crude protein or 8.5 g lysine/kg seemed to be required to maximise milk yield and litter growth rate (Table 3).

Table 3. *The effects of dietary protein concentration on the performance of first-litter sows during lactation (King* et al.*, 1993).*

Dietary protein (g/kg)...	63	98	133	168	203	238	Significance[a]
Feed intake (kg/d)	3.79	3.71	3.81	3.80	3.76	3.63	NS
Protein intake (g/d)	239	364	507	638	763	864	
Weight loss of sows (kg)	27.4	23.3	25.3	22.3	23.8	24.5	NS
Preweaning growth rate (g/d)	179	193	215	228	213	216	***
Milk yield, early lactation (kg/d)	7.79	8.02	9.12	8.89	8.39	9.19	*
Milk yield, late lactation (kg/d)	7.02	7.40	8.42	8.40	7.76	8.90	**

[a]Linear response; *, P<0.05; **, P<0.01; ***, P<0.001; NS, not significant.

The results of the study by Mahan and Mangan (1975) also showed that if a sufficient amount of exogenous protein is not available during lactation, body protein reserves will have an effect on milk production and lactation feed intake. Clowes *et al.* (2003) analysed 16 experiments and demonstrated that when sows mobilise more than 16 percent of their body protein during lactation, wean-to-oestrous interval starts to increase.

In a more recent study, Hewitt *et al.* (2009) fed primiparous sows a diet that contained either 0.58 or 0.90 g available lysine/MJ DE (14.3 and 14.5 MJ DE/kg, respectively) during a 21 d lactation. Litter size was set at either 7 or 12 piglets. With a litter of 12 piglets, there was no significant difference in litter weight gain nor in weight loss of the sow despite a large difference in lysine intake, a result which is somewhat surprising given the results from previous studies (Table 4). However, there may have been differences in the composition of that weight loss between the two protein treatments. The study did demonstrate, however, that a consequence of having a larger litter was a reduction in weight gain of piglets and a possible reduction in subsequent litter size. As with energy intake it would seem that we may have to accept some reduction in performance as a consequence of increased litter size, especially with first-litter sows.

Table 4. *Response of sows and progeny to amino acid content of the lactation diet and litter size (Hewitt* et al.*, 2009).*

Litter size...	12	7	12	7
Available lysine/MJ DE...	0.90	0.90	0.58	0.58
Feed intake (kg/d)	5.63	5.57	5.70	5.70
DE intake (MJ/d)	82	81	82	81
Lysine intake (g/d)	86	86	56	56
Sow weight loss (kg)	29	23	31	23
Average piglet gain (kg)	3.71[a]	4.36[b]	3.67[a]	4.55[c]
Total born, parity 2	10.9	11.5	10.8	11.3

[abc]Means in a row with different superscripts differ significant (P<0.05).

Dietary fat

In an early review by Pettigrew (1981), it was concluded that supplementation of diets with fat during late gestation and lactation could increase milk production and the concentration of fat in milk. A more recent study by van den Brand *et al.* (2000) has examined the interaction between feeding level and dietary energy source. In this study sows were fed a diet high in either fat or starch at either a high (44 MJ/d) or low (33 MJ/d) level of energy intake. At the low feeding level, energy source had no effect on milk production, milk composition or litter growth rate. However, at the high feeding level, sows fed the fat-rich diet (81g/kg tallow) produced higher milk fat (84 versus 69 g/kg), higher milk energy concentrations (5.38 versus 4.77 kJ/g), and higher piglet body fat concentration (152 versus 135 g/kg) than sows fed the starch-rich diet. The results suggest that even at what was a relatively low level of energy intake, dietary fat was preferably used for milk fat synthesis and increased body fat gain in piglets while decreasing the loss of sow fat reserves. It is obviously important to look at more realistic levels of energy intake with litters of at least 12 to see if dietary fat has a similar effect.

Often the effects of fat on lactation performance are observed when different levels and sources of fat are imposed during gestation. For example, Lauridsen and Danielsen (2004) showed that at 80 g/kg inclusion, supplementation of animal fat, coconut oil, palm oil or sunflower oil increased litter weight gain whilst supplementation of fish oil and rapeseed oil did not affect progeny performance. In this study it was also evident that the milk fatty acid composition was affected by dietary fatty acid composition. Laws *et al.* (2009b) fed multiparous sows with either a control diet (13.1 MJ ME, 127 g/kg crude protein, 45 g/kg fat) or a diet similar to the control diet but with 10 percent extra energy (3.93 MJ/d) in the form of palm oil, olive oil, sunflower oil or fish oil. The diets were fed during either the first half (0-60 d) or second half (61-115 d) of gestation. Results showed that supplementation of sunflower oil during the first half of gestation increased the proportion of low birth weight piglets (20%) while supplementation of olive oil during the same period decreased the proportion of low birth weight piglets (5%) compared with control, palm oil and fish oil supplemented sows (9%, 11% and 12%, respectively). Another study by the same research group (Laws *et al.* 2009a) observed that sows fed sunflower oil during the first half of gestation had greater gestational gain in P2 backfat than sows supplemented with olive oil. This possibly indicates that extra energy supplemented in the form of sunflower oil might be partitioned to maternal gain rather than placental development. This research highlights that energy supply in the form of polyunsaturated fatty acids may increase the proportion of low birth weight pigs while energy supply in the form of monounsaturated fatty acids may reduce the incidence of low birth weight piglets. This could have important ramifications with an increase in litter size likely to decrease average piglet birth weights and is worthy of further consideration.

Dietary fibre

Again the effects of fibre on lactation performance often arise from changes in the levels and sources of fibre that are offered during the preceding lactation. Increasing the fibre content in diets for gestating sows is one way that we may be able to increase nutrient intake of the sow during lactation. Van der Peet-Schwering *et al.* (2003) demonstrated that feeding high fermentable non-starch polysaccharides (NSP, soybean hull and sugar beet pulp, NSP 123 versus 300g/kg) decreased body weight and backfat gain during gestation but increased lactation feed intake by 9 percent. Therefore high levels of fermentable non-starch polysaccharides during gestation and high levels of starch during lactation could be the most effective feeding strategy to maximise lactation feed intake and milk production. However, to be really effective we would need to get an increase in intake during the second and third week of lactation when nutrient demand is at its peak, rather than during the first week of lactation.

The type of fibre is another consideration. Vestergaard and Danielsen (1998) have demonstrated that feeding fermentable fibre (sugar beet pulp) decreased gestation feed intake (2.5 versus 3.2 kg due to energy density of 8.7 versus 7.0 MJ of net energy (NE)/kg) and increased lactation feed intake (5.5 versus 5.1 kg/d) compared with feeding the same amounts of mixture of insoluble fibre (grass meal, wheat bran, oat hulls). Feeding mixed insoluble fibre did not increase lactation feed intake compared with sows fed a standard diet. This result implicates that insoluble fibre may have minimal effect on the development of gastrointestinal tract whilst soluble fibres supplies energy such as butyrates upon fermentation which is pivotal for mucosal development of the gastrointestinal tract.

In a recent study, Quesnel *et al.* (2009) fed sows either a low fibre (172 g/kg neutral detergent fibre (NDF), 33 g/kg acid detergent fibre (ADF)) or a high fibre diet (307 g/kg NDF, 110 g/kg ADF from sunflower meal, wheat bran, sugar beet pulp and soybean hull) during gestation. Energy intake during gestation was standardised at 33 MJ/d, and all sows were fed a standard diet during lactation. During lactation, sows that had been fed the high fibre diet during gestation ate 940 g/d more feed than sows fed the standard fibre diet. Piglets nursed from the sow fed a high fibre diet grew faster (244 versus 217 g/d, for 28 d lactation) than piglets nursed from the sow fed a standard fibre gestation diet. The benefit of feeding a high fibre diet during gestation on piglet performance predominantly occurred in the first week of lactation (220 versus 194 g/d). Such a study would be worth conducting with large and small litter sizes.

Dietary additives

It is not within the scope of this paper to review all of the possible additives that could be used to stimulate milk production either directly or indirectly. Much of the research has probably been done with relatively low litter sizes and with genotypes not representative of commercial production, which makes having confidence to implement the results difficult. Some additives are reported to stimulate feed intake of the sow and possibly milk production under some circumstances, whereas products such as betaine can help alter the maintenance requirements of the sow and potentially direct a greater proportion of nutrients into milk production. Other additives, such as organic minerals, may not have a direct effect on milk production but may still improve the survival of piglets and/or the subsequent reproductive performance of the sow and so should be considered as part of any feeding strategy.

Alternative manipulation with metabolic modifiers

Tremendous improvements in the efficiency of production in growing pigs has been achieved in the past 20 years through research and subsequent adoption of metabolic modifiers, in particular the use of somatotropin and ⊠-agonists (Dunshea and Walton, 1995). The vast majority of this research has been conducted with the grower-finisher pigs where, undisputedly, the greatest gains for the pork industry can be made. In more recent years the possibility of using these same technologies to help improve performance of the lactating sow has been investigated.

Somatotropin

Harkins *et al.* (1989) administered porcine somatotropin (pST) between d 12 and 29 of lactation and showed an increase in milk production of 22 percent on d 28 of lactation (11.0 versus 9.0 kg/d), with a similar response in piglet weaning weight (6.52 versus 6.17 kg). However, sows treated with pST consumed less feed during the treatment period (4.8 versus 5.4 kg/d) and lost more weight (-13.6 versus -7.0 kg) and backfat (-3.7 versus -1.2 mm). However, in other studies sows treated with pST showed no response in either milk yield or piglet growth rates, but still consumed less feed and lost more weight (Cromwell *et al.*, 1992; Toner *et al.*, 1996). King (2000) suggested that sows' milk production may respond to pST only when sows have heavier litters and larger litter size which place sufficient nursing demand on the sow to exceed the intrinsic limit to milk yield. It would also be important that nutrient intake of sows was not a limitation, so it might be a strategy that could be used with particular multiparous sows that fit certain criteria. Research currently underway in Australia will hopefully determine the suitability of this technology as a way to counter the demands of large litters.

Ractopamine

Pain *et al.* (2007) supplemented 10 ppm of ractopamine from d 1 to 13 of lactation and 20 ppm from d 13 until weaning and found that ractopamine supplementation during lactation did not alter lactation weight loss but increased milk fat on d 3 and decreased milk protein on d 13 and 20. Ractopamine supplementation to the lactating sow also decreased piglet weight gain between weeks 3 to 4 of lactation (260 versus 310 g/d), so on that basis it would not seem to be a strategy for increasing milk production. However, it may have a role in gestation diets if it can be used to manipulate the body composition of sows pre-farrowing. For example, Head and Williams (1995) demonstrated that piglets suckling the lean sows grew 50 percent faster than piglets suckling fat sows, and one possibility was that increasing lean gain in gestation could increase the secretory capacity of mammary glands and therefore potential milk production post-partum. As with pST, the use of ractopamine may present opportunities for how we use nutrition to rear larger litters and the results of research currently in progress will be of great interest.

Feeding strategies over parities

When we consider how sows might be able to rear significantly more piglets, then we need to consider the different capabilities of primiparous as compared to multiparous sows. As stated previously, this might reflect differences in the way gilts and sows partition energy during lactation as a way of protecting the maternal growth processes in gilts, but alternatively may be simply a difference in secretory capacity of mammary tissue (Williams, 1995). There is certainly greater attention given to how gilts are selected and introduced into the breeding herd now than previously, although in many commercial piggeries more progress has still to be done. The main objective is to allow the gilt sufficient time to build up her body fat and protein reserves before breeding, and they should also be fed a higher quality diet during the first lactation to minimise the mobilisation of body reserves.

When we develop feeding programs for gilts and sows, it is common to consider the stage of gestation and lactation as two quite discrete phases. This is primarily done as a matter of convenience since it also coincides with the way sows are accommodated. However, Mahan (2007) has analysed the total mineral content of foetal tissue throughout gestation and reported that approximately 50 percent of minerals were deposited within the last 14 d of gestation. At best the feeding level of sows might be increased in late gestation, but the supply of nutrients is probably still not sufficient to meet this sudden increase in demand. In future, there may be greater attention to different feeding levels during different stages of gestation and even different diets to maximise sow performance.

It is normal to consider the period of lactation as one phase and to thus feed the same diet throughout lactation, yet the nutrient requirements of the sow during the first week are relatively low compared to that during the subsequent weeks. Perhaps there is merit in having a three-diet program for sows, with a gestation diet fed for the first 3 months of gestation, a transition diet fed for the last part of gestation and first week of lactation, and then a super diet for the remaining period of lactation. This is certainly a concept that could be modelled and is worthy of testing with gilts and sows that are known to have large litters.

The Piglet

There are a multitude of management strategies that can be employed that will have an indirect effect on nutritional requirements of the sow and, more importantly, the capacity to rear large litters. It is not appropriate to dedicate discussion in this paper to those techniques, suffice to say that they include practices such as cross fostering, age at weaning and split weaning. Those techniques with a more direct relationship with nutrition include providing piglets with creep feed and/or liquid diets pre-weaning.

Creep feeding

There is a plethora of studies in which the effects of creep feeding during lactation on weaning weight and subsequent performance have been investigated (see reviews by Pluske *et al.*, 1995; King and Pluske, 2003). The major argument for providing creep feed to piglets is that it attempts to bridge the gap between the piglet's energy requirement and nutrients obtained from the milk (Pluske *et al.*, 2005). Creep feed consumption varies significantly within and between litters. For example, Fraser *et al.* (1994) estimated that creep feed intake accounted for only 1-4 percent of the variation in bodyweight gain in piglets during the first 14 d after weaning at 28 d of age, but the majority of these studies would have been done with much smaller litter sizes than what we are now contending with.

If piglets really do use creep feed as a supplementary source of nutrients then one would expect consumption to increase with litter size, assuming that the sow has reached peak milk production. Techniques to get a qualitative measure of creep feed intake have been developed (Pluske *et al.*, 2007) and this together with the advent of new products designed to enhance piglet intake and performance might mean that it is worth doing more research in this area, particularly at larger litter sizes. The criteria upon which we base the success of a creep feeding strategy should also be taken into account, because if we can enhance gut health and prepare the piglet to cope with the stress of weaning then this might be classed as a more satisfactory long-term result as compared to weight of the piglet at weaning.

Liquid feeding

Supplementing piglets with liquid diets has been shown to give benefits to the growth of piglets pre- and post-weaning. For example, Dunshea *et al.* (1997) fed piglets liquid milk replacer both prior to weaning and in the first week after weaning. Piglets that received milk before and after weaning were 10 percent heavier at 120 d of age compared to those that suckled the sow and were weaned onto dry starter feed. Even when supplementary milk is available *ad libitum* to the piglet pre-weaning, piglets still remove a similar amount of milk from the sow (King et al,.1998). Williams (1995) suggested that the cues that arise from sow-piglet interaction still override the potential nutritional response. While providing piglets with supplementary liquid diets will increase weight at weaning and possibly lead to improved performance thereafter, it is a difficult practice to implement on a commercial scale and so is rarely done. However, it may well become a more standard practice if the economic benefits of producing large litters are large enough to warrant the investment in equipment and labour.

Total artificial rearing

It has been known for decades that young, artificially-reared (ie. weaned at 1-2 d of age) piglets given *ad libitum* access to liquid milk diets can grow at rates in excess of 500 g/d (Pluske *et al.*, 2005). Williams (2003) suggested that if studies such as these were repeated with modern genotypes, young pigs might grow even faster. Is it still beyond us to do this on a commercial scale, at least with the extra piglets in a litter that will not cope if left to compete with their littermates? If we can make big gains in litter size, then some form of artificial rearing from birth or even at 7-10 d of lactation when milk demand by piglets may outstrip the amount of milk the sow can produce, might have to be considered, especially on larger farms where the investment in infrastructure could be cost effective. An alternative would be to have a group of nurse sows that continue to lactate for as long as possible and are hence used as a home for extra piglets.

Sow research

To a large extent our knowledge of how to feed the sow to enable her to rear large litters is very poor. The vast majority of sow research was done many years ago with genotypes and litter sizes that are quite different to what we have today, let alone what we might have in the future. We therefore need to take some care in how we interpret the results of that research for future needs. It is fair to say that we don't have an accurate direct measure of how much milk modern sows can produce, especially not when rearing litters of 12 or more. Unfortunately, some of our lack of progress stems from not being able to measure milk production easily, unlike parameters such as number born alive. However, piglet growth rate should be an acceptable indirect measure of milk yield as the efficiency of conversion of milk into piglet growth is relatively constant at about 4 ml milk:1 g growth (depending upon piglet age) where piglet growth is not compromised by disease or environmental conditions. We may need to place a greater emphasis on selecting sows for their rearing ability, even if measures of milk production are indirect measures.

Whatever research is done must take into account possible long-term effects, since we know that a drain on the sows body reserves has a direct impact on her subsequent reproductive performance. High levels of culling in many countries is something that we can ill afford to continue. Unfortunately it is expensive to conduct good sow experiments, especially over several parities, but gains could be significant. We could make more use of modelling, but then this still needs validation with research. It is certainly important to take a multi-disciplinary approach to the problem, but in research and practice it still relies on getting the basics right.

Summary

In theory it shouldn't be difficult to rear 13 to 14 pigs per litter, making use of a range of management and nutritional strategies that are available. It is going to be far more difficult to then take that number beyond 14 as might be possible through genetic selection. There is no simple fix, but instead a need to address the basics of good management and not expecting something for nothing. The modern sow quite possibly has the potential to produce enough milk to rear the larger litters that genetic and reproductive technologies might deliver. However, it seems, at least with the primiparous sow, that attempts to alter diet composition and increase feed intake fails to give us the increases in piglet growth rates that we have been hoping for. Part of the reason might be that there are other limitations in place that are masking the real effects. Finally, and probably most importantly, our capacity to achieve target levels of production relies on good management and staff implementing work practices and new technologies.