Early feeding for lifetime performance of pigs

J.R. Pluske[1], H.G. Payne[2], I.H. Williams[3] and B.P. Mullan[2]

[1]School of Veterinary and Biomedical Sciences, Murdoch University, Murdoch 6150 WA, J.Pluske@murdoch.edu.au
[2]Animal Research and Development, Department of Agriculture, Locked Bag No. 4, Bentley Delivery Centre 6983 WA
[3]School of Animal Biology, The University of Western Australia, Stirling Highway, Nedlands 6009 WA

Summary

Correct feeding and management of the young pig for optimum lifetime performance is a key goal of pig producers, although the associations between these variables are often difficult to quantify. It is well recognised that commercial growth rates of suckling and weaned pigs are less than those that can be achieved when pigs are reared independently of the sow and/or fed greater quantities of a more nutritious source of nutrients such as bovine milk. However, such management interventions for attaining greater postnatal growth rates are not commonplace in the pig industry; the most common form of supplementary feeding of young pigs is creep/starter feed. A frequent question asked by producers and the feed manufacturing industry is whether pigs that achieve a 'good start' during the weaning period extend the growth advantage through to slaughter. Data presented in this paper suggest that the weight of the pig at birth explains a substantial proportion of the variation in postnatal growth. An array of different dietary and management interventions has been used to manipulate weaning weight and growth rate after weaning with the aim of maintaining a weight advantage through to slaughter. However, in many cases, the 'control' pigs appear to compensate and there are no differences in performance and carcass indices at slaughter. Despite this, recent data from experiments conducted in Western Australia show that processes occurring before and after weaning could influence carcass weight and dressing percentage of pigs that weigh more than 105 kg at slaughter. In particular, the effects of the rearing environment during suckling, the type of creep diet fed during suckling and the housing system after weaning appeared to influence carcass weights and dressing percentages.

Keywords: piglet, weaning, lifetime performance, creep feeding, milk, environment

Introduction

The young pig can grow very fast but a number of factors including the milk produced by the sow may limit the extent to which this inherent genetic potential is realised. It has been known for decades that young, artificially–reared (i.e., weaned at 1–2 days of age) piglets given *ad libitum* access to liquid milk diets can grow at rates in excess of 500 g/d (Hodge 1974; Williams 1976; Harrell *et al*. 1993). Excellent growth rates and feed conversion can also be achieved in the post–weaning period. For example, Pluske *et al*. (1996) demonstrated that individually penned weaned pigs 28 days of age, which were fed bovine whole–milk every two hours for five days grew at a rate in excess of 500 g/d and converted milk dry matter to empty bodyweight gain at ratios approximating 1.0 (Table 1). However, many of these studies were conducted with older genotypes; Williams (2003) commented that if studies such as these were repeated with modern genotypes, young pigs might grow even faster and hence demonstrate a higher potential for lean tissue gain. There is thus little doubt that the performance of the commercially reared piglet, both before and after weaning, is substantially less than the maximum that can be achieved.

Whittemore and Green (2001) suggested that the growth of a pig from birth to maturity is best described by a Gompertz function, which infers that the pig has a predetermined growth path and that there are large, fast–growing animals and smaller, slower–growing animals. The function also means that a larger genotype or a pig with a greater propensity for growth will, at any age, be bigger and grow faster than a smaller genotype, and that pigs that are heavier at birth and (or) weaning will maintain this advantage as they grow older and attain mature body weight (Williams 2003). However, the Gompertz function fails to describe the post–weaning period during which pigs usually lose weight and then slowly recover; it sometimes takes 6–9 days for them to regain their maintenance energy requirement (Pluske *et al*. 1995). The challenge to people involved in most facets of pig production is to minimize the growth check after weaning so that the young pig re–establishes its genetically determined growth path and reaches market weight as quickly as possible.

The influence of early nutrition and management on lifetime performance is clearly an important area of investigation due to its potential influence on whole–of–life productivity. Many studies on this topic have only considered the growth of piglets to a certain point after weaning, for example, to 30 kg or to 10 weeks of age, assuming that any weight advantage at this juncture would translate to a weight advantage at slaughter. This may not necessarily be the case and several studies in the past 5–10 years have facilitated further elucidation of this topic.

In this paper, we review how pre– and post–weaning nutrition and management affect subsequent performance of pigs through to slaughter. Initially, we discuss the role of bodyweight; this is followed by a summary of research on the general effects of pre– and post–weaning nutrition and management on post–weaning performance until slaughter weight.

The importance of bodyweight and early nutrition

Weight at birth, weaning and during the immediate post–weaning period are major determinants of the subsequent growth performance of pigs (Wolter and Ellis 2001), although the manner in which pigs reach a heavier weight also appears crucial. Williams (2003) reviewed numerous studies showing that weights at birth and one week of age are correlated with weaning weight, and that weight at weaning is correlated to subsequent performance. In addition, Tokach *et al*. (1992) and Azain (1993) reported that pigs growing well (225–340 g/d) in the first week after weaning reached market weight 10–28 days before pigs exhibiting poor gain (0–110 g/d) in the first week after weaning. However, details of birth weights were not provided. The effect of weight gain (and thus feed intake) in the first week after weaning and the effect of weaning weight are additive and account for approximately 80% of the variation in body weight on day 20 after weaning and 34% of variation in body weight at 118 days of age (Miller *et al*. 1999; Ilsley *et al*. 2003). Furthermore, Lawlor *et al*. (2002a) commented that the type of diet fed after weaning can affect the significance of the relationship between birth weight and post–weaning performance. They recommended feeding a high–density diet after weaning to take advantage of this relationship.

Pigs that are heavier at weaning seem to maintain their weaning weight advantage to slaughter weight (Mahan and Lepine, 1991; Dunshea *et al*. 2003), but the manner in which a piglet attains that weight appears to have a marked influence on subsequent growth performance. Williams (2003) argued that if food intake is genetically determined to drive growth, which is also genetically determined, then it is most unlikely that a transient period of higher–than–normal nutrition (e.g., higher creep feed intake during lactation) will change a long–term hypothalamic food intake ‘setting’. Consequently, any increase in weight caused by an increase in growth would, at best, be maintained or, at worst, disappear with time.

Several recent studies that used large data sets support this theory. Wolter *et al*. (2002a) found that increasing weaning weight by means of supplemental milk replacer during a 21–day lactation had no significant effect on performance after weaning to 14 kg body weight, or from weaning to slaughter at 110 kg. On the other hand, piglets that were heavier at weaning (partially because they were heavier at birth) ate more and grew faster to slaughter (Table 2). Nevertheless, piglets fed milk replacer took three days less to reach slaughter weight than piglets that were not offered milk replacer. Lawlor *et al*. (2002a) reported a 0.6 kg increase in

Table 1 The performance of pigs fed various diets until weaning at 28 days of age and for five days after weaning (SR, sow reared; starter, solid starter diet; Ma, bovine milk fed at maintenance energy level; 2.5 Ma, bovine milk fed at 2.5 times maintenance energy level; *Ad libitum,* bovine milk offered *ad libitum*; adapted from Pluske *et al*. 1996).

	Treatment						
	SR	Starter	Ma	2.5 Ma	*Ad libitum*	SED	*P*–value
Body weight (kg)							
Weaning	8.9	9.0	9.1	9.2	9.2	0.86	>0.05
Five days after weaning	–	10.5	9.4	10.5	11.7	0.86	>0.05
Empty body weight (kg)							
Weaning	8.7	8.8	8.9	9.0	9.0	0.85	>0.05
Five days after weaning	–	10.0	9.2	10.3	11.3	0.84	>0.05
Daily body weight gain (g)							
Body weight	–	288	58	272	514	80.1	<0.001
Empty body weight	–	231	49	253	463	74.2	<0.001
Voluntary food intake (g/d dry matter)	–	286	102	234	400	41.0	<0.001
Gross energy intake (MJ/d)	–	5.1	2.3	5.2	8.9	0.76	<0.001

weaning weight at 28 days and attributed this to creep feeding during lactation. This weight advantage was lost by day 26 after weaning whereas pigs inherently heavier at weaning (7.1 kg vs. 5.8 kg) remained heavier 26 days later (17.5 kg vs. 15.4 kg) because they ate more feed. These data are consistent with those of Fraser *et al*. (1994) who estimated that creep feed intake during lactation accounted for only 1–4% of the variation in bodyweight gain after weaning.

Supplementary feeding during lactation

There is a plethora of studies in which the effects of creep feeding during lactation on weaning weight and subsequent performances were investigated (see reviews by Pluske *et al*. 1995; King and Pluske 2003). The major argument for offering supplementary food to suckling piglets is that it bridges the gap between the piglet's energy requirement and nutrients obtained from milk, which increases as lactation advances. In practice, this is hard to verify because it is difficult to measure the creep feed consumption of individual piglets among a suckling litter, but this has recently been attempted (Pluske *et al*., unpublished). Another argument, albeit less convincing, is that the consumption of creep feed prepares the gut for the digestion of carbohydrates and plant proteins that will be fed after weaning (e.g., Kelly *et al*. 1990a, 1990b). Chapple *et al*. (1989) reported that the variation in amylolytic activity of the pancreas of piglets was more a function of the sow (litter of origin) than of the intake of solid feed during lactation and immediately after weaning. Similarly, Lindemann *et al*. (1986) and de Passille *et al*. (1989) found that pepsin and maltase activities in the gastrointestinal tract were not related to weaning weight or the duration of creep feeding during lactation. More recently, Bruininx *et al*. (2004) reported that there was no association between creep feed intake before weaning and gut morphology at five days after weaning.

Yet another argument offered in support of creep feeding during lactation is that it familiarises piglets with solid feed so that the transition at weaning is less stressful. However, there is little robust evidence to support this sentiment. For instance, Kuller *et al*. (2004) conducted a study in which sows were either intermittently suckled for 12 h/d from day 11 to encourage their piglets to become familiar with creep feed before weaning or continuously suckled over a

Table 2 The effects of birth weight and provision of milk replacer during lactation on growth and performance of pigs to market weight at 110 kg (adapted from Wolter *et al*. 2002b).

	Birth weight[A]		Milk replacer[B]		*P*–value	
	Heavy	Light	Yes	No	Birth weight	Milk replacer
BW[C] (kg)						
Birth	1.83	1.32	1.58	1.58	0.001	0.76
Weaning	6.58	5.72	6.60	5.69	0.001	0.001
End of study	110.3	109.2	109.7	109.9	0.14	0.80
Daily gain (g/d)						
Birth to weaning	222	205	236	192	0.05	0.95
Weaning to 14 kg	450	409	421	432	0.001	0.26
25 kg to 65 kg	952	904	943	913	0.01	0.08
Weaning to 110 kg	851	796	827	820	0.001	0.43
Feed intake (g/d)						
Weaning to 14 kg	489	448	469	466	0.001	0.75
25 kg to 65 kg	1863	1800	1871	1791		
Weaning to 110 kg	1866	1783	1841	1808	0.001	0.17
Gain : Feed						
Weaning to 14 kg	0.93	0.90	0.90	0.92	0.01	0.05
25 kg to 65 kg	0.52	0.50	0.51	0.51	0.41	0.24
Weaning to 110 kg	0.46	0.45	0.45	0.45	0.11	0.37
Days from birth to 110 kg BW	141	148	143	146	0.001	0.01

[A]Heavy pigs weighed 1.8 kg (SD = 0.09 kg) and light pigs weighed 1.3 kg (SD = 0.07 kg) at birth
[B]Milk replacer was offered *ad libitum* from plastic milk feeders from day 3 of lactation. Replacer was prepared by hand–mixing a commercial milk powder (280 g/kg crude protein, 23 g/kg lysine, 15.6 MJ/kg ME) with warm water (30°C) in ratio of 1 part powder to 10 parts warm water
[C]BW: body weight

27–day lactation. They found that although piglets that had been subjected to intermittent suckling consumed more creep feed during and after lactation than those that had suckled continuously, bodyweights of these groups were identical by the seventh day after weaning.

Despite the large body evidence on the effects of creep feeding, evidence in support of the notion that creep feeding during lactation improves growth performance after weaning is equivocal (e.g., Barnett *et al*. 1989; Pajor *et al*. 1991; Fraser *et al*. 1994). Pluske *et al*. (1995) and Brooks and Tsourgiannis (2003) reported large variation in the apparent intake of creep–fed piglets (assessed on a litter basis). Pluske *et al*. (1995) estimated that the contribution of creep feed to daily energy intake prior to weaning at 21–35 days of age ranged from 1.2% to 17.4%; these estimates were confirmed by Lawlor *et al*. (2002a). The intake of dry creep feed during lactation is low, variable and, in pigs weaned at less than about 21 days of age, unlikely to influence weaning weight appreciably (King and Pluske 2003). However, Appleby *et al*. (1991) reported that creep feed intake during a 27–day lactation was enhanced when piglets were provided with a feeder with eight access points rather than two, and that piglets that ate more solid feed before weaning gained more weight in the 14 days after weaning. Despite this, pigs with a higher intake were also heavier at birth, possibly confounding the effects. Appleby *et al*. (1992) reported an inverse relationship between birth weight and creep feeding behaviour, but by 42 days of age there was no difference in bodyweight between the groups.

Creep feed consumption varies substantially within and between litters. Fraser *et al*. (1994) estimated that creep feed intake accounted for only 1–4% of the variation in bodyweight gain in piglets during the first 14 days after weaning at 28–days of age even though there were significant litter–of–origin effects on the intake of dry feed during lactation. Pluske *et al*. (1995) and King and Pluske (2003) commented that there is a highly significant effect (30% to 60% of total variance) of litter–of–origin on weaning weight and subsequent post–weaning performance. This indicates that pre–weaning factors have a major influence on weaning weight and subsequent growth rate; pre–natal (e.g., placental efficiency) and post–natal components are likely to exist. Rooke *et al*. (1998) reported that the relative importance of pre–natal vs. post–natal effects on weight was 3:1.

In a novel approach, Bruininx and colleagues in The Netherlands used faecal Cr_2O_3 as a marker for classifying piglets as 'good eaters', 'moderate eaters', or 'non eaters' of creep feed during lactation. Using this approach in conjunction with computerised feeding stations that recorded individual feed intake after weaning, Bruininx *et al*. (2002b) found that pigs classed as 'good eaters' pre–weaning took less time to eat after weaning compared with other groups, and that they consumed more feed during the first eight days after weaning. By day 34 after weaning, the effect of greater creep feed consumption during lactation intake on feed intake was less pronounced, although daily gain was still higher. The methodology used in this study indicated that some pigs eat more than others do after weaning because of their higher pre–weaning consumption of dry feed. However, no data were provided on whether this advantage persisted until slaughter. A study in Western Australia (Pluske *et al*., unpublished data) is seeking to clarify this relationship.

The nutrient composition of the diet consumed during lactation also appears to have an influence on subsequent weight gain. Dunshea *et al*. (1999) found that providing skim milk powder (20% dry matter) from day 10 of a 20–day lactation not only increased weaning weight by 0.7 kg, but also had a significant positive effect on bodyweight at 42 and 120 days after weaning compared to piglets that did not receive the milk supplement. Wolter and Ellis (2001) reported that weaning weight had a greater effect on age at slaughter than growth rate in the first two weeks after weaning, which was manipulated by offering a liquid milk replacer. However, milk replacer was not offered during lactation. These contrasting results are difficult to reconcile, but Williams (2003) postulated that consumption of skim milk powder during suckling might have compensated for the inferior quality of sow's milk because it has a better protein:energy ratio for muscle accretion (Campbell and Dunkin 1982; Williams 1995).

In their review, King and Pluske (2003) reported that pigs offered a liquid milk replacer during lactation had a weight advantage of 11% to 35% at weaning. Heo *et al*. (1999) reported that 14–day–old weaned piglets fed a liquid milk replacer achieved a mean growth rate of 470 g/d in the first seven days after weaning. Kim *et a1*. (2001) showed that feeding 11–day–old weaned piglets a liquid milk–replacer for the first 14 days after weaning using an automated milk machine increased weight at 28 days of age by 1.62 kg. This advantage was maintained to market weight. There was no evidence of compensatory gain in dry–fed control pigs, and the liquid–fed pigs reached market weight 3.7 days earlier than the dry–fed pigs. These results demonstrate the potential benefit of additional nutrients for weaning weight and a clear benefit of using supplemental milk replacer. However, Armstrong and Clawson (1980) did not observe increased growth in piglets offered liquid milk replacer during a 21–day lactation; perhaps this indicates that the sow provided sufficient milk.

Offering liquid milk replacer during and after the weaning period has also been shown to reduce the severity and extent of the growth check. Dunshea *et al*. (1999) attempted to alleviate the post–weaning growth check by providing extra milk at the time of weaning. Pigs that were offered liquid milk replacer in addition to dry starter feed gained 1.2 kg during the first week after weaning whereas pigs that received only dry starter feed gained 0.4 kg during this period. The effects of liquid milk replacer before weaning and in the first week after weaning were additive; pigs that received liquid milk replacer before and after weaning were 10% heavier at 120 days of age than pigs that were suckled by the sow only and weaned onto dry starter feed (Dunshea *et al*. 1999). Much of this improvement is most likely attributable to the extra nutrient intake from supplemental milk replacer prior to and immediately after weaning. Furthermore, King *et al*. (1998) reported that provision of either bovine milk or a synthetic milk formulation for 24 days of a 28–day lactation enhanced piglet growth rate compared to counterparts that were not offered milk. Piglets offered bovine milk drank 130% more than piglets offered the synthetic milk supplement. Collectively, it would appear that the practice of offering newly weaned pigs a milk replacer has the best potential for overcoming the post–weaning decline in dry matter intake and hence increasing growth rate after weaning.

Liquid diets for enhancing feed intake before and after weaning

In contrast to the equivocal data on the intake of dry creep feed, liquid feed (dry diets in a gruel/slurry form or liquid milk diets) appears to be a promising way of increasing weaning weight and post–weaning performance. Brooks and Tsourgiannis (2003) state that a liquid diet has a dry matter content similar to that of sow's milk, satisfies nutrient and water requirements and overcomes the problem of learning to consume solid feed. Solid diets in the form of gruel/slurry induce an association of feed with water, which could enhance dry matter intake. Toplis *et al*. (1999) stimulated piglets to consume 374 g/d of gruel (1:2 :: meal:water) in the last 10 days of a 24–day lactation, yet they weighed 0.2 kg less than piglets that only suckled. However, gruel–fed pigs grew 150% faster in the 35 days after weaning than those that did not receive creep feed during lactation (150 g/d vs. 49 g/d), and 30% faster (416 g/d vs. 317 g/d) for five weeks after weaning. The possible reasons for this were not discussed. Lawlor *et al*. (2002b) did not observe consistent effects of feeding liquid feed or acidified liquid feed to pigs weaned at 28 days of age. From a limited number of studies, it would appear that benefits derived from feeding weaner diets in liquid (gruel/slurry) form are equivocal.

Lactation management techniques and early growth of piglets

Under current husbandry systems, the piglet relies mainly on the milk of the sow for nutrients. Piglets consume colostrum within 24–36 hours of parturition and then consume milk at regular intervals until weaning (Pluske and Dong 1998). The intake of colostrum before closure of the lining of the small intestine to immunoglobulins is of critical importance to subsequent survival and performance of the young pig, even in the post–weaning period (see Pluske and Dong 1998; King and Pluske 2003). Colostrum is given to weaker piglets and in cases of agalactia to increase survival rate, weaning weight, and to reduce variation in weaning weight (King and Pluske 2003). Practices such as split weaning and cross suckling immediately after birth ensure a more equitable distribution of colostral immunoglobulins across the spectrum of weights within a litter (Donovan and Dritz 2000). Many studies have shown benefits of colostrum in terms of gut development, thermogenesis, protein synthesis and protection against enteric pathogens (Le Dividich and Noblet 1981). Split weaning involves weaning part of the litter and leaving the lighter pigs to suckle for an additional 5–7 days. Several workers have shown that the light piglets that remain with the sow grow faster than those that have to compete with larger littermates (Le Dividich 1999). For example, Pluske and Williams (1996) split–weaned the heavier piglets from litters at 22 days of age and showed that the bodyweight of the remaining piglets increased by 60% during the following week. Lighter piglets of split–weaned litters weighed 15% more than those of full litters at weaning at 29 days of age (7.7 kg vs. 6.7 kg) but this weight advantage dissipated by nine weeks of age (19.3 kg).

Post–weaning nutritional and management interventions for growth until slaughter

In a series of experiments conducted at The University of Illinois, Wolter and colleagues used in excess of 6,000 pigs weaned at approximately 21 days of age to study the influence of diet (pre– and post–weaning), space allocation, feeder–trough space, group size and stocking density on performance in wean–to–finish pig units (Wolter *et al*. 2000, 2002a, 2002b, 2003a, 2003b). A consistent feature of these studies (Table 3) was that interventions during the first eight weeks after weaning such as diet complexity and changes to space allocation had no impact on weight or carcass parameters at market stage (114 kg). Pigs that were fed the simple diet or restricted in space did not perform as well as pigs given the alternative treatments during the eight weeks after weaning but compensated afterwards. Nevertheless, the variation in growth of pigs fed the simple diet was greater than that of pigs fed the complex diet and more pigs were removed from the trial from the restricted treatment than from the unrestricted treatment (Wolter *et al*. 2003a).

Wolter and Ellis (2001) used a 2 × 2 × 2 factorial design to study the effects of weaning weight (5.4 kg vs. 3.9 kg), post–weaning growth rate and gender (barrows vs. gilts) on performance after weaning. Post–weaning growth rate was accelerated by a regimen in which pigs were housed in a special nursery and fed milk replacer plus a dry diet for 14 days after weaning; this was compared to a conventional regimen in which pigs were housed in a standard nursery for an equivalent period and fed a dry diet only. Housing and nutrition from the end of the treatment period until slaughter at 100 kg were identical. The accelerated growth treatment resulted in greater weights than the conventional treatment at 14 days after weaning (9.2 kg vs. 8.1 kg) and at 56 days of age (19.6 kg vs. 18.3 kg). However, early growth rate had no effect on growth from 35 days of age to slaughter weight or days to slaughter weight. Pigs of the conventional treatment had 1.5 mm more backfat at slaughter than those of the accelerated treatment. Pigs that were heavier at weaning were heavier at birth and at 56 days of age and reached slaughter weight 8.6 days earlier than those that were lighter at weaning. In this study, weaning weight had a greater effect on age at slaughter than growth rate during the first two weeks after weaning (Wolter and Ellis 2001).

Dunshea *et al*. (2003) designed a 2 × 2 × 2 factorial study to investigate how gender, weaning age (14 days vs. 28 days) and weaning weight (heavy vs. light) influences post–weaning performance and performance to slaughter. The greatest determinants of performance after weaning were age and weaning weight but the key determinant of lifetime performance was weaning weight and by inference, birth weight. Age at weaning had little effect on lifetime growth rate, but back–fat thickness at slaughter for pigs weaned at 14 days was increased relative to that of pigs weaned at four weeks of age. Therefore, heavy–for–age pigs appear to outperform other studies. light–for–age pigs; these results concur with numerous other studies. light–for–age pigs; these results concur with numerous other studies.

Rearing and housing effects on lifetime performance

In a study conducted at the Department of Agriculture's Medina Research Station in Western Australia, H.G. Payne and others investigated the influence of rearing environment (indoor born vs. outdoor born) and housing system (conventional semi–slatted flooring vs. deep litter flooring) on performance and carcass characteristics from weaning to slaughter at ~ 105 kg. In a second trial, they investigated the effect of creep feeding during a 28–day lactation on pre– and post–weaning performance and performance and carcass characteristics to slaughter at ~ 105 kg. These studies are, to our knowledge, the first to investigate associations between pre– and post–weaning environments with deep–litter systems. The second study is one of only a few in which weight at birth, weaning and slaughter, and time to a constant slaughter weight was measured.

Table 3 The effects of diet complexity and space allocation during the first eight weeks after weaning on growth performance of pigs (adapted from Wolter *et al*. 2003a).

	Treatment							
	Diet complexity[A]		Space allocation[B]			*P*–value		
	Simple	Complex	Restricted	Unrestricted	SEM	Diet	Space	D × S
BW[C] (kg)								
Weaning	5.0	5.0	5.0	5.0	0.01	0.74	0.91	0.91
After week 2	7.0	7.5	7.3	7.3	0.04	0.001	0.41	0.30
After week 4	11.9	12.5	12.1	12.3	0.08	0.001	0.05	0.19
After week 8	28.0	28.8	27.4	29.3	0.20	0.01	0.001	0.65
After week 23	114.4	114.4	114.5	114.3	0.37	0.81	0.69	0.94
Daily gain (g)								
Weaning–week 2	147	182	163	166	2.7	0.001	0.43	0.38
Weeks 5–8	574	580	548	607	5.3	0.41	0.001	0.21
Weaning–week 23	680	679	680	678	2.9	0.87	0.61	0.82
Feed intake (g/d)								
Weaning–week 2	205	239	217	227	2.3	0.001	0.01	0.70
Weeks 5–8	942	937	903	977	7.8	0.62	0.001	0.74
Weaning–week 23	1671	1673	1678	1666	8.0	0.90	0.34	0.68
Gain : Feed								
Weaning–week 2	0.72	0.76	0.75	0.73	0.008	0.001	0.10	0.37
Weeks 5–8	0.61	0.62	0.61	0.62	0.003	0.03	0.01	0.12
Weaning–week 23	0.40	0.40	0.41	0.40	0.001	0.91	0.41	0.67

[A]Both diets contained cereal grain and soybean meal. The simple diet contained less milk products, processed carbohydrates and animal proteins than the complex diet
[B]Restricted, 2 cm feeder–trough space per pig and 0.21 m^2 floor space per pig; unrestricted, 4 cm feeder–trough space per pig and 0.64 m^2 floor space per pig
[C]BW: body weight

In the first study, two replicates of a 2 × 2 factorial experiment were used to examine associations between pigs born indoors or outdoors and kept indoors (intensive) or on deep litter after weaning at approximately 21 days of age. In the first replicate (21 November 2002 to 8 April 2003), antimicrobials were included in the creep/starter diet to protect pigs against intestinal diseases. In the second replicate (23 October 2003 to 17 March 2004), antimicrobials were omitted from the creep/starter diet. The results from both replicates are shown in Tables 4 and 5.

Despite some inconsistencies in production indices between the two replicates, which were probably a consequence of the antimicrobials in the creep/starter diet in replicate 1, carcass weight and dressing percentage of outdoor–born pigs and pigs raised on deep litter was consistently higher than those born indoors and raised on conventional flooring (Tables 4 and 5). Further analysis showed that pigs that were born outdoors, reared outdoors for the duration of lactation, and then housed on deep litter had a higher bone mineral content and a higher bone density, which may be due to the additional physical activity of pigs in these environments. Cox and Cooper (2001) and Johnson *et al*. (2001) reported that outdoor pigs spent more time walking compared to indoor pigs. Exposure to ultra–violet light outdoors may have promoted synthesis of vitamin D and caused greater reabsorption of calcium from the digestive tract.

Payne and colleagues investigated the influence of pre–weaning nutrition on whole–of–life growth performance and carcass composition. The aim was to

Table 4 Main effects of lactation and post–weaning environments on pig production in replicate 1 in which the creep/starter diet contained antimicrobials.

	Lactation environment		Post–weaning environment	
	Indoor	**Outdoor**	**Intensive**	**Deep litter**
Start weight (kg)	5.5	5.7	5.5	5.7
47–day weight (kg)	25.1	27.7***	25.4	^A^27.4***
Final weight (kg)	106.2	106.8	106.4	106.7
Days on trial	137	137	139	134***
Daily gain (weaning–47 d; g/d)	416	467***	423	460***
Daily gain (weaning–finish; g/d)	744	740	727	758***
Carcass weight (kg)	79.2	81.0***	79.1	81.0***
P2 fat thickness (mm)	13.6	14.2	14.2	13.6
Dressing percentage	74.4	75.8***	74.4	75.9***
Feed consumed (weaning–finish; kg/d)	1.77	1.77	1.71	1.83***
Feed : gain (weaning–finish)	2.38	2.36	2.32	2.42***

***Statistically different (P<0.05) main effect (i.e., lactation vs. post–weaning environment) within rows

Table 5 Main effects of lactation and post–weaning environments on pig production in replicate 2 in which antimicrobials were not included in creep/starter diets.

	Lactation environment		Post–weaning environment	
	Indoor	**Outdoor**	**Intensive**	**Deep litter**
Start weight (kg)	5.6	5.6	5.6	5.6
47–day weight (kg)	25.3	24.8	25.3	24.8
Final weight (kg)	107.3	107.3	107.0	107.6
Days on trial	143	^A^151***	149	145
Daily gain (weaning–47 days; g/d)	418	409	418	409
Daily gain (weaning–finish; g/d)	721	683	686	718***
Carcass weight (kg)	79.3	81.1***	79.1	81.0***
P2 fat thickness (mm)	12.4	13.5	12.3	13.6***
Dressing percentage	73.4	75.1***	73.5	74.9***
Feed consumed (weaning–finish; kg/d)	1.71	1.69	1.63	1.77
Feed : gain (weaning–finish)	2.42	2.52***	2.40	2.54***

***Statistically different (P<0.05) main effect (i.e., lactation vs. post–weaning environment) within rows.

examine the effect of substrates available to outdoor piglets in the previous experiment during lactation in the absence of other factors present in the outdoor milieu. Twenty–four sows and 241 piglets were used in two replicates of 12 sows and their litters. After farrowing, equalisation of litter size and standard husbandry procedures were applied. Sows and their litters were allocated to one of three pre–weaning nutritional treatments: no creep feed, a commercial pelleted creep feed or an outdoor mix. The latter consisted of a mixture of sow feed, fresh straw, soil and organic matter (faeces, stubble) in a ratio of approximately 5:1:25, which simulated materials that outdoor born–and–reared piglets consume. The commercial and outdoor diets were offered between 7 days of age and weaning at 28 days. After weaning, piglets were all fed and housed indoors under identical conditions until slaughter at approximately 105 kg. The diets did not contain growth promoting antibiotics or pharmacological levels of Zn or Cu.

Growth rate during lactation did not differ ($P>0.05$) between treatments. However, pigs allocated to the nutritional treatments performed better ($P<0.001$) in the first week after weaning (123 g/d and 117 g/d for commercial and outdoor treatments, respectively) compared with piglets that were not offered creep feed (76 g/d). Pigs that were offered no creep feed, the commercial diet or the outdoor diet grew at 769, 756 and 789 g/d respectively between weaning and slaughter ($P<0.005$; LSD = 20.5). There was no difference between treatments ($P>0.05$) in daily gain between birth and slaughter. Nevertheless, the outdoor diet had a stimulatory effect on hot carcass weight and dressing percentage after statistical correction for birth weight, gender, P2 back–fat depth and liveweight at slaughter (Table 6). These data concur with the previous experiment conducted by Payne and colleagues in Western Australia and suggest that, in this particular genotype, factors associated with exposure to an outdoor environment have a beneficial effect on carcass conformation 19–20 weeks later.

These results indicate that factors before and after weaning influence carcass weight and dressing percentage. In the first experiment, it was evident that the increased carcass weights and dressing percentages of pigs housed on deep litter after weaning were independent of the pre–weaning environment. In the second experiment, the effects of ingestion of the outdoor mix before weaning persisted until slaughter. We suggest that the increase in carcass weight was due to increased bone mass.

Conclusions

The relationships between early nutrition and subsequent lifetime performance are clearly of interest to the pig industry and would be of particular utility for improving productivity and profitability if they could be defined more precisely. Our current view is that the

Table 6 Effects of offering no creep food, commercial creep feed, or an outdoor mix on performance and carcass characteristics of pigs from birth to slaughter.

	Treatment during lactation			
	No creep feed	**Commercial creep feed**	**Outdoor mix[A]**	**LSD[B] (5% level)**
Body weight (kg)				
Weaning (28 d)	9.1	8.7	8.9	0.9
7 d post–weaning	9.7	9.8	10.0	0.8
28 d post–weaning	18.7	19.3	19.9	1.6
Final weight	107.1	106.2	107.4	1.4
Daily gain (g/d)				
Birth–weaning	266	256	260	31
Weaning–7 d after weaning	60	123	131	63**
Weaning–28 d after weaning	344	366	378	63
Birth–day after weaning	307	316	325	23
Birth–finish	677	677	693	23
Weight/age[C] (g/d)	686	687	701	24**
HCW[D] (Trim 13; kg)	70.4	70.3	71.7	1.27**
P2 fat thickness (mm)	12.4	12.7	13.2	1.78
Dressing percentage	65.7	65.9	66.8	1.08**

[A]Outdoor mix consisted of creep feed, straw, soil and organic matter
[B]LSD: least significant difference
[C]Weight/age = (Final weight/final age)*1000
[D]HCW: hot carcass weight

weight of the pig at birth, and consequently at weaning, explains a considerable proportion of the variation in postnatal growth. Numerous dietary and management interventions have been used with varying degrees of success to manipulate weaning weight and growth rate after weaning with the aim of maintaining a weight advantage to slaughter. It appears possible to change the association between liveweight early in life and lifetime performance to some extent by providing liquid milk diets early in life. However, recent data show that processes occurring before and after weaning may influence carcass weight and dressing percentage of pigs that weigh more than 105 kg at slaughter. In particular, the effects of rearing environment during lactation, type of creep feed consumed during lactation and housing system after weaning appear to influence carcass weight and dressing percentage.

Acknowledgements

The studies conducted by H.G. Payne and colleagues at the Medina Research Station in Western Australia were part–funded by Australian Pork Limited.

References

Appleby, M.C., Pajor, E.A. and Fraser, D. (1991). Effects of management options on creep feeding by piglets. *Animal Production* 53, 361–366.

Appleby, M.C., Pajor, E.A. and Fraser, D. (1992). Individual variation in feeding and growth of piglets–effects of increased access to creep food. *Animal Production* 55, 147–152.

Armstrong, W.D. and Clawson, A.J. (1980). Nutrition and management of early weaned pigs: effects of increased nutrient concentrations and/or supplemental liquid feeding. *Journal of Animal Science* 50, 377–384.

Azain, M.J. (1993). Impact of starter on nursery performance. Swine Report No. 86, pp. 49–54. University of Georgia, Georgia, USA.

Barnett, K.L., Kornegay, E.T., Risley, C.R., Lindemann, M.D. and Schurig, C.R. (1989). Characterisation of creep feed consumption and its subsequent effects on immune response, scouring index and performance of weanling pigs. *Journal of Animal Science* 67, 2698–2708.

Brooks, P.H. and Tsourgiannis, C.A. (2003). Factors affecting the voluntary feed intake of the weaned pig. In: *The Weaner Pig*: *Concepts and Consequences*, pp. 81–116 (eds. J.R. Pluske, J. Le Dividich and M.W.A. Verstegen). Wageningen Academic Publishers, Wageningen, The Netherlands.

Bruininx, E.M.A.M., Binnendijk, G.P., van der Peet–Schwering, C.M.C., Schrama, J.W., den Hartog, L.A., Everts, H. and Beynen, A.C. (2002). Effect of creep feed consumption on individual feed intake characteristics and performance of group–housed weanling pigs. *Journal of Animal Science* 80, 1413–1418.

Bruininx, E.M.A.M., Schellingerhout, A.B., Binnendijk, G.P., van der Peet–Schwering, C.M.C., Schrama, J.W., den Hartog, L.A., Everts, H. and Beynen, A.C. (2004). Individually assessed creep feed consumption by suckled piglets: influence on post–weaning food intake characteristics and indicators of gut structure and hind–gut fermentation. *Animal Science* 78, 67–75.

Campbell, R.G. and Dunkin, A.C. (1982). The effect of birth weight on the estimated milk intake, growth and body composition of sow–reared piglets. *Animal Production* 35, 193–197.

Chapple, R.P., Cuaron, J.A. and Easter, R.A. (1989). Effect of glucocorticoids and limited nursing on the carbohydrate digestive capacity and growth rate of piglets. *Journal of Animal Science* 67, 2956–2973.

Cox, L.N. and Cooper, J.J. (2001). Observations on the pre– and post–weaning behaviour of piglets reared in commercial indoor and outdoor environments. *Animal Science* 72, 75–86.

de Passille, A.M.B., Pelletier, G., Menard, J. and Morrisset, J. (1989). Relationships of weight gain and behavior to digestive organ weight and enzyme activities in piglets. *Journal of Animal Science* 67, 2921–2929.

Donovan, T.S. and Dritz, S.S. (2000). Effect of split nursing on variation in pig growth from birth to weaning. *Journal of the American Veterinary Medical Association* 217, 79–81.

Dunshea, F.R., Kerton, D.J., Eason, P.J. and King, R.H. (1999). Supplemental skim milk before and after weaning improves growth performance of pigs. *Australian Journal of Agricultural Research* 50, 1165–1170.

Dunshea, F.R., Kerton, D.J., Cranwell, P.D., Campbell, R.G., Mullan, B.P., King, R.H., Power, G.N. and Pluske, J.R. (2003). Lifetime and post–weaning determinants of performance indices of pigs. *Australian Journal of Agricultural Research* 54, 363–370.

Fraser, D., Feddes, J.J.R. and Pajor, E.A. (1994). The relationship between creep feeding behaviour of piglets and adaptation to weaning. Effect of diet quality. *Canadian Journal of Animal Science* 74, 1–6.

Harrell, R.J., Thomas, M.J. and Boyd, R.D. (1993). Limitations of sow milk yield on baby pig growth. In: *Proceedings of the 1993 Cornell Nutrition Conference for Feed Manufacturers*, pp. 156–164. Cornell University, New York State, USA.

Heo, K.N., Odle, J., Oliver, W., Kim, J.H., Han, I.K. and Jones, E. (1999). Effects of milk replacer and ambient temperature on growth performance of 14–day–old early–weaned pigs. *Asian–Australasian Journal of Animal Science* 12, 908–913.

Hodge, R.M.W. (1974). Efficiency of food conversion and body composition of the preruminant lamb and the young pig. *British Journal of Nutrition* 32, 113–126.

Ilsley, S.E., Broom, L.J., Miller, H.M. and Toplis, P. (2003). Birth weight and weaning weight as predictors of pig weight at slaughter. In: *Manipulating Pig Production IX*, p. 31 (ed. J.E. Paterson). Australasian Pig Science Association, Werribee, Australia.

Johnson, A.K., Morrow–Tesch, J.L. and McGlone, J.J. (2001). Behaviour and performance of lactating sows and piglets reared indoors or outdoors. *Journal of Animal Science* 79, 2571–2579.

Kelly, D., O'Brien, J.J. and McCracken, K.J. (1990a). Effect of creep feeding on the incidence, duration and severity of post–weaning diarrhoea. *Research in Veterinary Science* 49, 223–228.

Kelly, D., Smyth, J.A. and McCracken, K.J. (1990b). Effect of creep feeding on structural and functional changes of the gut of early weaned pigs. *Research in Veterinary Science* 49, 350–356.

Kim, J.H., Heo, K.N., Odle, J., Han, I.K. and Harrell, R.J. (2001). Liquid diets accelerate the growth of easily weaned pigs and the effects are maintained to market weight. *Journal of Animal Science* 79, 427–434.

King, R.H., Boyce, J.M. and Dunshea, F.R. (1998). Effect of supplemental nutrients on the growth performance of sucking pigs. *Australian Journal of Agricultural Research* 49, 883–887.

King, R.H. and Pluske, J.R. (2003). Nutritional management of the weaner pig. In: *The Weaner Pig: Concepts and Consequences*, pp. 37–51 (eds. J.R. Pluske, J. Le Dividich and M.W.A. Verstegen). Wageningen Academic Publishers, Wageningen, The Netherlands.

Kuller, W.I., Soede, N.M., van Beers–Schreuers, H.M.G., Langendijk, P., Taverne, M.A.M., Verheijden, J.H.M. and Kemp, B. (2004). Intermittent suckling: Effects on piglet and sow performance before and after weaning. *Journal of Animal Science* 82, 405–413.

Lawlor, P.G., Lynch, P.B., Caffrey, P.J. and O'Doherty, J.V.O. (2002a). Effect of pre– and post–weaning management on subsequent pig performance to slaughter and carcass quality. *Animal Science* 75, 245–256.

Lawlor, P.G., Lynch, P.B., Gardiner, G.E., Caffrey, P.J. and O'Doherty, J.V.O. (2002b). Effect of liquid feeding weaned pigs on growth performance to harvest. *Journal of Animal Science* 80, 1725–1735.

Le Dividich, J. (1999). The neonatal and weaner pig: Management to reduce variation. In: *Manipulating Pig Production VII*, pp. 135–155 (ed. P.D. Cranwell). Australasian Pig Science Association, Werribee, Australia.

Le Dividich, J. and Noblet, J. (1981). Colostrum intake and thermoregulation in the neonatal pig in relation to environmental temperature. *Biology of the Neonate* 40, 167–174.

Lindemann, M.D., Cornelius, S.G., El Kandelgy, S.M., Moser, R.L. and Pettigrew, J.E. (1986). Effect of age, weaning and diet on digestive enzyme levels in the piglet. *Journal of Animal Science* 62, 1298–1307.

Mahan, D.C. and Lepine, A.J. (1991). Effect of pig weaning weight and associated nursery feeding programs on subsequent performance to 105 kilograms body weight. *Journal of Animal Science* 69, 1370–1378.

Miller, H.M., Toplis, P. and Slade, R.D. (1999). Weaning weight and daily liveweight gain in the week after weaning predict piglet performance. In: *Manipulating Pig Production VII*, p. 130 (ed. P.D. Cranwell). Australasian Pig Science Association, Werribee, Australia.

Pajor, E.A., Fraser, D. and Kramer, D.L. (1991). Individual variation in the consumption of solid food by suckling pigs and its relationship to post–weaning performance. *Applied Animal Behavioural Science* 32, 139–155.

Pluske, J.R. and Dong, G.Z. (1998). Factors influencing the utilisation of colostrum and milk. In: *The Lactating Sow*, pp. 45–70 (eds. M.W.A. Verstegen, P.J. Moughan and J.W. Schrama). Wageningen Pers, Wageningen, The Netherlands.

Pluske, J.R. and Williams, I.H. (1996). Split weaning increases the growth of light piglets during lactation. *Australian Journal of Agricultural Research* 47, 513–523.

Pluske, J.R., Williams, I.H. and Aherne, F.X. (1995). Nutrition of the neonatal pig. In: *The Neonatal Pig — Development and Survival*, pp. 187–235 (ed. M.A. Varley). CAB International, Wallingford, UK.

Pluske, J.R., Williams, I.H. and Aherne, F.X. (1996). Villous height and crypt depth in piglets in response to increases in the intake of cow's milk after weaning. *Animal Science* 62, 145–158.

Rooke, J.A., Shanks, M. and Edwards, S.A. (1998). Maternal and dietary influences on post–weaning piglet growth. *Proceedings of the British Society of Animal Science*, p. 156.

Tokach, M.D., Goodband, R.D., Nelssen, J.L. and Katts, L.J. (1992). Influence of weaning weight and growth during the first week post–weaning on subsequent pig performance. Kansas University Swine Day, pp. 15–17. Report of Progress No. 667. Kansas University, Kansas, USA.

Toplis, P., Blanchard, P.J. and Miller, H.M. (1999). Creep feed offered as a gruel prior to weaning enhances performance of weaned piglets. In: *Manipulating Pig Production VII*, p. 129 (ed. P.D. Cranwell). Australasian Pig Science Association, Werribee, Australia.

Whittemore, C.T. and Green, D.M. (2001). Growth of the young weaned pig. In: *The Weaner Pig: Nutrition and Management*, pp. 1–15 (eds. M.A. Varley and J. Wiseman). CAB International, Wallingford, UK.

Williams, I.H. (1976). Nutrition of the young pig in relation to body composition. PhD thesis, University of Melbourne, Victoria, Australia.

Williams, I.H. (2003). Growth of the weaned pig. In: *The Weaner Pig: Concepts and Consequences*, pp. 15–35 (eds. J.R. Pluske, J. Le Dividich and M.W.A. Verstegen). Wageningen Academic Publishers, Wageningen, The Netherlands.

Wolter, B.F. and Ellis, M. (2001). The effects of weaning weight and rate of growth immediately after weaning on subsequent pig growth performance and carcass characteristics. *Canadian Journal of Animal Science* 81, 363–369.

Wolter, B.F., Ellis, M., Curtis, S.E., Parr, E.N. and Webel, D.M. (2000a). Feeder location did not affect performance of weanling pigs in large groups. *Journal of Animal Science* 78, 2784–2789.

Wolter, B.F., Ellis, M., Curtis, S.E., Parr, E.N. and Webel, D.M. (2000b). Group size and floor–space allowance can affect weanling–pig performance. *Journal of Animal Science* 78, 2062–2067.

Wolter, B.F., Ellis, M., Corrigan, B.P., DeDecker, J.M., Curtis, S.E., Parr, E.N. and Webel, D.M. (2003a). Impact of early postweaning growth rate as affected by diet complexity and space allocation on subsequent growth performance of pigs in a wean–to–finish production system. *Journal of Animal Science* 81, 353–359.

Wolter, B.F., Ellis, M., Corrigan, B.P., DeDecker, J.M., Curtis, S.E., Parr, E.N. and Webel, D.M. (2003b). Effect of restricted postweaning growth resulting from reduced floor and feeder–trough space on pig growth performance to slaughter weight in a wean–to–finish production system. *Journal of Animal Science* 81, 836–842.

Wolter, B.F., Ellis, M., Corrigan, B.P. and DeDecker, J.M. (2002a). The effect of birth weight and feeding of supplemental milk replacer to piglets during lactation on preweaning and postweaning growth performance and carcass characteristics. *Journal of Animal Science* 80, 301–308.

Wolter, B.F., Ellis, M., DeDecker, J.M., Curtis, S.E., Hollis, G.R., Shanks, R.D., Parr, E.N. and Webel, D.M. (2002b). Effects of double stocking and weighing frequency on pig performance in wean–to–finish production systems. *Journal of Animal Science* 80, 1442–1450.