How Does the Pre-weaning Environment Affect Gut Structure and Function, and Lifetime Performance of the Pig?

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Declaration

I declare that this is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

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ABSTRACT

The reduction in feed intake and growth rate that occurs following weaning is of major economic consequence to the pig industry. Currently, a range of antimicrobial products can be used to minimise the impact of weaning on piglet health and subsequent performance. However, the use of these products in pig diets is subject to increasing restriction worldwide because of perceived risks to public health and to the environment. Thus, alternative methods are required to mitigate the growth check that almost invariably occurs after weaning in most production systems.

Piglets produced outdoors are claimed to experience less of a growth check at weaning and to be able to thrive in relatively unsophisticated weaner accommodation. However, these claims have not been substantiated under Western Australian conditions, nor a scientific basis for these claims established. Consequently, a series of experiments was designed to test the general hypothesis for this thesis – '*the gut structure and function, and lifetime performance of the weaned pig are affected by its pre- and post-weaning rearing environments'*.

Experiment 1 was conducted in two parts to quantify differences in the growth performance, health and gut structure of weaner pigs produced indoors or outdoors and reared in conventional or deep-litter pens. The weaner diet in the first part of the experiment contained 100 ppm of olaquindox and 3,000 ppm of zinc oxide (Exp1a). This experiment was repeated without using dietary antimicrobial products (Exp1b). Experiment 2 was conducted in conventional buildings to examine the effect of exposing piglets in lactation to similar substrates to those available to outdoor piglets

used in Exp1a and Exp1b in the absence of other differences in the outdoor production milieu.

Pre-weaning environments in Exp1a (indoor production (IP) and outdoor production (OP)) appeared to have little effect on gut structure and overall growth rate but significantly affected carcass composition, whereas post-weaning environments (conventional (C) or deep-litter (DL)) affected both overall growth rate and carcass composition. Although feed disappearance was similar, OP pigs grew faster than IP pigs in the first 47 d after weaning in Exp1a but not in Exp1b. Lifetime growth rate (GR), P2 backfat, feed disappearance and feed conversion ratio (FCR) were not significantly affected by the production environment in Exp1a whereas OP pigs grew slower with higher P2 backfat and FCR in Exp1b. Interestingly, OP pigs had heavier carcass weights and higher dressing percentages than IP pigs in both parts of the experiment. The effects of post-weaning environment were more consistent as DL pigs grew faster, were fatter, and had higher carcass weights and dressing percentages than C pigs.

Villus height and crypt depth of IP and OP pigs were not different at 21 (weaning) or 28 d, but villus height decreased and crypt depth increased in the week after weaning. Pigs reared in C pens had greater faecal concentrations of volatile fatty acids than pigs in DL, indicating that the latter ingested sufficient straw to alter fermentation characteristics.

In Experiment 2, there were no differences in gut structure or pre-weaning and lifetime GR of pigs offered no creep feed (NC), a commercial creep feed (CF) or an ‘outdoor’ mix (OM) comprising of 1 part straw, 5 parts sow feed and 25 parts of soil taken from

paddocks in which OP pigs used in Exp1a and Exp1b were farrowed. However, NC pigs grew slower in the week after weaning than the other two treatments. Backfat and feed disappearance were similar for all treatments but pigs on the OM treatment had higher carcass weights and dressing percentages than pigs on the NC and CF treatments. Villus height and crypt depth were not different between treatments and, although the piglets were weaned at 28 d, villus height decreased and crypt depth increased in the week after weaning to an extent similar to that experienced by piglets weaned at 21 d in Experiment 1.

Although all piglets received intramuscular injections of 200 mg iron (Fe) dextran when 1 to 2 days old, piglets offered the OM during lactation had higher serum iron and blood haemoglobin (Hb) levels than those offered NC or CF. Furthermore, half the piglets offered NC or CF had Hb levels indicative of chronic Fe deficiency anaemia. The average parity of sows used in this experiment was 6.3 litters, suggesting that piglets may have been born with low Fe stores, possibly because of low Fe stores in their dams due to sub-optimal mineral nutrition over successive parities.

In summary, the findings from these experiments partly supported the general hypothesis for this thesis. Under the conditions of these experiments, access to outdoor substrates in lactation had little effect on gut structure and lifetime growth rate but increased both carcass weight and dressing percentage, whereas rearing in DL pens increased feed intake, FCR, growth rate, P2 backfat, carcass weight and dressing percentage.

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ABBREVIATIONS AND DEFINITIONS

ADG	Average daily gain (g/d)
ANOVA	Analysis of variance
AP	Any antimicrobial product including but not limited to antibiotics, zinc, copper and acidifiers in various forms
BCR	Branch chain fatty acid ratio
C	Conventional
CF	Creep Feed
DAFWA	Department of Agriculture and Food Western Australia
DL	Deep-litter
Dressing percentage	HSCW ÷ Live weight at slaughter x 100
DXA	Dual energy X-ray absorptiometry
FCR	Feed conversion ratio (kg : kg)
GIT	Gastrointestinal Tract
GR	Growth rate (g/d)
HSCW	Hot standard carcass weight
IP	Indoor production (piglets farrowed and suckled indoors)
OM	'Outdoor' mix comprising of: 1 part straw, 5 parts sow feed and 25 parts soil
OP	Outdoor production (piglets farrowed and suckled outdoors)
NF	No creep feed
P2	Site for subcutaneous backfat measurement (including skin) 65 mm from the dorsal midline and level with the posterior edge of the last rib
VFA	Volatile fatty acid

GENERAL INTRODUCTION

At weaning, piglets must adapt to major changes in their social and physical environments, as well as to their diets. Piglets are separated from their mothers, often from some or all of their littermates, and then mixed with unfamiliar piglets to form larger-sized groups. Piglets are usually moved into other accommodation that may be equipped with unfamiliar types of floors, feeders and drinkers, and subjected to changes in the thermal environment. The newly-weaned pig must also adjust to unfamiliar energy and protein sources in diets that are generally offered dry in meal or pellet form. Major changes to the gut occur following the replacement of sow's milk with solid food (Pluske et al., 2001). Typically, piglets may not eat for 6-12 hours after weaning, with some still not eating after 24 hours (Le Dividich & Herpin, 1994; Bruininx et al., 2001). The associated decrease in energy intake following the change to solid food disrupts gut function, interrupts growth and can predispose the newly weaned pig to enteric disease such as post-weaning colibacillosis. The move to unfamiliar surroundings and the need to form new dominance hierarchies established by fighting both add to the stress of weaning (Fraser et al., 1998) and increase the newly-weaned pig's susceptibility to enteric and other diseases.

The reduction in feed intake that occurs following weaning has significant economic consequences for the pig industry. The associated mortality, morbidity and diminished performance, and the direct costs of treatment and prophylactic measures implemented contribute significantly to the cost of production of pork.

Although there have been many advances in the nutrition, housing and management of the weaner pig, the problem remains intractable. Currently, antibiotic growth promoters, mineral compounds such as ZnO and $CuSO_4$, and acidifiers are used to minimise the impact of weaning on health and subsequent performance. For example, it was estimated that 31 tonnes of active ingredients in antimicrobial products (excluding anticoccidial agents) were sold in Australia for use in pigs from 2001-2002, plus a proportion of another 78 tonnes of antimicrobials designated for use in multi-species preparations (Australian Pesticide & Veterinary Medicines Authority, 2005). However, the use of some of these products in Australia eventually may be subject to restrictions similar to those currently imposed in the European Union. Thus there is a need to develop alternative strategies for the management of the weaned pig in anticipation of some antimicrobial products being withdrawn or their use restricted in Australia.

While all piglets are subject to similar stressors after weaning, the pre-weaning environments of indoor and outdoor piglets differ markedly. It is possible that enriched environments experienced by outdoor piglets may better prepare them for weaning (Cox & Cooper, 2001). Similarly, enriched post-weaning environments provided in deep-litter housing systems may mitigate some of the stressors experienced at weaning (Kelly et al., 2000a) as well as enhancing performance during the grow-out period (Lyons et al., 1995; Guy et al., 2002a). However, the relative importance of various social, behavioural and environmental factors (including possible nutritional differences due to ingestion of straw, soil and pasture

residues) experienced by pigs in some outdoor and deep-litter housing systems is unclear.

Piglets produced in outdoor systems in the United Kingdom are claimed to be more robust and suffer less of a growth check at weaning than do their indoor counterparts (Beynon, 1989). Although there is some evidence from the United States of America to support these claims (Gentry et al., 2002a), the post-weaning performance of outdoor piglets in Western Australia (which comprise 20-25% of local weaner production) has not been reported. Demonstration of superior post-weaning performance of outdoor pigs under local conditions, and the subsequent investigation, identification and understanding of the factors responsible, potentially may lead to interventions that enhance post-weaning performance in all types of production systems.

Outdoor piglets are also reported to have a greater capacity to thrive in less-sophisticated grower/finisher accommodation (Beynon, 1989). If so, this may have implications for the Western Australian pig industry which currently accommodates a significant proportion of pigs on deep-litter in low-cost housing for some or all of the grow-out period (Payne et al., 2000). Outdoor piglets may experience less of a growth check than indoor piglets when weaned into unsophisticated deep-litter housing because of previous exposure to more enriched (but also more challenging environments) afforded by outdoor production systems. Again, outdoor weaners demonstrate superior performance under these conditions and causal factors are identified, it may be possible to develop pre-weaning interventions that enable

indoor weaners to match the post-weaning performance of outdoor counterparts when weaned into deep-litter housing systems.

Although reports from the literature and anecdotal evidence from producers collectively suggest environmental factors influence the piglet's response to weaning and its subsequent performance, studies that quantified or elucidated reasons for these effects appear lacking. Therefore, a series of experiments was designed to test, under conditions typically found in Western Australia, the general hypothesis for this thesis that '*the gut structure and life-time performance of the weaned pig are affected by its pre- and post-weaning rearing environments*'.

CHAPTER 1: LITERATURE REVIEW

1.1 Introduction

The growth and development of a pig from birth to slaughter around 155 d of age or 100 kg live weight (Australian Pork Ltd, 2006) are the results of its genetic inheritance and a complex chain of events and processes that commence at conception and continue throughout the pig's life. These events and processes are affected by, amongst other things, the housing system in which pigs are produced and grown. For example, British producers claim that piglets produced in outdoor systems are more robust and suffer less of a growth check at weaning than their indoor counterparts (Beynon, 1989). This is supported by commercial data from the United Kingdom Meat and Livestock Commission's 1996 Pig Year Book (Edwards & Rooke, 1999) which show that pigs suckled in outdoor units experience less of a growth check at weaning than pigs from indoor accommodation. Scientific substantiation of these claims and subsequent identification of factors responsible for observed superior performance of outdoor piglets possibly may lead to interventions that benefit the entire industry by enhancing the post-weaning performance of pigs in all types of production systems.

The mortality, morbidity and diminished performance that occur after weaning, and the direct costs of treatment and prophylactic measures implemented, already contribute significantly to the cost of production. Any restriction or prohibition of the use of dietary antimicrobial products and antibiotic growth promoters currently used in Australia to lessen health problems and (or) minimise the growth check that occur

around weaning will add appreciably to the cost of production, at least in the short term until producers adopt different management strategies to replace their use. During the first year after the withdrawal of dietary antibiotics in Sweden, for example, post-weaning mortality increased by about 1.5% and the time taken for piglets to reach 25 kg live weight increased by about five days (Gill et al., 2005). However, changes to housing and management practices subsequently restored productivity to pre-restriction levels but at the expense of a 4–10% increase in cost of production. The Danish experience followed a similar trend to Sweden's after the removal of dietary antibiotic growth promoters, with a 0.7% increase in post-weaning mortality and a 5% decrease in growth to 30 kg live weight (Maribo, 2005). The experiences of the Swedish and Danish pig industries highlight the role of housing and management in the development of new strategies to replace antimicrobial products as the primary means of minimising the post-weaning growth check of pigs.

A significant proportion of pigs in Australia are accommodated in deep-litter housing for some or all of the grow-out period (Payne et al., 2000). Outdoor weaners are considered better able to thrive in less-sophisticated accommodation than indoor weaners (Beynon, 1989), and may adapt more readily to deep-litter housing systems commonly used in Western Australia. Factors believed to impact on pig development and performance after weaning that can be attributed to diverse production systems are therefore considered in this review. Other factors that will be considered include:

- The use of antimicrobial products in pig production
- The weaning process and its consequences

- Salient features and environmental-, behavioural- and production-consequences of various production and rearing systems
- Nutritional differences between indoor and outdoor piglets

Finally, the general hypothesis for this thesis is developed based on all the literature reviewed.

1.2 The Use of Copper, Zinc and Antibiotic Growth Promoters in Pig Production

Copper sulphate, zinc oxide and antibiotics (collectively referred to in this thesis as antimicrobial products or APs) have been used as growth promoters by the global pig industry for over fifty years. Although the economic and production benefits of using these products are widely acknowledged, their use is now subject to increasing regulation. For example, the withdrawal of selected antibiotic growth promoters (AGPs) began in Sweden in 1986, culminating with a ban on the use of all AGPs in the European Union (EU) in 2006. The withdrawal of approval for the use of AGPs in the EU was in response to concerns about transference of antibiotic resistant genes from animal to human microbiota (Castanon, 2007). The decision to restrict the use of AGPs was apparently made on the basis of the Precautionary Principle in the absence of irrefutable evidence of actual risk to human health from their use (Philips, 2007). The same author also cited evidence (Cox, 2005; Singer et al., 2007) of possible benefits to human health from the use of AGPs that outweigh the risks. Philips (2007) argued the deterioration in animal health seen in the EU in the years following the ban on AGPs (which may have been a consequence of the ban) and the corresponding increase in the use of therapeutic antibiotics, have created new pressures on antibiotics of direct relevance to human health. Furthermore, Philips (2007) suggested there was now a

greater likelihood of unhealthy animals, including those subclinically infected, entering the food chain, thereby increasing the likelihood of bacterial contamination of carcasses and the risk to humans of diseases such as campylobacteriosis. However, it is unlikely that EU regulatory controls will be relaxed in the foreseeable future, given the weight of current scientific opinion supportive of the ban. There are fewer restrictions on the use of antibiotic growth promoters in Australia and a relatively wide range of products is still available for use in the pig industry, subject to approval and regulation by the Australian Pesticides and Veterinary Medicines Authority (APVMA). Stringent on-farm quality assurance systems are mandatory to demonstrate adherence to withholding periods determined by APVMA for all approved antibiotics. Additionally, an Export Slaughter Interval is applied to compounds generally considered banned internationally for use in food animals (Australian Quarantine and Inspection Service Meat Notice #2006/13).

Accumulation of copper and zinc in soil occurs following land application of manure from pigs fed diets containing of high levels of copper (150–250 ppm) and zinc (> 2,000–3,000 ppm). Such growth promoters pose a serious threat to the environment. High levels of these metals in the top soil layer have consequences for soil microbes and plant growth, and are a potential threat to animal and human health (Jongbloed & Lenis, 1998). Furthermore, such accumulation considerably increases the risk of surface water contamination by copper and zinc from runoff and groundwater pollution through leaching. In some parts of the world, this has led to regulations that govern land application rates for pig manure and dietary inclusion rates for copper and zinc. For example, in 2004 the EU determined that copper and zinc can only be included in pig

diets at non-pharmacological levels (Commission Regulation 1334/2003, Official Journal of the European Union). Currently, there are no Australian regulations governing the use of copper and zinc in pig diets. However, licensing authorities generally require producers who spread pig manure on land to operate according to approved environmental management plans that specify nutrient application rates together with stringent protocols for monitoring soil, ground and surface water to prevent adverse consequences to the environment (Australian Pork Ltd, 2004).

1.3 The Weaning Process

There is a vast amount of literature on all aspects of the weaning process which has been comprehensively reviewed in two recent text books (Varley & Wiseman, 2001; Pluske et al., 2003). However, this section will focus on how the weaning process in modern production systems differs from the natural process. Knowledge of the behavioural and adaptive consequences of divergence from the natural weaning process may help explain some of the reported differences in post-weaning performance between pigs produced indoors or outdoors.

In modern Australian production systems, both indoor and outdoor, pigs are weaned by abrupt separation from their mothers at an average age of 21.8 d (Australian Pork Ltd, 2006), although some commercial systems wean as early as 14 d and others as late as 35 d. However, from a biological perspective, it has been suggested that weaning should be considered a process, not a sudden event occurring at some arbitrarily determined age (Martin, 1984). Weaning is a gradual process under natural circumstances, involving a progressive reduction in milk intake with a corresponding increase in the intake of solid food that culminates when piglets become nutritionally and behaviourally independent

of their mothers sometime between 15 and 19 weeks of age (Jensen, 1988; Jensen & Recén, 1989).

Some consider the weaning process begins when suckling frequency starts to diminish (Puppe & Tuchscherer, 2000). In a study of sows and their litters in conventional farrowing crates during a 35 d lactation period, Puppe & Tuchscherer (2000) estimated the highest suckling frequency occurred around day 8.5 of lactation with 31.4 sucklings per 24 h period, although daily suckling frequency remained above 24 successful attempts per day until weaning at 35 d. However, creep feed consumption by piglets remained low until the fifth week of lactation when it increased considerably. In comparison, suckling peaked slightly later at between two to three weeks of age, decreasing uniformly throughout the remainder of lactation until weaning occurred at 17.2 weeks in the semi-natural environment provided in seven to 13 hectare enclosures comprised of "fields, swamps, mossy areas, primary forest and fir plantations" (Jensen & Recén, 1989). Another study found that the frequency of sucklings decreased significantly over the first four weeks post-partum, then gradually decreased over the remainder of lactation and ceased at 16.8 weeks after parturition (Jensen, 1988). The proportion of sucklings terminated by sows in this study increased significantly between weeks 1–4 with over 90% of sucklings terminated by sows from week four onwards. A significant decrease in the proportion of sucklings initiated by sows also occurred from weeks 4–10. Collectively, the above findings indicate that sows begin to gradually reduce suckling frequency sometime during the second or third week of lactation when able to exert control over suckling frequency by separating themselves from their litters.

However, the decrease in suckling frequency initiated by the sow is generally insubstantial until the four or fifth week post-partum.

In contrast to the natural weaning process, piglets weaned in commercial production systems must, on the day they are separated from their mothers, immediately start adapting to major changes in their social and physical environments, as well as switching to solid diets in meal or pellet form that contain starch instead of fat as the main energy source. Piglets are not only separated from their mothers, but often from some or all of their littermates and mixed with unfamiliar pigs to form larger-sized groups. Piglets are usually moved into other accommodation that may be equipped with unfamiliar types of floors, feeders and drinkers, and are subjected to changes in their thermal environment. The move to unfamiliar surroundings and the need to form new dominance hierarchies that are established by fighting, add to the considerable stress of weaning (Fraser et al., 1998). Relatively early weaning around 21 d post-partum, as commonly practised in Australia, constitutes a major divergence from the natural process which has important consequences for the pig. The interaction between the physical and social environments at weaning can have profound effects on pig behaviour and performance, and offers a fruitful area for further research (Weary et al., 2008).

1.4 Consequences of Weaning

1.4.1 Decreased feed intake

Dependency on sow milk, as measured by the number of sucklings per day, does not start to diminish significantly until at least four weeks post-partum. The piglet's appetite for dry food also appears to remain low until the fourth or fifth week post-

partum (Puppe & Tuchscherer, 2000). Weaning around 21 d thus precedes the onset of the natural decrease in suckling frequency and the corresponding increase in the piglet's appetite for dry food by at least one or two weeks, giving rise to a period of anorexia. Typically, piglets may not eat for 6-12 hours post-weaning, with about 10% of pigs not eating after 24 hours (Le Dividich & Herpin, 1994; Bruininx et al., 2001). The associated decrease in energy intake following a complete change to solid food causes interruption to growth and disruption to gut structure and function (Hampson, 1986; McCracken et al., 1999; Pluske, 2001), and can predispose the newly-weaned pig to enteric disturbances such as malabsorption and diseases such as post-weaning colibacillosis (Nabuurs, 1995).

1.4.2 Continuity of fluid intake after weaning

Continuity of fluid intake after weaning is not well understood. Little is known about the water intake of piglets around weaning, and there does not appear to be a theoretical foundation with regard to drinking behaviour of piglets (Dybkjær et al., 2006). Piglets weaned at 28 d were reported to consume about 1.25 kg of milk daily in late lactation (King et al., 1998) which equates to about 1.0 kg of water, assuming 18% total solids content of sow milk at day 28 of lactation (Klobasa et al., 1987). Although suckling piglets have been observed to start drinking water soon after birth (Kabuga & Annor, 1992) and to consume 36 ml/d at day 1, rising to 403 ml at day 28 after birth (Nagai et al., 1994), there appears to be little advantage in providing supplementary water to piglets under three weeks of age under normal conditions (Gill et al., 1991).

The total daily fluid intake of a piglet just before weaning at 28 d of age is about 1.4 kg/d, when estimates of daily intake of milk (King et al., 1998) and water (Nagai et al.,

1994) are added together. This estimate is slightly higher than measured intakes of around 1.0 kg/pig/d for the first five days after weaning at 28 d in two experiments conducted by McLeese et al (1992) using good quality water (217 mg/L TDS) supplied in bowls proven to waste very little water. Water intake declined from the first day after weaning and remained low for the next four days before rising steadily over the following two weeks in both of these experiments. Water intake did not appear to meet apparent physiological need during the first five days post weaning, but thereafter increased commensurately with feed intake and body-weight gain.

Both under- and over-consumption of water may occur after weaning, causing a reduction in feed intake and performance (Brooks & Tsourgiannis, 2003). Under-consumption can occur if piglets are unable to locate drinkers in the pen, cannot reach and properly operate the drinkers provided or if water flow rates from the drinkers are too low. A water delivery rate of 175 ml/min reduced water use and feed intake compared to flow rates of 350 ml/min or more (Brooks & Carpenter, 1990). Over-consumption may occur when pigs drink water to achieve feelings of satiety (Yang et al., 1981) or when flavours have been added to encourage consumption, resulting in pigs consuming water in place of food. The degree to which piglets can maintain continuity of fluid intake after weaning may be influenced by pre- and post-weaning housing system. Piglet familiarity with the type and placement of drinkers may impact on post-weaning water intake and hence, feed intake. Little is known about the adaptation of outdoor piglets (with no prior experience to waterers other than to the trough provided for the sow) to nipple- or cup-drinkers commonly used after weaning.

Having discussed some of the consequences of weaning, it is logical to consider whether weaning at 21 d as widely practised in Australia differentially affects piglets produced indoors or outdoors, and whether the effects of premature weaning can be ameliorated by choice of post-weaning housing. However, it is first necessary to describe salient features of, and points of difference between, indoor and outdoor, and conventional and deep-litter housing systems commonly used in Western Australia.

1.5 Salient Features of Indoor and Outdoor Farrowing Systems

Typically, parturition and lactation of indoor sows take place in farrowing crates contained in buildings that range from uninsulated structures with manually-controlled natural ventilation to fully-insulated structures with automatically-controlled mechanical ventilation and evaporative cooling. The requirements of sows and their piglets and the design of farrowing crates were comprehensively described by Baxter (1984). Essentially, the farrowing crate comprises a discreet space for the sow and a safety zone for the piglets. The sow space is usually a crate that prevents the sow from turning around but of sufficient space and of a geometry that allows her to stand up and lie down in a controlled manner. The crate is provided with feeding and drinking equipment. The piglet safety zone is generally equipped with a micro-climate to prevent chilling, either in the form of a box equipped with a heat source, a heat mat, or a heat source suspended above an unheated mat. The safety zone is often equipped with a creep feeder in which high quality feed is offered from about day 7 after birth, and with a nipple drinker commonly positioned below the sow drinker. Modern crates generally have fully-perforated floors to facilitate the descent of excrement into an underfloor manure pit. Temporary accumulation of sow faeces can occur at the rear of the crate but

otherwise the floor remains clean. Piglets are not generally exposed to direct sunlight, but crates are sometimes illuminated by indirect natural light entering through windows and ventilation openings, otherwise artificial lighting is used.

In contrast, sows in outdoor production systems are provided with individual farrowing huts in small paddocks often containing 8–10 huts, although gilts are sometimes farrowed individually in smaller paddocks containing only one hut. Huts are spaced a minimum of six metres apart to give each sow its own space, and are moved to a fresh area within the paddock after each litter (Macgugan & Fahy, 2007). The number of huts per paddock varies from one to over 20 depending on herd size and managerial preference, with paddock size adjusted accordingly to reflect a stocking rate of 10–12 sows per hectare. Paddocks are rotated every 1–2 years to avoid excessive nutrient build-up and to minimise denudation of plant cover. In Western Australia, however, paddocks are often totally denuded of plant cover regardless of rotation length. Huts vary considerably in design from uninsulated, half-round structures fabricated from curved sheets of corrugated iron (Thornton, 1999) to fully-insulated rectangular structures (Macgugan & Fahy, 2007). No piglet safety areas are provided in the huts although the roof curvature of some huts forms protected areas along the sides at the base of the hut where sows cannot walk or lie down. All styles of huts typically have a minimum floor area of 4 m^2 and are equipped with fenders (usually about 1100 mm wide, 1200 mm long and 380–400 mm high) that are fitted externally around the door of the hut to form an outside area for the piglets (Agribiz Engineering, 1999). The fender is designed to contain piglets within the hut while allowing the sow free access in and out of the hut. The hut is equipped with an adjustable ventilation aperture in the rear wall, and straw bedding is provided for warmth and the protection of the litter from the

environment. Water and creep feed are not provided to the piglets but they have access to straw, pasture residues and soil within the hut and fender. Piglets often climb in and out of the fender area at will during the latter days of lactation and follow their mother to the feeding and watering areas, thus piglets have opportunity to ingest sow feed and to mix with other pigs. Outdoor piglets are exposed to direct natural light in the fender area. Access to substrates generally available in the outdoor environment meets the EC directive 2001/93/EC that states: "*Pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, sawdust, mushroom compost, peat or a mixture of such, which does not compromise the health of the animals"*, (Bracke et al., 2006), obviating the need for further environmental enrichment.

In summary, the pertinent differences between indoor and outdoor farrowing systems are: 1) outdoor piglets are not provided with creep feed or water within the farrowing hut, but have access to soil, straw and pasture residues; 2) outdoor piglets are exposed to wider climatic variation; 3) outdoor piglets may be more active than their indoor counterparts; and 4) the outdoor environment is richer and provides more stimulation for piglets. The relevance of these differences will become apparent later in this review.

1.6 Salient Features of Conventional and Deep-Litter Rearing Systems

Conventional rearing systems are generally comprised of weaner, grower and finisher pens contained in buildings capable of providing an appropriate climate for each class of pig. There is a trend in recent times for pigs to be housed in the same pen from weaning through to market weight, particularly in deep-litter systems. Three-pen systems make more efficient use of space and are therefore cheaper, but overcrowding can occur if

pigs are not moved into the next class of accommodation in a timely manner. Although accommodation for the three classes of pigs has much in common, weaner and grower-finisher accommodation will be described separately.

1.6.1 Weaner pens

Flooring material and stocking density are two of the major features of pen structure most likely to influence the conditions under which the weaner pig is housed (Madec et al., 2003). Floors of conventional weaner pens are either fully- or part-slotted, with a variety of materials used for this purpose (Taylor et al., 1994). Flooring materials are a compromise between the need for hygiene on one hand and the comfort and welfare requirements of the pig on the other. Pens with the highest ratio of solid to slatted areas tend to be safer and more comfortable for the pig, while those with the highest proportion of void area are likely to be cleaner but associated with a higher incidence of leg injuries (Baxter, 1984). In contrast, deep-litter weaner pens have a solid base (soil, compacted aggregate or concrete) covered with a bed of straw or other organic material (Payne et al., 2000). Lower levels of leg injuries have been reported for pigs on deep-litter compared to those on bare concrete or slatted floors (Lyons et al., 1995; Kelly et al., 2000b; Guy et al., 2002b).

Deep-litter pens can be contained in simple, well-ventilated structures where inside temperature is only a few degrees higher than the outside temperature (Payne, 1997). However, the evaporative and upper critical temperatures (ECT and UCT) for pigs on deep bedding are lower than on concrete floors, rendering pigs more susceptible to heat stress and lower growth in hot weather (Payne, 2004).

Weaner pens with fully-slotted floors are generally contained in environmentally controlled buildings in which air temperature is adjusted between 24–30°C to maintain pigs within their thermal comfort zone (Taylor et al., 1994). However, a survey of weaner rooms in South Australia (SA) found that temperatures fell within the recommended range for only about 32% of the time (Banhazi, 2006). Alternatively, rooms are maintained at lower temperatures and pens instead are provided with localised heat sources and other means of retaining heat such as floor mats and hovers to create microclimates appropriate to the pigs' needs (Madec at al., 2003), or outdoor kennels are used (Taylor et al., 1994).

Air quality is also frequently sub-optimal in both weaner rooms and in weaner kennels. In a survey of 28 farms in SA and WA (Cargill et al., 1995), mean concentrations in both weaner rooms and kennels exceeded the recommended levels of 2.4 mg/m^3 for total dust, 0.23 mg/m^3 for respirable dust and 100,000 CFU/m^3 for total bacteria (Pointon et al., 1995).

1.6.2 Grower/finisher accommodation

Conventional grower and finisher accommodation share many of the characteristics of weaner accommodation, the major difference being the precision with which air temperature and ventilation rate are controlled. Buildings are generally naturally ventilated with no supplementary heating or microenvironments (Taylor et al., 1994). Air temperatures are frequently sub-optimal. Banhazi (2006) reported that temperatures in SA grower and finisher sheds were within recommended ranges for less than a third of the time on an annual basis, and were below recommended temperatures 82% of the

time in winter and above 46% of the time in summer. Spray cooling is common in both conventional and deep-litter grower and finisher buildings in WA.

Most conventional grower and finisher pens in WA have floors that are 75% solid and 25% slotted although there is a growing trend towards fully-slotted floors. Pens with partly-slotted floors tend to have solid partitions around the solid floor areas and open partitions around the slotted area. Pens are equipped with ad libitum feeders and at least two nipple drinkers. Traditionally group size has varied from 10–40 pigs per pen, but the advent of larger breeding herds and the introduction of automatic weighing and sorting facilities has facilitated the use of pens containing up to 700 pigs. The latter are generally managed on an all-in, all-out basis and cleaned between batches of pigs, whereas many older sheds contain pigs of different ages in pens that are seldom thoroughly cleaned between batches.

Deep-litter pens in Western Australia are usually contained in low-cost shelters that vary in width 9–12 m, in length 20–45 m, with roofs 4–6 m high in the roof centre (Payne, 1997; Payne et al., 2000). Shelters vary in design but generally comprise of a tarpaulin stretched over a steel frame with 1.2 m high side walls of solid material, with gates and blinds or shutters forming the end walls. Generally there is a raised feeding platform at one end on which ad libitum feeders are positioned. A number of drinking bowls are mounted on the side wall opposite the feeders. Group size generally ranges from 100 to 400 pigs per pen, but one large producer operates groups of 1,000 pigs per pen. Shelters are generally filled with pigs aged within seven days of each other. A layer of fresh straw is provided when pigs enter a shelter and new straw added as required to maintain

a clean lying area for all pigs. The spent litter is usually removed after each batch of pigs.

1.6.3 Space allowance

Space allowance differs between conventional and deep-litter systems. The standard in the Australian 'Model Code of Practice for the Welfare of Animals: Pigs (2007)' specifies that the minimum available floor areas for weaner, grower and finisher pigs in conventional pens are "…calculated as m^2 per pig = 0.030 x $bodyweight^{0.67}$ " with the recommendation that pigs housed for more than 1-2 weeks in deep-litter systems should be provided with at least 30% more space per pig. The latter recommendation results in slightly less space than suggested for pigs on deep litter in the Canadian 'Recommended Code of Practice for the Care and Handling of Farm Animals: Pigs' (AAFC, 1993) which calculates space allowance as 0.045 x $bodyweight^{0.67}$ for pigs in bedded pens with solid floors.

Air space per pig tends to be considerably higher in straw-bedded systems than in conventional housing. A survey of 160 pig housing facilities in four states of Australia found that pigs in straw-based shelters had a mean air space of 4.5 m^3/pig compared to 3.0 m^3/pig in conventional finisher sheds (Banhazi et al., 2000). The greater air space per pig in deep-litter shelters is a consequence of greater floor space allocation and higher roofs necessary to provide clearance height for machinery used to add bedding or remove spent litter.

In summary, deep-litter housing in Western Australia differs from conventional housing in the following ways: 1) the use of bedding that allows pigs a choice of micro-

environment; 2) the provision of greater floor and air space per pig; and 3) greater environmental enrichment which allows greater expression of the pig's natural behaviours.

1.7 Behavioural, Social and Environmental Consequences Arising from Differences Between Indoor and Outdoor Production Systems

1.7.1 Suckling frequency

Sows in conventional farrowing crates cannot move away from their piglets which may lead to higher nursing frequencies and lactation levels compared to outdoor sows that can limit suckling opportunities by absenting themselves from their litters. When indoor sows were provided with a 'get-away' area in experimental farrowing pens, their nursing frequency was negatively correlated with time spent away from their litters which increased from less than 20% on day 6 after farrowing to over 70% by day 27 (Pitts et al., 2002). Both nursing frequency and average piglet weight gain tended to decrease as use of the get-away area increased, leading the authors to conclude that the main welfare benefit for piglets by providing sows with opportunity to control lactation appeared to be the reduction of the growth check at weaning. This finding is supported by other work in which piglets had access to a creep area where, after 14 days of age, they could mix with piglets from two other litters (Weary et al., 2002). Litters of sows with access to get-away areas spent more time in the creep area than control piglets, ate more creep feed but tended to gain less weight before weaning at 28 days, and continued to eat more and gain more weight from 28 to 42 days of age, such that average body weights were similar to control pigs at 42 days.

Similar suckling patterns and proportions of time spent by sows with their litters were reported by Arey and Sancha (1996), who studied sow and litter behaviour and productivity in straw-bedded voluntary-accessed family farrowing pens and in conventional farrowing crates. The frequency of nursing bouts was higher in the farrowing crates while the duration of nursing bouts was longer in the family pens. Piglet weight gain was higher in the family system only in week 2. There were no significant differences between systems in the time piglets spent standing or sitting inactive, feeding, drinking, eliminating, locomotion, play-fighting or being aggressive. Post-weaning performance was not reported.

Kuller et al. (2004) also found that ADG was negatively affected when litters were separated from their dams for a fixed interval of 12 h/d from day 11 post-partum until weaning at day 27. This resulted in lower average weaning weights (7.2 vs. 7.9 kg) despite creep feed intake over this period averaging 686 g/piglet compared to 314 g/piglet for those with continuous access to the sow. However, creep feed intake of separated litters was 38% greater in the week after weaning (281 vs. 204 g/d per piglet), resulting in higher ADG (255 vs. 177 g/piglet) and similar litter weights 7 d after weaning (9.0 vs. 9.1 kg/piglet) to litters with continuous access to their dams. In a later experiment, intermittent suckling produced similar responses in the two-week periods before and after weaning, but did not affect lifetime performance (Kuller et al., 2007). However, the percentage of piglets within litters classified as eaters was not increased, suggesting that intermittent suckling only stimulated creep feed intake of piglets that were already eating.

It appears that even short periods of intermittent suckling can increase feed intake post-weaning. Thymann et al. (2007) found that fasting suckling piglets by separation from their dams only once for 24 hours on day 21 prior to weaning at 28 d post-partum was sufficient to increase post-weaning feed intake, but not sufficient to affect clinical traits and intestinal morphology. Other attempts to stimulate intake of creep feed pre-weaning by interrupting suckling in conventional farrowing pens by separating piglets from the sow have produced contradictory results (van Beers-Scheurs & Bruininx, 2002).

Studies of nursing patterns of outdoor sows have also produced conflicting results. Some studies only report hut occupancy which presumably is correlated with nursing pattern. Newly-farrowed sows have been estimated to spend, on average across all seasons, 8.2% of the total 24-hour day outside their farrowing huts in the first five days after farrowing compared to 21.7% during the remainder of lactation, assuming that all time during darkness was spent inside their huts (Buckner et al., 1998). In another study, the time sows spent outside their farrowing huts increased from 17% on day 1 to 70% on day 11 and 74% on day 20, respectively (Hötzel et al., 2004). In this study, where fenders were removed from farrowing huts a day after birth (allowing piglets to roam with their dams), outdoor piglets spent significantly less of the observed time in nursing behaviours than did indoor piglets (18% vs. 32% at day 1, 13% vs. 25% at day 12, and 12% vs. 21% at day 21 of lactation, respectively), indicating considerable auto-regulation of nursing frequency by the sows. Cox & Cooper (2001) found that indoor piglets engaged in teat manipulation (udder massaging and teat sucking) for 17.3% of the observed time before weaning around 24 days of age compared to 9.6% for outdoor piglets, presumably because the outdoor sows were able to regulate nursing by separation from their litters. On the other hand, no difference in the nursing interval of

indoor and outdoor sows and in the percentage of time that piglets spent nursing was observed between 4–10 d post-partum, during which time outdoor piglets were confined to their farrowing huts by the use of fenders (Johnson et al., 2001). The different nursing patterns observed by Johnson et al. (2001) compared to Cox & Cooper (2001) may reflect differences in litter size. Litter size of outdoor sows at weaning, 7.6 and 11.6 piglets, respectively, was four pigs fewer in Johnson et al. (2001) than in Cox and Cooper (2001) which may have lessened their need to avoid their piglets.

The effects of reduced suckling frequency when creep feed is not provided, as is generally the case in outdoor systems, have not been well-documented. The only large-scale comparison of production measures of indoor and outdoor sows and litters of the same genotype and health status appears to be that of Johnson et al. (2001) who found no statistical differences ($p > 0.05$) in litter birth and weaning weights for over 140 litters in each system. In summary, it appears that outdoor piglets experience reduced suckling frequency as a result of the sow's ability to limit suckling opportunities, but this does not appear to have an adverse effect on growth performance from birth to weaning if weaning occurs between 3–4 weeks of age. However, it remains to be determined whether outdoor piglets, in the absence of creep feed, ingest alternative materials such as soil, straw, pasture and sow feed in sufficient quantity to reduce the post-weaning growth to the extent seen when indoor piglets whose pre-and post-weaning creep feed intake has been increased by management-imposed reductions in suckling frequency.

1.7.2 Behavioural development

While all piglets are subject to similar stressors at weaning (changes in their diet, social and physical environments), it is possible that the enriched environment experienced by outdoor piglets during lactation may better prepare them for weaning. Outdoor piglets perform more rooting, standing and locomotive behaviours compared to indoor piglets, as well as more investigative behaviours directed at sow feed prior to weaning and less fighting after weaning than indoor piglets (Cox & Cooper, 2001). Thus, outdoor rearing may provide piglets with behavioural skills that are beneficial in the post-weaning environment. Cox & Cooper (2001) suggested that the outdoor piglet's tendency to sample food may have been encouraged by the social facilitation that occurred when piglets followed sows to food scattered on the ground and chewed on the rolls (large pellets) provided for the sows. More importantly, outdoor piglets spend more time feeding during the first few days after weaning (Webster & Dawkins, 2000; Cox & Cooper, 2001). Increased feeding time after weaning may result in higher feed intakes sufficient to prevent or reduce villous atrophy and crypt hyperplasia caused by low energy intakes, possibly resulting in a smaller post-weaning growth check (Pluske et al., 1997).

1.7.3 Physiological effects

It has been suggested that an outdoor environment from birth to weaning influences the development of muscle and other tissue of suckling pigs. Outdoor pigs are more active pre-weaning than indoor pigs, spending nearly double their time walking (20.3 vs. 10.1%, $P = 0.02$) and almost half as much more time standing (22.1 vs. 15.7%, $P = 0.19$) (Johnson et al., 2001). Similar differences in activity between outdoor and indoor

pigs were observed by Cox and Cooper (2001). It appears that the additional activity not only enhances post-weaning growth performance of outdoor-born piglets but also affects carcass quality (Gentry et al., 2002a, 2000b; Gentry et al., 2004). In these experiments, outdoor-born compared to indoor-born pigs had higher backfat, more tender pork with greater flavour intensity scores independent of backfat effects, and higher type I and lower type IIA fibres in the longissimus muscle when reared indoors or outdoors after weaning.

1.7.4 Gut development and ecology

There are few studies that compare the gut development and ecology of piglets reared indoors or outdoors from birth to weaning. Sows are thought to be the main source of intestinal microflora to neonatal piglets (Collinder et al., 2002). Intestinal microflora then undergo age related changes for over 120 days before the adult microflora is established. Dietary and environmental factors such as contact with soil micro-organisms by outdoor pigs also impact on the establishment of the intestinal microflora which in turn affects short chain fatty acid production (SCFA). Differences, most pronounced at 20 days of age, between indoor and outdoor pigs have been found in: the total amount of short chain fatty acids (SCFA); proportions of acetic, propionic and butyric acids; conversion of bilirubin to urobilinogens; degradation of faecal tryptic activity; and degradation of mucin (Collinder et al, 2002). Although these are all microflora-related biochemical functions, the composition of the gut microflora was not enumerated by Collinder et al. (2002). However, phylogenetic diversity of the intestinal bacterial community in pigs has been described by Leser et al. (2002) who used comparative 16S ribosomal DNA sequence analysis to examine tissue samples taken

from the ileum, caecum and colon of grower pigs fed a variety of diets, but outdoor pigs were not included in this study.

The gut serves as an entry point for many pathogens but also as the natural residence for many commensal bacteria. The natural protection against pathogens in the gut is in part provided by the microenvironment created by the commensal bacterial populations, in part by the innate immune system, and also, part of the protection is due to specific acquired immunity (Cebra, 1999). Indigenous bacteria are not distributed randomly throughout the gastrointestinal tract (GIT), but are instead found at population levels and in specie distributions that are characteristic of specific regions of the tract.

The stomach and proximal small intestine contain relatively low levels of microbes (10^3–10^5 bacteria/g or ml content) (Mackie et al., 1999) due to lower pH and rapid flow of digesta. The predominant species consist of acid-tolerant lactobacilli and streptococci. The distal small intestine (ileum) contains a denser and more diverse population of microbes (10^8/g or ml content). The large intestine is the primary site of microbial colonisation due to slowed transit time and is therefore characterised by large populations (10^{10}–10^{11}/g or ml content) of extremely diverse bacteria. Including the increasing gradient of bacterial numbers from the stomach to the colon, there is also a characteristic spatial distribution of organisms within each compartment. At least four microhabitats have been described: the intestinal lumen; the unstirred mucus layer or gel that covers the epithelial cells of the tract; the deep mucosal layer situated within the villous crypts; and the surface of the mucosal epithelial cells (Berg, 1996; Mackie et al., 1999).

The distinction between indigenous and non-indigenous microbes in the study of acquisition and development of GIT microbes is critical to the ecological understanding of colonisation, succession and interaction between microbes and host. In general terms, indigenous microbes are ubiquitous in the GIT ecosystem and occupy all habitats and niches available. On the other hand, non-indigenous microbes are species found in a habitat without establishing themselves and are simply in passage derived from food or water, from another habitat in the GIT ecosystem or elsewhere on the host, such as from the skin or upper GIT (Dubos et al., 1965). Colonisation describes the process by which a population of bacteria in the gastrointestinal tract becomes stable in size over time without requiring periodic reintroduction (Gaskins, 2001). These bacteria colonise the tract at an equal or faster rate than their rate of elimination. Clearly some indigenous bacteria may only become pathogenic when the ecosystem is disturbed in some way, such as a dietary shift during commercial weaning.

1.7.5 Air quality

Outdoor pigs may be exposed to lower atmospheric microbial loadings than indoor pigs (Kleinbeck & McGlone, 1999). Compared to indoor piglets, outdoor pigs had fewer white blood cells at 28 d, decreased lymphocyte numbers, a higher neutrophil percentage and a higher neutrophil : lymphocyte ratio. Outdoor pigs also had lower natural killer cell (NK) activity than indoor pigs. The reported decreased NK activity, increased percentage of blood neutrophils, and increased neutrophil : lymphocyte ratio were indicative of a stress response. However, it was concluded the increased gain and haemoglobin concentrations did not suggest that the outdoor pigs were sufficiently stressed to cause such a response and that, in this instance, low microbial exposure was

a more plausible explanation than stress-induced immunosuppression. Kleinbeck and McGlone (1999) concluded that the immune status and performance of outdoor pigs in their experiment were consistent with the segregated early weaning model that includes low microbial load and high performance in an early-weaned, stressed animal.

1.8 Environmental, Behavioural and Production Consequences of Differences Between Conventional and Alternative Post-Weaning Housing Systems

1.8. 1 Thermal environment

Provision of an appropriate thermal requirement at weaning is essential to the health and well-being of the pig. The pig's temperature requirement is determined by its live weight, energy intake, whether it is individually or group housed, pen floor type, and air speed at pig level (Close & Mount, 1975; Close, 1981). Most pigs experience an abrupt and substantial decrease in feed intake after weaning, often taking a week or more to re-establish pre-weaning levels of energy intake (Pluske et al., 1997). There is usually a concurrent increase in heat production after weaning caused by transportation, regrouping and increased activity in new surroundings which combines with a decrease in feed intake to create a net energy deficiency (Madec et al., 2003). The same authors presented evidence that subcutaneous backfat can decrease by over 30% in the first week after weaning, depending on feed intake, environmental temperature and available fat stores at weaning. Loss of subcutaneous fat and the associated decrease in body thermal insulation renders the pig more vulnerable to cold stress and further increases the heat production required to maintain body temperature. The combination of reduced feed intake, increased heat production and the resulting net energy deficiency that occurs after weaning markedly affects the thermal requirements of the pig. In conventional

housing, ambient temperature is usually set according to the requirement of the average pig in the airspace, which may disadvantage atypical pigs. Thus deep litter and other systems that offer piglets greater control over their own thermoregulation through choice of their own microenvironment may enhance welfare and possibly, production efficiency.

Bedding reduces the pig's lower critical temperature (LCT) by 7–8° C (Verstegen & van der Hel, 1974). Other work suggests the LCT of pigs housed on deep straw may be even lower. When an electrically-heated, artificial pig equivalent to a 35 kg live pig was used to measure heat loss in deep straw bedding, the LCT for groups of ad libitum-fed pigs 70%-embedded in straw was predicted to be -22° C (Sällvik & Wejfeldt, 1993). Temperatures in straw nests built in the open by free-ranging sows during a Swedish winter varied between 11–26°C while outside temperatures ranged between -17°C and 7°C (Algers & Jensen, 1990). Nest temperatures declined rapidly after piglets left the nest, indicating the piglets themselves acted as heat generators and the insulating properties of the nest materials protected piglets from very low ambient temperatures.

It is therefore unsurprising that newly-weaned piglets can thrive in deep-litter systems in which they can partially or completely bury themselves in the bedding material. Kelly et al. (2000a) found that piglets housed in deep-straw pens grew faster during the 3–4 week period after weaning than those in pens with limited straw, or in small and large flat deck pens with expanded metal flooring, despite the temperature in the straw room being decreased from 24°C to 16°C compared to 27°C to 18°C in the flat-deck room. However, others have reported that piglets weaned at between 21–28 d into straw-

bedded kennels ate less and grew slower than those in flat-deck pens (Britton et al., 1993; Suster et al., 2005).

1.8.2 Environmental enrichment

The indoor and outdoor farrowing, and the conventional and deep-litter rearing systems described in Sections 1.5 and 1.6 of this review provide environments that range from sterile to semi-natural in terms of environmental richness afforded to pigs. Therefore it is pertinent to review possible consequences of differences in environmental richness. Studies into the effects of environmental enrichment on the behaviour and performance of the weaned pig have produced variable results. The use of straw in deep-litter systems, in addition to providing thermal and perhaps physical comfort (Day et al., 2002), provides a stimulus and outlet for exploratory and manipulative activities (Fraser et al., 1991). It is generally thought that only substrates incorporated into pen design meet the elements of complexity, unpredictability and responsiveness necessary to stimulate natural behaviours (Beattie et al., 1995). The provision of peat and straw in racks has also been reported to decrease harmful social behaviour, improve growth and FCR, increase carcass weight and backfat, and improve meat quality (Beattie et al., 2000). In contrast, other forms of behavioural enrichment such as rocking metal bars with rubber belts on the ends or sugar-mineral blocks suspended in metal baskets, have been found to reduce aggression and improve animal growth (Schaefer et al., 1990). Similarly, pigs from an outdoor production system weaned at 21–28 d into conventional flat-deck pens enriched with toys ate more and grew faster in a 30-day experimental period than those weaned into similar flat decks without toys or into straw-bedded kennels (Britton et al., 1993).

Moving pigs from enriched to barren environments may have adverse consequences. Day et al. (2002) found that moving pigs from accommodation with straw to accommodation with no straw increased the occurrence of undesirable behaviour directed at pen mates, but did not report any performance data to indicate the impact of the undesirable behaviour on production. There do not appear to be any reports on the effect of moving piglets born outside into unenriched indoor accommodation after weaning.

The importance of straw for pig welfare has recently been reviewed by Tuyttens (2005), who concluded that straw has many positive effects on welfare: by improving physical comfort; by providing pigs with some control of their microclimate and hence thermal comfort (unless temperatures are high); and by providing a stimulus and outlet for exploration, foraging, rooting and chewing behaviours. Conversely, the same researchers also found that pigs housed in barren environments can be strongly motivated to express these behaviours, while the inability to do so may result in behavioural problems and (or) anomalies such as aggression, ear and tail-biting, and other oral behaviours directed to pen fittings or pen-mates.

Straw is also a source of non-starch polysaccharides, albeit in relatively indigestible form, which are generally perceived to have a positive effect on gut health (Gerrits & Verstegen, 2005). The quantity of straw ingested by weaner pigs in bedded systems has not been reported although the intake of rice hull bedding by 20–25 kg pigs was estimated to comprise 5.6% of their diet (van Barneveld et al., 2003). It remains unknown whether the casual ingestion of straw by piglets born outdoors or by weaners

on deep litter is sufficient to affect gut microbiota or to have any beneficial effect on gut development.

The evidence above suggests that environmental enrichment by the provision of edible substrates such as straw stimulates exploratory and foraging behaviours in the young pig, and therefore may increase feed intake after weaning, but this relationship does not appear to have been quantified.

1.8.3 Comparisons of pig performance in different post-weaning rearing systems

The majority of grower-finisher pigs have been housed in concrete-floored pens since the intensification of the Australian pig industry began in the 1960s. However, deep-litter pens in low-cost shelters became popular in the 1990s to facilitate age segregated all-in, all-out and multi-site management systems at a time when conventional buildings were relatively expensive and bedding sources cheap. Little was then known about pig performance in deep-litter compared to conventional housing systems. Payne et al. (2000) conducted an Australia-wide survey of producers who used deep-litter systems. Most respondents to the survey reported an improvement in performance when growing pigs of any age were moved from conventional into alternative housing systems. However, performance data collected during the survey was regarded as indicative only as few producers had conducted well-designed trials or kept accurate records of growth rates. Table 1.1 contains values calculated from reported average weights and ages at various stages in the production chain, or from carcass weights and nominal age at slaughter. Interestingly, the weighted-average growth rate from the survey for grower/finishers in shelters was 828 g/d compared with 821 g/d achieved in trials at the Medina Research Station (Payne, 1997), suggesting that the figures shown in Table 1.1

are a reasonably good estimation of performance across the Australian industry at that time.

Most producers contacted during the survey reported that pigs ate more, grew faster, and were healthier but also fatter with worse FCRs in deep-litter compared to conventional housing. Payne et al. (2000) suggested that appetite may have been stimulated by a combination of factors including: increased physical activity, lower air temperatures in deep-litter pens, enhanced gut motility caused by ingestion of bedding and increased exercise, and improved access to feeders. The resultant higher feed intakes, sometimes in combination with inappropriate diet specifications, plausibly explain the reported performance differences in the two housing systems.

Table 1.1 Growth performance of pigs reared in shelters (from Payne et al., 2000)

	Farm average	Weighted average	Lowest value	Highest value
Weaners				
Age into shelter (d)	19.3	14.8	14	21
LW[1] into shelter (kg)	5.9	4.7	4.5	6.5
Age out of shelters (d)	62.3	69.0	53	70
LW out of shelter (kg)	25.4	58.0	20.0	30.0
GR[2] in shelters (g/d)	438	424	388	480
Weaner to Finisher				
Age into shelter (d)	19.0	18.9	17	21
LW[1] into shelter (kg)	5.7	6.0	5.0	6.0
Age out of shelters (d	156.3	156.7	140	168
LW out of shelter (kg)	101.3	103.2	95.0	109.0
GR[2] in shelters (g/d)	699	709	665	748
Grower to finisher				
Age into shelter (d)	64.8	67.6	56	70
LW[1] into shelter (kg)	25.9	27.0	20.0	30.0
Age out of shelters (d)	164.0	165.1	161	182
LW[1] out of shelter (kg)	102.5	106.8	86.0	110.0
GR[2] in shelters (g/d)	805	828	571	1019

[1]Live weight, [2]Growth rate.

However, comparisons of pig performance in deep-litter or conventional buildings conducted on large commercial piggeries in Australia, North and South America reported by Payne et al. (2000) indicated that growth rate was lower in deep-litter shelters and, although there was no clear trend in housing effects on carcass backfat, FCR was higher in deep-litter systems (Table 1.2).

Table 1.2 Performance of grower-finisher pigs in conventional or deep-litter housing systems

Location	Live weight (kg)		ADG(g)	FCR	P2 (mm)	Mortality (%)
	Start	End				
Australia (NSW)						
Deep-litter	19.6	99.0	789	2.80	11.8	2.3
Conventional	18.7	99.5	760	2.70	10.5	4.1
Australia (WA)						
Deep-litter	28.0	110.0	836	2.61	12.2	n.a.[1]
Conventional	28.0	106.2	879	2.54	12.2	n.a.
Chile						
Deep-litter	22.8	101.0	770	2.94	n.a.	n.a.
Conventional	23.7	105.0	800	2.87	n.a.	n.a.
USA (Nebraska)						
Deep-litter	23.6	112.3	712	3.34	21.8	10.6
Conventional	25.9	117.9	816	3.11	22.1	8.3
USA (North Carolina)						
Deep-litter	21.2	109.6	910	2.37	n.a.	2.6
Conventional	26.1	110.3	960	2.22	n.a.	2.6

[1]not available

One of the major issues identified by Payne et al. (2000) was the apparent increase in P2 backfat of pigs reared in shelters compared to similar animals reared in confinement buildings. Some of the reported increase, up to 3 mm in some cases, may have been related to heavier carcass weights resulting from faster growth rate of pigs marketed on an age basis, or failure to adapt diet specifications and feeding programs appropriate to increased feed intake and growth rates. Alternatively, improved health status in shelters may have caused nutrients to be partitioned differently, rendering more energy available for growth or fat deposition rather than supporting immune responses. It is also possible

that reduced stress in more enriched environments may have resulted in nutrients being partitioned differently.

Numerous other experiments comparing the post-weaning performance of pigs in a variety of post-weaning accommodation are reported in the literature. The results of some of these experiments and the effects of diverse environments on growth, feed efficiency, and carcass fat content are summarised in Table 1.3. In most cases, individual experiments have used weaners from only one production system. For example, the performance of piglets born and raised indoors until weaning have been studied in a variety of conventional, deep-litter, straw-flow or outside pens by Lee et al. (1995), Lyons et al. (1995), Kelly et al. (2000a), Guy et al. (2002a), Bondesan et al. (2004) and Heyer et al. (2006). More recently, because of the growing interest in organic pork production, other workers have studied the post-weaning performance of piglets produced outdoors in deep-litter, outside pens and on pasture (Stern et al., 2003; Kelly et al., 2007), or in conventional and outside pens (Folestam, 2005; Strudsholm & Hermansen, 2005). Other experiments have compared performance and behaviour of piglets produced indoors or outdoors and reared in the same type of system after weaning (Hotzel et al., 2004; Rudine et al., 2007). Only one experiment (Gentry et al., 2002b) could be found that compared the post-weaning performance of indoor- and outdoor-born weaners in either conventional or outdoor housing. However, Miller et al. (2007) investigated the performance of indoor and outdoor piglets weaned at four or six weeks of age, and found that outdoor piglets were heavier than indoor piglets at both weaning ages, but there was no difference in gut maturity attributable to the rearing environment.

Not surprisingly, given the diversity in experimental design and housing environments, these experiments have produced conflicting results and show no consistent trends in growth and characteristics. Post-weaning growth of indoor-born pigs reared in straw-based pens or huts was superior in five of the eight experiments reviewed, whereas FCR and backfat were mostly not significantly different between housing systems. The most comprehensive and convincing study (MLC, 2005) compared fully-slotted versus straw-based housing systems in a series of four trials conducted in identical buildings with similar ventilation systems. These studies found no significant effects of housing on overall performance and carcass quality, although feed intake and daily gain were higher in the fully-slatted system during the grower stage and conversely higher in the straw-based system during the finisher stage. Morbidity and mortality rates were similar between treatments, although the reasons for removal and welfare indicators differed between systems.

Table 1.3 The effects of pre- and post-weaning environment and housing on pig performance

Authors	Type of environment and housing: Pre-wean		Post-wean	ADG[1]	DFI[2]	FCR[3]	Backfat	KO%[4]
Lyons et al. (1995)	Indoor	Indoor	Straw	↑[5]***[6]	↑*[8]	n.s.d.[9]	n.s.d.	n.r.[10]
	Indoor	Indoor	no-straw					n.r
Lee et al. (1995) year 1	Indoor	Indoor	Solid floor	↑trend	n.r.		↑trend	
	Indoor	Outdoor	Huts+pasture		n.r.	↑trend		↑trend
year 2	Indoor	Indoor	Solid floor	n.s.d.	n.r.			
	Indoor	Outdoor	Huts+pasture	n.s.d.	n.r.	↑*	↑trend	↑trend
year 3	Indoor	Indoor	Solid floor		n.r.			
	Indoor	Outdoor	Huts+pasture	↑*	n.r.	↑*	↑trend	↑trend
Guy et al. (2002a)	Indoor	Indoor	Fully slatted		↓**[7]	↑**	↑*	n.s.d.
	Indoor	Indoor	Deep-litter	↑***				n.s.d.
	Indoor	Outdoor	Huts+pasture	↑**		↑**		n.s.d.
MLC (2005)	Indoor	Indoor	Straw based	n.s.d.	n.s.d.	n.s.d.	n.s.d.	n.s.d.
	Indoor	Indoor	Fully slatted					
Heyer et al. (2006)	Indoor	Outdoor	Huts+pasture					
	Indoor	Outdoor	Huts+pasture	↑*	↑*		↑***	
	Indoor	Indoor	Indoor	↑*	↑**	↑***	↑***	↑***
Millet et al. (2004)	indoor	Indoor	Part-slatted		↑***	n.s.d.	n.s.d.	
	indoor	Outdoor	Deep-litter + Outdoor run	↑***	↑***	n.s.d.	n.s.d.	↑***
Strudsholm and Hermansen (2005)	Outdoor	Indoor	Deep-litter + Outdoor run	n.s.d.	n.r.		↑***	n.s.d.
	Outdoor	Outdoor	Huts+pasture	n.s.d.	n.r.	↑*		n.s.d.
Folestam (2005)	Outdoor	Indoor	Part-slatted		n.r.	n.s.d.	n.s.d.	↑**
	Outdoor	Outdoor	Huts+pasture	↑***	n.r.	n.s.d.	n.s.d.	
Bondesan et al (2004)	Outdoor	Indoor	Deep-litter + Outdoor run	n.r.	n.r.	n.r.	↑**	n.r.
	Outdoor	Outdoor	bush+pasture	n.r.	n.r.	n.r.		n.r.
Kelly et al. (2007)	Outdoor	Outdoor	Huts+pasture	n.s.d.	↑***	↑***	n.s.d.	↑***
	Outdoor	Indoor	Deep-litter + Outdoor run	n.s.d.			n.s.d.	
Stern, et al. (2003)	Outdoor	Indoor	Deep-litter		n.r.	n.s.d.	↑***	
	Outdoor	Outdoor	Huts+pasture	↑*	n.r.	n.s.d.		↑***
	Outdoor	Indoor	Deep-litter	n.s.d.	n.r.			
	Outdoor	Outdoor	Huts+pasture	n.s.d.	n.r.	↑***		↑***
Gentry et al. (2002a)	Indoor		n.a		n.r.	n.r.	n.s.d.	
	Outdoor		n.a	↑**	n.r.	n.r.	n.s.d.	↑trend
	n.a	Indoor	Fully slatted	n.s.d.	n.s.d.			
	n.a	Outdoor	Huts+pasture	n.s.d.	n.s.d.	↑*	↑*	↑trend
Gentry et al. (2002b)	Indoor	Indoor	Fully slatted		n.r.	n.r.	↑*	
Exp.1 - summer	Outdoor	Outdoor	Huts+pasture	↑***	n.r.	n.r.		↑trend
Gentry et al. (2002b)	Indoor	Indoor	Fully slatted	n.s.d.	n.r.	n.r.	↑*	↑trend
Exp.2 - winter	Indoor	Outdoor	Huts+pasture	n.s.d.	n.r.	n.r.		
Gentry et al. (2004)	Indoor		n.a	n.s.d.	n.r.	n.r.		
	Outdoor		n.a	n.s.d.	n.r.	n.r.	↑**	↑trend
	n.a	Indoor	Fully slatted	n.s.d.			n.s.d.	n.s.d.
	n.a	Outdoor	Huts+pasture	n.s.d.	↑**	↑**	n.s.d.	n.s.d.

[1]average daily gain, [2]daily feed intake, [3]feed conversion ratio, [4]killing out %, [5]increase (↑) or decrease (↓) in value relative to other treatments in study at [6]P<0.001, [7]P<0.01 or [8]P <0.05, [9]not significantly different to other treatments in study, [10]not reported.

When all variables are controlled, it appears that performance of indoor-born pigs is similar in fully-slotted and straw-based grower-finisher systems. In contrast, two out of four studies of the post-weaning performance of outdoor-born piglets suggest a tendency

for faster growth associated with higher feed intake and FCR when they are reared on pasture compared to indoors in either slotted-floor or deep-litter pens. The two experiments that actually compared the post-weaning performance of indoor- or outdoor-born pigs housed in fully-slatted pens or on pasture with straw-based huts also produced conflicting results. In Gentry et al. (2002a), the outdoor-born piglets grew faster than indoor-born piglets whereas in Gentry et al. (2004), growth was similar for pigs from both birth environments.

There do not appear to be any reports in the literature of studies that compared the post-weaning performance of piglets produced indoors or outdoors and reared in conventional or deep-litter housing systems from weaning to 100 kg live weight. Data from locally conducted studies of this type would help Western Australian producers make informed decisions on which pig housing system to adopt.

1.9 Creep Feeding

Creep feeding is not generally practised in outdoor production systems, a major point of difference with indoor farrowing systems where creep feeding is common, particularly when weaning at 28 d. There are few studies on the provision of creep feed to outdoor piglets and reasons for not feeding creep cannot be found in the limited literature on outdoor pig production, but presumably the logistical difficulty of providing creep feed in the outdoor environment far outweighs any potential benefit from so doing. However, one study (Miller et al., 2007) showed that although outdoor piglets appeared to consume nearly twice as much creep feed as indoor piglets, it was not associated with increased intestinal maturity.

The variation in creep feed intake within and between litters and the weak positive relationship between pre-weaning creep feed intake and post-weaning growth have been noted by many authors and was comprehensively reviewed by Pluske et al. (1995). Likewise, the relationship between pre-weaning food consumption and post-weaning growth has been reviewed by Brooks and Tsourgiannis (2003) and Pluske et al. (2006). Both of these reviews concluded that the typically low consumption of dry creep feed offered to piglets prior to weaning at 21 d or less was unlikely to improve feed intake and live weight gain thereafter. More recently, studies using qualitative assessments of creep feed consumption by sucking piglets indicate that creep feed consumption during lactation stimulates food intake and growth after weaning (Bruininx at al, 2004; Callesen et al., 2007; Pluske et al., 2007). The proportions of piglets deemed to be 'eaters' of creep feed ranged from 77% (Callesen et al., 2007) to 85% (Pluske et al., 2007). The causes of the large variation within and between litters in creep feed intake during lactation remain largely unknown (Callesen et al., 2007).

Evidence that any beneficial effects from dry creep feed intake during lactation persist until slaughter is sparse. An experiment by Kokosinska and Williams (2005) found that offering a high (compared to an average) quality creep feed from day 10 until weaning at day 18, and for a further 21 d after weaning, did not increase weaning weight but resulted in higher weights at the end of the creep feeding period, a weight advantage that persisted until slaughter at 105 kg live weight. The high quality creep contained more digestible energy protein sources, mannan oligosaccharides, betaine and organic minerals. However, the experimental design rendered it impossible to determine how much, if any, of the increase in live weight gain by piglets fed the high quality diet was due to feed consumption during lactation. There do not appear to be any other reports of

long-term advantages from dry creep feed intake during lactation. Moreover, Lawlor et al. (2002) demonstrated that although weaning weight could be increased by manipulating pre-weaning nutrition and management, any weight advantage disappeared after 14 d. Similarly, Edge et al. (2008) found that weaning at eight compared to four or six weeks did not benefit physical performance from birth to slaughter, although there were significant benefits from later weaning to piglet performance during the immediate post-weaning period. Thus, the consequences of not providing dry creep feed to outdoor piglets are probably insignificant.

There is a dearth of information on the amount of substrates ingested by outdoor piglets in place of creep feed, and on whether all piglets eat these substrates or if there is a proportion of non-eaters as seen in studies on the consumption of creep feed. There is a similar lack of information on the effects of consuming outdoor substrates by sucking pigs. Although many factors undoubtedly contribute to the smaller post-weaning growth check experienced by outdoor pigs as described by Edwards and Rooke (1999), the possibility exists that ingestion of other substrates in the outdoor milieu is equally or more beneficial than creep feed in stimulating gut development and post-weaning feed intake.

1.10 Iron Status

Soil is a natural source of iron but is not available to piglets raised in intensive production systems, necessitating supplementation by injection or oral administration of other forms of iron. The need for supplemental iron to prevent iron deficiency anaemia in piglets has long been recognised. McGowan and Crichton (1923; 1924) first described iron deficiency in piglets confined in concrete pens and accurately attributed

the condition to a lack of iron in sow's milk and withholding other sources of iron from the piglets, although noting that piglets may have obtained some iron by ingesting sow faeces and sow feed spilt on pen floors. Their findings were subsequently confirmed by numerous authors over the following 20 years, reviewed by Venn et al. (1947). Seminal work by Venn et al. (1947) established that administration of iron to sows during pregnancy did not increase the total quantity of iron transmitted to the progeny through the placenta or the percentage of iron in piglets at birth, and administration of iron to sows during lactation did not raise the percentage of iron in their milk. In their experiment, the bodies of piglets at birth contained about 50 mg of iron, and less than 5 mg of organic iron in the liver, an amount insufficient to meet requirements of the body in the following three weeks. They calculated that piglets required about 7 mg of iron per day to support normal growth and prevent anaemia, of which less than 1 mg was supplied in sow milk. Furthermore, Venn et al. (1947) confirmed the benefits of administering iron to piglets during lactation, either as a daily dose of approximately 11 mg per kilogram of body weight or by allowing free access to soil. The intestines of one pig reared outdoors contained 513 mg iron which was calculated to have come from at least 40 g of soil, and the authors concluded from their and other published work that "….a trough of soil or sods inside the pen still seems to be the best solution of the problem", that is the prevention of anaemia in piglets maintained in concrete pens.

Other methods used for providing supplemental iron to piglets included dosing pigs with ferrous sulphate tablets, introducing reduced iron powder into piglets' mouths and painting a mixture of molasses and ferrous sulphate on the sow's teats (McDonald et al., 1955), all of which were messy, time-consuming and of uncertain efficacy. The major breakthrough in treating iron deficiency anaemia in piglets occurred following the

development of an iron dextran product by London and Twigg in 1952 for the intramuscular treatment of hypochromic anaemia in man (Ullrey et al., 1959). McDonald et al. (1955) were the first to report that iron dextran containing 3% iron was absorbed and utilised for haemoglobin regeneration when injected intramuscularly, and could prevent anaemia when given early in life. This was confirmed shortly after by Barber et al. (1955) who found that a single injection of 100 mg iron on day seven was as effective as orally dosing with iron pyrophosphate for 7 d commencing at day 7 of life in arresting the fall in blood haemoglobin content after birth and raising it to normal levels by day 14. Brownlie (1955) also found iron dextran effective in curing anaemia when injected at 11 or 10 days of life, estimating that it was approximately 85% utilised in the nine days after treatment. Maner et al. (1959), Rydberg et al. (1959) and Zimmerman et al. (1959) also provided further evidence of the efficacy of iron dextran compared to other sources of iron in preventing and curing piglet anaemia.

Attempts to increase iron reserves of piglets and the iron content of sow milk by feeding or dosing sows with iron met with mixed success. Pond et al. (1961) found that intramuscular injection of iron into sows perinatally did not increase the iron content of milk and failed to prevent piglet anaemia. Feeding chelated iron to sows in late gestation and during lactation increased milk iron and prevented piglet anaemia (Brady et al., 1978), but the increase in milk iron was insufficient to account for the maintenance of adequate piglet haemoglobin, suggesting the primary route for Fe transfer was via the sow's faeces. This was confirmed by Sansom and Gleed (1981) who found that while milk of sows housed on solid floors remained free of a radioactive marker, their faeces and bedding became radioactive. So too did their piglets, enabling the authors to measure the radioactivity gained from the ingestion of radioactive

material and thereby deduce that piglets ingested about 20 g of faeces and bedding daily. This amount would be enough to prevent piglet anaemia if the sow's diets were supplemented with iron to increase the Fe concentration of her faeces to approximately 2 mg Fe/g of fresh faeces. Furthermore it has been estimated, using the technique of Sansom and Gleed (1981), that even piglets of sows housed on relatively clean fully-slotted floors ingested 8.5 g/d of sow faeces, sufficient to prevent anaemia if the sow's diet contained 2,000 mg Fe/kg as demonstrated on two commercial piggeries as part of the same study (Gleed & Sansom, 1982).

There are conflicting reports on the amount of other forms of supplemental iron that should be administered to piglets to meet requirements. According to Venn et al. (1947), rapidly growing piglets require a total of 250–350 mg of iron to support normal growth and maintain adequate haemoglobin levels over the first three weeks of life, of which 23 mg Fe may be obtained from sow's milk and 78 mg scavenged from their surroundings and sow faeces. Thus piglets require an additional 150–250 mg of supplemental iron over 21 d, equivalent to 7–12 mg Fe per day to prevent deficiency. Assuming 85% utilisation as determined by Brownlie (1955), administration of 200 mg of iron dextran will supply 170 mg of iron, which should theoretically be sufficient to meet the additional requirement of most piglets. However, this amount may be excessive as some workers have found that one injection of 100 mg iron dextran administered within three or four days of birth to pigs weaned at three weeks of age was sufficient to maintain blood haemoglobin at adequate levels and for optimal growth, and was superior to other forms of iron supplementation (Ullrey et al., 1959; Zimmerman et al., 1959; Rydberg et al., 1959; Kay et al., 1980). Although higher haemoglobin levels were found at 14 and 21 days after birth in piglets injected with 150 mg compared with

100 mg of iron dextran on the first day of life, haemoglobin levels and weight gains at 28 d were similar (Wahlstrom & Juhl, 1960).

The threshold level of blood haemoglobin at which piglet performance is affected by iron deficiency is not well defined. There appears to be agreement that piglets become anaemic when haemoglobin in blood falls below 6 g per 100 ml^{-1} (Matrone et al., 1960), but the accepted level at which piglet performance is affected remains contentious. The Agricultural Research Council (1981) recommended haemoglobin concentrations of 80 g/L to maintain adequate growth. This was confirmed by Egeli and Framstad (1998) who found that piglets with a haemoglobin concentration of ≤ 80 g/L on days 14, 21, and 28 of life, which they designated as anaemic, were lighter at days 21 and 35 than piglets with a haemoglobin concentration of > 80 g/L on days 14, 21, and 28 of life which were considered normal. However, Miller et al. (1982), Pollman (1983) and Daykin et al. (1982) used 9 g/dl as the minimum required for maximum growth rate of nursing pigs, this being the midpoint between the lower level of the normal range of 100 g/L (Schalm, 1975) and the 80 g/L suggested by the Agricultural Research Council (1981). In Nutrient Requirements of Swine (1998), haemoglobin levels of 10 g/dl are considered adequate, 8 g/dl suggestive of borderline anaemia, and 7 g/dl indicative of anaemia.

Supplemental iron is not usually provided to piglets produced outdoors as it is generally considered that iron requirements are met through the ingestion of soil. Recent experiments conducted in Scotland (Brown et al., 1996), the USA (Kleinbeck and McGlone, 1999) and Mexico (Góngora et al., 2004) with outdoor production systems on a variety of soil types have shown no benefit in supplemental iron. In a survey of eight

farms in North Eastern Scotland (Brown et al., 1996), average soil iron content was 13 g/kg of dry matter (range 4.1–30.8) but there was no correlation between blood haemoglobin content of piglets and the amount of iron in the soil, although the farm with the lowest piglet haemoglobin value also had the lowest soil iron content. Thus Brown et al. (1996) concluded that piglets in their study obtained sufficient iron from sources other than milk to render it unnecessary for most outdoor pig producers to inject suckling pigs with iron. There is some evidence this is not always the case. Piglets, born and reared outdoors on sandy soils in England, developed anaemia 7–10 days after birth, displaying classic signs of the disease with a sample of piglets recording haemoglobin levels of under 5 g/dl (Venn & Davies, 1965). This was attributed to the soil containing low levels of iron (160–740 ppm Fe) compared to other soils in the UK which ranged from 1,500–7,900 ppm when analysed using 0.1 N hydrochloric acid as a solvent to simulate the action of pig gastric juice. Szabo and Bilkei (2002) also found supplemental iron was essential to maintain performance and to prevent anaemia in outdoor piglets under the conditions of their experiment conducted in Hungary.

In summary, continuous access to soil containing iron from birth to weaning may result in piglets having a superior iron status at weaning compared to piglets that only receive a parenteral iron supplement one or two days after birth. Since marginal iron deficiency, indicated by haemoglobin levels less than 100 g/L, can depress piglet performance and vigour before and after weaning (Schrama et al., 1997), any comparison of the post-weaning performance of indoor and outdoor piglets should take into account their iron status at weaning to eliminate iron deficiency as a factor in any observed performance differences.

1.11 Conclusions

Clearly, marked differences in pre- and post-weaning environments afforded by diverse housing systems can potentially affect the lifetime growth and development of pigs. It is equally clear that these effects have not been fully documented or understood, despite their ramifications for commercial production. Well-designed studies of the post-weaning performance of pigs born indoors or outdoors in conventional or deep-litter pens do not appear to have been conducted and many questions remain unanswered. For example, do outdoor weaners suffer less of a growth check after weaning and if so why? Do piglets born outdoors adapt more readily to being reared on deep-litter in low-cost shelters? Conversely, are outdoor weaners disadvantaged compared to indoor weaners when reared indoors in conventional pens, and do differences after weaning persist throughout the grower/finisher phase? Finally, what are the long term consequences of access to soil prior to weaning? Answering these questions would add considerably to the body of knowledge on the production consequences of pre- and post-weaning housing environments.

Therefore an experiment was conducted to compare the gut development, health, growth performance and carcass composition of pigs derived from indoor and outdoor housing systems when reared in conventional or deep-litter pens. This was followed by another experiment that allowed one factor specific to outdoor production, i.e. the ingestion of common substrates, to be studied in the absence of other environmental and behavioural differences in the outdoor milieu. These two experiments enabled testing of the general hypothesis for this thesis that '*the gut development and lifetime performance of the weaned pig are affected by its pre- and post-weaning rearing environments*'.

CHAPTER 2: GENERAL MATERIALS AND METHODS

All experiments were conducted at the Medina Research Station (Department of Agriculture and Food Western Australia (DAFWA)). Physical resources at the Station were insufficient for all components of Experiment 1 to be conducted simultaneously, therefore it was conducted in two parts. The first part, Experiment 1a (**Exp1a**), was conducted between 21st November 2002 and 8th April 2003 and the second part, Experiment 1b (**Exp1b**), from 23rd October 2003 to 17th March 2004. Experiments 1a and 1b were identical in design and methodology (see Chapter 3) with the exception that antimicrobial products were used in the first stage weaner diet in **Exp1a** in accordance with industry practice, but were omitted from the diets fed in **Exp1b**.

2.1 Animals

The experiments were approved by the Animal Ethics Committee (AEC) of DAFWA (Approval Numbers: **Exp1a**, AEC number 4–02–15; **Exp1b**; AEC number 6–03–41; Experiment 2, 1–04–5) and conducted according to the requirements of the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes as specified by the *Animal Welfare Act (2002)*.

Indoor pigs (IP) used in Experiment 1 were produced on a 900-sow commercial breeder unit (Latitude 33°17' S, Longitude 115°43' E), approximately 130 km south of the Medina Research Station (Latitude 32°1' S, Longitude 115°48' E). Outdoor pigs (OP) used in the same experiment were produced on a 400-sow farrow-to-finished extensive production unit (Latitude 32°39' S, Longitude 117°07' E), approximately 135 km south

east of the Medina Research Station. Both herds were depopulated about a year before the start of this study, and were re-stocked with gilts and boars of the same maternal and terminal sire lines from the same multiplier herd. The health status of IP and OP pigs, as determined by faecal swabs taken at the start and abattoir health checks conducted at the end of each study, was deemed to be similar.

The 32 multiparous Large White x Landrace crossbred sows used in Experiment 2 (of a different genotype to that used in Experiment 1) were obtained at 56 to 63 days of gestation from a high health-status 4,000-sow breeder unit located about 35 km SSE of the Medina Research Station. The sows farrowed in two batches of 16, the first batch from 1st to 4th August and the second batch from 13th to 17th September 2004. Twelve healthy sows with 10 viable teats and normal appetites were selected from each batch to participate in the experiment.

2.2 Housing

2.2.1 Pre-weaning accommodation (Experiment 1)

Indoor pigs were born and reared until weaning in conventional farrowing facilities. Sows and litters were housed in conventional slotted-floored farrowing crates (2,400 mm long by 1,800 mm wide) in an environmentally-controlled building maintained at 24°C ± 2°C. Piglets were provided with a heat lamp over a mat in a covered creep area and a nipple drinker mounted below the sow drinker.

Outdoor pigs were born in portable farrowing arcs (2,400 mm wide by 1,800 mm wide by 1,200 mm high at centre). Arcs were placed on fresh ground within a two hectare farrowing paddock and provided with approximately 10 kg of barley straw before each

farrowing. Piglets were contained in the arcs until 10–14 days of age by a fender attached to the doors of the arcs but had access to soil, pasture residues and straw within the arc and fender. After 10–14 days piglets were able to leave the farrowing arc at will. Water troughs and wallows were provided for the sows, to which piglets also had access once they were able to leave the farrowing hut. At this stage, piglets also had access to sow feed that was spread on the ground or was provided in a self-feeder that piglets could feed from directly or from spillage surrounding the feeder.

2.2.2 Weaner accommodation (Experiment 1)

Conventional treatment pigs (C) were reared for the first seven weeks of the experiments in a naturally-ventilated, insulated weaner house in part-slatted pens that were 3,300 mm long and 1,200 mm wide, with a floor area of 3.4 m^2. Each pen was equipped with a 1,200 mm wide by 1,300 mm wide heated kennel with thick rubber-mat on the mesh floor. There were 10 pigs per pen; thus each pig was provided with a total floor-space allowance of 0.40 m^2 per pig, comprised of 0.16 m^2 kennel area and 0.24 m^2 slotted floor area. Each pen was equipped with two nipple drinkers and a bulk feeder with 12 feeding spaces that provided 115 mm of linear feeding space per pig.

Deep-litter (DL) treatment pigs were housed in two EcoShelters®, each containing four solid-floor pens that were 10,800 mm long by 4,300 mm wide. Each pen included a 300 mm high raised feeding platform 1,800 mm long and 4,300 wide at one end of the pen. There were 10 pigs per pen; thus each pig was provided with a total floor space of 4.6 m^2, comprised of 3.9 m^2 of bedded area and 0.7 m^2 of feeding pad. For the 7-week weaner phase of the experiment, the pens were equipped with a bulk feeder with 16

feeding spaces that provided 160 mm/pig of feeder space, four Drik-O-Mat® drinking cups, and spray cooling along one side of the pen.

2.2.3 Grower/finisher accommodation (Experiment 1)

After seven weeks, C pigs were transferred to a naturally-ventilated grower/finisher house and reared in part-slatted pens (3,200 mm long by 2,400 mm wide) with a total floor area of 7.7 m^2, providing 0.77 m^2 per pig of floor-space. Each grower/finisher pen was equipped with a 300 mm wide single space feeder, two nipple drinkers, and spray cooling over the slotted-floor section of the pen.

The DL treatment pigs remained in the weaner accommodation for the grower/finisher phase of the experiment, but at the end of the weaner phase (47 d) the DL pigs were moved into the diagonally-opposite pens, and the weaner feeders replaced with grower/finisher feeders. Thus DL pigs were subjected to a change in pen and feeders in an attempt to simulate the changes in accommodation and equipment to which C pigs were exposed at this stage of the experiment. An initial bed of barley straw, approximately 200 mm deep, was provided in DL pens at the start of the experiment and fresh straw then added as necessary to maintain 50% of the bedded area in a clean, dry condition.

Although pen size, feeders and drinkers all differed between C and DL pens, floor and feeder space allowances, and the number of drinkers per pig, liberally exceeded recommended requirements in both housing systems (Model Code of Practice for the Welfare of Animals – Pigs 3rd Edition, 2008, CSIRO Publishing, Collingwood, Australia) and therefore were not considered limiting to pig performance.

2.2.4 Accommodation for the sacrifice cohort (Experiment 1)

The 12 IP piglets of the sacrifice cohort were housed in a typical C pen, while their 12 OP counterparts were housed in a typical DL pen from 21 d (weaning) until slaughter at 28 or 42 d of age.

2.2.5 Sow accommodation (Experiment 2)

During gestation, sows were housed in pairs in partially-slatted pens in an insulated, naturally-ventilated building. The pens were 2.1 m long and 2.4 m wide, providing a floor-space allowance of 2.5 m^2 per sow. Sows were fed on the solid floor area and provided with two nipple drinkers positioned over the slotted-floor area at the rear of each pen. Sows were transferred into the farrowing accommodation as a batch when the first sow in the batch reached 110 d of gestation.

Sows farrowed in conventional crates contained in an environmentally-controlled room maintained at 24ºC ±1º until the youngest litter was seven days old, when the temperature was reduced to 22ºC ±1º. Each crate was free-standing, with a fully-slotted base supported 150 mm above the room floor. The crates were positioned in two rows of eight with 1200 mm between rows, each crate spaced 600 mm apart within rows and also from the rear wall. This provided all-round access to the crates and to the floor beneath and enabled creep feed that fell through the slotted base to be retrieved for the purpose of measuring feed disappearance. Each crate was 2,400 mm long by 2,100 m wide with a creep area 2.4 long by 0.6 m wide equipped with a similar-sized floor mat. The creep area was covered 600 mm above the mat with a hover-board containing a 150-watt infrared heat lamp. A removable plastic feed trough, 600 mm long by 100 mm

wide by 75 mm deep, was mounted on the side wall of the creep area opposite the sow feeder. A nipple drinker for piglets was positioned below the sow drinker adjacent to sow feeder.

2.2.6 Weaner pens (Experiment 2)

At weaning, all piglets were moved into an naturally-ventilated, insulated grower house and reared until nine weeks of age in part-slatted pens (3,200 mm long by 1,150 mm wide) containing insulated weaner-kennels (1,200 mm long by 1,150 mm wide) equipped with heat lamps. The total space allowance was 0.37 m^2 per pig with 0.14 m^2 per pig within the kennel and 0.23 m^2 per pig in the open pen. A nipple drinker and a drinking cup were provided over the slatted area at the rear of the pen. Feed was offered for two weeks in 450 mm wide dry feeders placed at the rear of the kennels and then in 1200 wide feeders positioned against the side wall of the kennel.

2.2.7 Grower/finisher pens (Experiment 2)

At nine weeks, pigs were moved within the same building into part-slatted grower/finisher pens, each 3,600 mm long by 1,800 mm wide with a space allowance of 0.93 m^2 per pig. Each pen was equipped with a single space feeder positioned in a front corner of the pen with pig access parallel to the pen front, and two nipple drinkers positioned over the slatted area at the rear of the pen. Automatically-controlled spray cooling was provided over the slotted-floor area of each pen. The spray cooling system activated at 26°C, operating on a spray cycle of five minutes on and 25 minutes off.

2.3 Slaughter Procedures

Pigs from **Exp1a** were slaughtered at an abattoir located 18 km from Medina Research Station, a journey of about 20 minutes. However, this abattoir closed early in 2004, necessitating pigs from **Exp1b** to be transported for about 2 hours to an abattoir located 100 km from the research station. At both abattoirs, trimmed hot carcass weight (AUS-MEAT Limited (2009) – Trim Number 13; head, kidneys, flare fat and fore trotters removed) and P2 backfat thickness, measured with a Hennessy Grading Probe 65 mm from the midline at the head of the last rib, were recorded by abattoir personnel. AUS-MEAT Limited Trim Number 13 carcass weights were converted to hot standard carcass weights (HSCW) by multiplying by a conversion factor of 1.1 to compensate for removal of the head, flare fat, kidneys and fore trotters (AUS-MEAT Limited, 2009).

Abattoir health checks were carried out by a veterinarian under the National Pig Health Monitoring Scheme (PHMS). Under the scheme, groups of slaughtered pigs are monitored for the presence of actinobacillus pleuropneumonia, enzootic pneumonia, pleurisy, ileitis, nephritis, ascariasis, nephritis, peritonitis, pericarditis, erysipelas, arthritis and sarcoptic mange.

Animals from Experiment 2 were treated similarly to those from **Exp1b**, all being slaughtered at the second facility.

2.4 Euthanasia and Procedures for Blood, Gut and Organ Sampling

Piglets selected for tissue and digesta sampling were euthanased by cardiac injection of 162 mg per kg live weight of sodium pentobarbitone (Lethobarb®, May and Baker, Sydney, Australia) followed by immediate exsanguination. Blood samples were taken

during exsanguination and were stored on ice for subsequent determination of a range of haemological indices. The abdominal cavity was opened, from the pubis to the sternum, the entire gastrointestinal tract removed, and then divided into four sections (stomach, small intestine, caecum and colon) that were each tied-off with string before being separated. Digesta samples were taken from the stomach, small intestine, caecum, colon and large intestine and placed in specimen tubes and then immersed in ice for subsequent volatile fatty acid (VFA) analysis. Samples were subsequently stored at -20º C until analysis at the Animal Health Laboratories, DAFWA, South Perth. The pH of digesta at the sample sites was also measured using a portable pH meter (Schindengen pH Boy–2, Schindengen Electric MFG, Tokyo, Japan).

Swabs taken from the small intestines of indoor and outdoor piglets euthanased at weaning on the farms of origin prior to the start of **Exp1a** and **Exp1b** were submitted to the Animal Health Laboratories at Bendigo, Victoria for the culture of enteric bacteria.

The small intestine was stripped free of its mesentery and a 20 mm section removed from a point approximately 50% along the length of the organ and placed in a 10% phosphate-buffered formalin in solution. After fixation for several days, ring-shaped lengths of small intestine were excised from each sample section, dehydrated and embedded in paraffin wax. From each of these, six transverse sections (4–6 μm) were cut, stained with haematoxylin and eosin, and mounted on glass slides. The height of ten well-orientated villi and their associated crypts was measured with a light microscope using a calibrated eyepiece graticule (after Pluske et al. 1996*a*).

After removal, the heart, lungs, pancreas, liver, spleen and kidneys were blotted dry with paper towelling and then weighed. The stomach, small intestine, caecum and colon were weighed with their contents, and then reweighed after the contents had been removed and the organs dried with paper towelling.

2.5 Carcass Composition

Carcasses of euthanased pigs, following evisceration, were washed and dried before being weighed, bagged and stored on ice for transportation to DAFWA's Meat Laboratory where they were placed in a -20ºC freezer. Once frozen, the carcasses were boxed and transported to a cold store until freighting to the Victorian Institute for Animal Science (Werribee, Victoria) where carcass composition was determined by dual energy X-ray absorptiometry using a Hologic QDR 4500A fan beam X-ray bone densitometer, as described by Suster et al. (2003 and 2004a).

2.6 Faecal Sampling

Faecal samples were taken from five randomly-selected focus pigs per pen at age 33, 47, 68 and 145 d in **Exp1a**, and at age 21, 25, 49 and 63 d in **Exp1b** to determine volatile fatty acid concentrations. Pens of pigs were moved into a holding pen with a clean solid floor. Previously selected and identified pigs were observed until spontaneous defecation occurred and a clean sample of faeces obtained. Samples were placed in sterile plastic jars and immediately placed on ice prior to freezing at -20ºC.

2.7 Analytical Methods

2.7.1 Volatile fatty acids

The VFA concentration (C2:C6) were determined according to Pluske et al. (2003) as follows: thawed digesta samples from the ileum, caecum, proximal colon and distal colon were diluted either 1:1 (w/v) (ileal digesta) or 1:2 (w/v) (caecal and colonic digesta) with distilled water, mixed, centrifuged and the supernatant fraction analysed chromatographically. The supernatant fraction (0.1 ml) was added to 1 ml internal standard solution containing methyl valerate before processing on a capillary gas chromatograph (GC). A working standard and a control (distilled water) were included in each run of the analysis, with the working standard containing acetic acid (60 mM), propionic acid (20 mM), isobutyric acid (6.7 mM), butyric acid (20 mM), isovaleric acid (10 mM), valeric acid (10 mM) and caproic acid (4 mM). The Hewlett Packard 5890A capillary GC (Agilent Technologies, Forest Hill, Victoria, Australia) was maintained at injector and detector FID settings of 260 and 265°C, respectively, and an initial and final oven temperature of 120 and 240°C, respectively. The carrier gas flow rate was 5 ml/min and the split flow rate was 70 ml/min. The Hewlett Packard Chemstation integration system was used to calculate the VFA concentrations from the area of the peaks.

2.7.2 Haematological indices

At collection (see Section 2.4), 8 ml of blood was added to EDTA-blood collection tubes (Becton Dickingson, Rutherford, NJ) for complete blood counts, and 8 ml added to plain tubes for haptoglobin analysis. The tubes were immediately placed on ice for

transport to the Clinical Pathology Laboratory in the School of Veterinary and Biomedical Sciences, Murdoch University, where they were stored at 4°C prior to analysis within 24 hours of collection using the Advia 120 haematology analyser (Bayer Corporation, Tarrytown, NY) and the porcine option of the associated multispecies software.

CHAPTER 3: EXPERIMENT 1

POST-WEANING GROWTH, GUT STRUCTURE AND FUNCTION OF INDOOR- AND OUTDOOR-PRODUCED PIGLETS REARED IN CONVENTIONAL OR DEEP-LITTER PENS

3.1 Introduction

Weaner pigs from outdoor production systems have been described as being healthier, more active, and faster-growing after weaning than counterparts produced in intensive housing systems (Beynon, 1989). Surprisingly, although around 20 per cent of Western Australian sows farrow outdoors, the post-weaning performance of their progeny has not been documented or compared with progeny from indoor systems. However, results from a limited number of scientific comparisons conducted elsewhere are equivocal. For example, Gentry et al. (2002a) found that pigs produced outdoors grew faster from weaning to slaughter than their counterparts produced indoors, whereas Rudine et al. (2007) found whole-of-life average daily gain to be similar for pigs from either indoor or outdoor production systems.

Weaner pigs produced outdoors are also reported to adapt better than indoor weaners to less-sophisticated rearing systems (Beynon, 1989). If so, this may have significance for the Western Australian pig industry which raises the majority of its weaners in low-cost, straw-based shelters. Piglets born outdoors may be exposed to bacteria beneficial to the establishment and maintenance of a robust gastrointestinal tract (GIT), which might explain their reported post-weaning vigour. Similarly, enriched post-weaning environments provided by deep-litter housing systems may promote gut development

and therefore enhance post-weaning growth of piglets born indoors (Beattie et al., 2000).

In Australia, antimicrobial products (APs) are almost always used in commercial weaner diets to alleviate adverse consequences of relatively early weaning at an average age of 21.8 d (Australian Pork Ltd, 2005). The response to APs is generally greater in unhygienic and stressful conditions and when sub-clinical disease is present (Cromwell, 1991). Thus, the use of APs may be of little benefit to outdoor piglets if indeed their gut health is enhanced by the development of beneficial microbiota in response to substrates present in outdoor systems (and possibly further enhanced in enriched and perhaps less-stressful post-weaning environments afforded by deep-litter housing systems). On the other hand, outdoor and deep-litter housing systems may be less hygienic than conventional systems, in which case the response to APs may be greater. Therefore, it was decided to compare the post-weaning performance of indoor- and outdoor-born pigs in two studies, firstly using dietary APs and secondly without their use, to test the general hypothesis that the growth performance, gut development and health of the weaned pig are influenced by its pre- and post-weaning rearing environments. More specifically, the following hypotheses were tested:

1. Piglets farrowed outdoors have more developed gastrointestinal tracts at weaning than piglets farrowed indoors.

2. Piglets farrowed outdoors adapt more readily to rearing in deep-litter housing systems than piglets farrowed indoors, as indicated by higher post-weaning feed intake and growth rate.

3. Pre- and post-weaning housing environments affect lifetime growth performance, production efficiency and carcass composition.

4. Piglets farrowed outdoors remain healthier after weaning than indoor piglets.

Therefore the aim of this experiment was to quantify any differences in the post-weaning gut development and growth performance of indoor- and outdoor-produced weaner pigs reared in conventional or deep litter pens with and without the use of dietary APs, with the following key objectives:

1. To measure and compare gut structure at 21 (weaning), 28 and 42 days of age of piglets derived from indoor and outdoor herds and reared in conventional or deep-litter pens.

2. To measure the health, growth performance and health from weaning to 23 weeks, and to assess the carcass composition of pigs derived from indoor and outdoor housing systems when reared in conventional or deep litter pens.

3.2. Materials and Methods

3.2.1 Experimental design

The experiment was conducted as two studies; Experiment 1a (**Exp1a**) in which APs were used in the first stage weaner diet and Experiment 1b (**Exp1b**) in which APs were not used. The experimental design for both parts of the experiment was a 2 x 2 factorial arrangement of treatments, with the respective factors being the type of production system used before weaning and the type of housing system used after weaning. Treatment 1 (IPC) comprised of indoor pigs (IP) reared in conventional (C) pens;

Treatment 2 (IPDL) comprised of IP pigs reared in deep-litter (DL) pens; Treatment 3 (OPC) comprised of outdoor pigs (OP) in C pens; and Treatment 4 (OPDL) comprised of OP pigs in DL pens. Thus, there were four pens of 10 pigs for each of the four treatments (N = 160) for each part of the experiment.

3.2.2 Animals

Eighty IP and 80 OP Large White x Landrace x Duroc female pigs (derived from Camborough 22 dams and Line 331 sires, PIC Australia) were brought to the Medina Research Station for each part of the experiment. The pigs were transported on the day of weaning at approximately 21 days of age and an average live weight of 5.6 kg. Piglets were collected from their farms of origin between 0800 and 0900 hrs on the day of weaning and taken on a two-hour journey to Medina Research Station where they were immediately ear-tagged and weighed. Pigs from each source were stratified by weight and allocated to treatment in a randomised block design.

Additionally, six contemporary female piglets from each production system were obtained at the start of both **Exp1a** and **Exp1b** to provide blood, tissue and digesta samples for histology and haematology, and carcasses for composition studies. Three piglets were taken from the same litter and one piglet from three other randomly selected litters. Selection of piglets for post-mortem sampling, for bio-security reasons, was carried out by farm staff who removed the piglets from sows at weaning and then transported them to sites outside of the piggery perimeter fences where, within two hours of weaning, they were weighed, euthanased, eviscerated and sampled as described in Chapter 2.4.

For **Exp1b**, a sacrifice cohort of 24 piglets, comprised of 12 piglets from the indoor and 12 from the outdoor farm, was taken at weaning (21 d) to the Medina Research Station to provide blood, tissue and digesta samples for histology (see Chapter 2.4) and haematology (see Chapter 2.9), and carcasses for composition studies at 28 and 42 d of age (7 and 21 d post-weaning) as described in Chapter 2.4.

3.2.3 Housing

Pigs were born and reared until weaning indoors in conventional farrowing crates (IP piglets) or outdoors in farrowing arcs in a small paddock (OP piglets). Thereafter, C pigs were housed in weaner kennels for seven weeks and then in part-slatted grower/finisher pens in a naturally-ventilated building, while DL pigs were housed in straw-based pens in a tarpaulin-covered shelter. The housing systems are described in detail in Chapter 2.2.2.1–3.

3.2.4 Nutrition

Indoor pigs received 200 mg of injectable iron dextran within two days of birth. No iron supplements were given to OP pigs prior to weaning in accordance with commercial practice for outdoor pig production in Western Australia, based on the assumption that piglets raised outdoors obtain sufficient iron from soil.

No creep feed was fed to IP or OP pigs before weaning. Pelleted feed was offered ad libitum throughout the experiment in a six diet phase-feeding program. Diets were supplied by a commercial feed-mill and were based on wheat, barley and lupins. The phase 1 diet in **Exp1a** (6 kg/pig) contained olaquindox at 100 ppm and zinc oxide at

3000 ppm but no other dietary APs were used in the experiment. The calculated composition of diets is shown in Table 3.1.

Table 3.1 Calculated composition of diets used in Experiments 1a and 1b

	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Diet 6
Allocation per pig (kg)	6	30	30	50	65	70
DE (MJ/kg)	16.0	14.8	14.3	13.8	13.0	12.6
CP (g/kg)	225	228	192	194	164	155
Av. lysine (g/MJ DE)	0.90	0.80	0.70	0.63	0.60	0.55
Crude fibre (g/kg)	25	30	50	50	60	70
Fat (g/kg)	117	62	44	53	40	26
Ca (g/kg)	9	10	9	9	9	9
Av. P (g/kg)	6	5	4	4	4	4

3.2.5 Measurements and observations

Pigs were observed at least twice daily and the incidence of mortality and morbidity recorded. The number and duration of treatments administered to sick or injured pigs was recorded, and the total number of treatment days calculated for each pen.

Pigs were weighed weekly using different scales for each housing system. Accuracy of the two sets of scales was verified using certified test weights prior to each weighing session. Feed used per pen was recorded weekly. Average feed usage per pig per day and feed conversion ratio (FCR) were calculated on a pen basis for the weaner, grower, and finisher phases, and for the overall experiment. Pigs were removed from their pens on attaining 105 kg live weight and slaughtered within 24 hours at a commercial abattoir. Slaughter procedures, and the determination of carcass weight, backfat and dressing percentage are described in Chapter 2.3. Carcass composition of piglets

slaughtered at 21 d of age in **Exp1a**, and at 21, 28 or 42 d of age (and of half-carcasses from pigs killed at 161 d) in **Exp1b**, was determined by dual energy X-ray absorptiometry (see Chapter 2.6).

Faecal samples were taken from five randomly-selected focus pigs per pen at ages 33, 47, 68 and 145 d in **Exp1a** and at 35, 49 and 63 d in **Exp1b** to determine short chain fatty acid concentrations (see Chapter 2.7 for sampling procedures and Chapter 2.8 for VFA analytical methods).

3.3 Statistical Analyses

Data were analysed using the ANOVA procedures of Genstat Release 6.1, Lawes Agricultural Trust (Rothamsted Experimental Station). Production system effects on piglets at weaning were compared using one-way ANOVA, while responses of IP and OP pigs to production and rearing housing systems were compared using two-way ANOVA. The main effects in the model were production system and rearing system which were considered fixed effects. Fisher's Protected-LSD comparisons were used (at 5% significance level) to compare treatment means of variables. Morbidity and mortality data were compared using the Chi-square test. The pen was the experimental unit for performance indices and the individual pig for blood, tissue, organ, and carcass composition measurements.

3.4 Results

3.4.1 Production indices

3.4.1.1 Experiment 1a

Outdoor pigs grew 12% faster than IP pigs during the first seven weeks of the experiment ($P < 0.001$), but overall growth rate of IP and OP pigs from start to 106 kg live weight was similar (Table 3.2).

Table 3.2 Experiment 1a - Growth performance of pigs from indoor (IP) or outdoor (OP) production systems reared in conventional (C) or deep-litter (DL) pens from 5 to 105 kg live weight

	Production (P)		Rearing (R)		s.e.d.	Significance (P value)		
	IP	OP	C	DL		P	R	P x R
Start weight (kg)	5.5	5.7	5.5	5.7	0.18	0.228	0.143	0.146
47 d weight (kg)	25.1	27.7	25.4	27.4	0.54	<0.001	<0.001	0.441
Final weight (kg)	106.2	106.8	106.4	106.7	0.55	0.258	0.541	0.589
Days on experiment	137	137	139	134	1.4	0.669	<0.001	0.819
Gain start–47 d (g/d)	416	467	423	460	9.1	<0.001	<0.001	0.730
Gain start–finish (g/d)	744	740	727	758	8.77	0.600	<0.001	0.520
HSCW[1] (kg)	79.2	81.0	79.1	81.0	0.24	<0.001	<0.001	0.440
Dressing %	74.6	75.8	74.4	76.0	0.24	<0.001	<0.001	0.580
Carcass P2 (mm)	13.6	14.2	14.2	13.6	0.43	0.160	0.210	0.090
Feed disappearance								
Start–47 d (kg/d)	0.72	0.74	0.74	0.72	0.020	0.528	0.512	0.214
Start–finish (kg/d)	1.77	1.77	1.71	1.83	0.038	0.988	0.007	0.809
Feed:gain ratio								
Start–47 d (kg:kg)	1.77	1.62	1.80	1.58	0.038	0.002	<0.001	0.172
Start–finish (kg:kg)	2.38	2.36	2.32	2.42	0.032	0.557	0.010	0.904

[1]Hot standard carcass weight

Deep-litter pigs grew 9% faster than C pigs over the first seven weeks of the experiment and 4% overall ($P < 0.001$). Consequently, the time taken to reach the target weight of 105 kg was similar for IP and OP pigs, while DL pigs reached the target weight five days sooner than C pigs ($P < 0.001$). Mean carcass weight was 1.8 kg higher for OP compared to IP pigs ($P < 0.001$) and 1.9 kg higher for DL compared to C pigs ($P < 0.001$). Consequently, killing-out percentage was higher for OP than for IP ($P < 0.001$), and for DL compared to C pigs ($P = 0.001$). Although P2 backfat was similar between IP and OP pigs ($P = 0.160$) and between C and DL pigs ($P = 0.210$), there was a trend ($P = 0.090$) for an interaction between production and rearing systems, so that OP pigs reared in conventional pens were over 1 mm fatter than OPDL, IPC and IPDL pigs. The average P2 measurement for OPC pigs was 14.9 mm compared to 13.5 mm for IPC pigs, 13.7 mm for IPDL pigs and 13.6 mm for ODDL pigs.

Feed disappearance from 0 to 47 d was similar between treatments ($P > 0.5$). However, the feed conversion ratio (FCR) from start to 47 d was lower for OP compared to IP pigs ($P = 0.002$) and for DL compared to C pigs ($P < 0.001$), reflecting the higher live weight gain of OP and DL pigs over this period. The overall feed disappearance and FCR of IP and OP pigs were similar. However, mean feed disappearance of DL pigs was 7% higher ($P = 0.007$) and FCR 4% higher ($P = 0.010$) than for C pigs.

3.4.1.2 Experiment 1b

It was discovered after the completion of the experiment that semen from a different terminal sire line (TSL) had been used to produce OP pigs in **Exp1b**. All piglets in **Exp1a** were produced with semen from TSL 331 boars, whereas only IP piglets in **Exp1b** were produced with TSL 331 semen while OP piglets were produced with TSL

400 semen. However, the experimental design was based on the premise that IP and OP pigs were of similar genotype, thus data from **Exp1b** were confounded by the use of different terminal sire lines. Consequently, for the purpose of analysing performance data, Exp1b was regarded as being two separate sub-experiments, **Exp1b**(IP) and **Exp1b**(OP), each with two treatments in a randomised block design, comprising of 80 IP pigs allocated to conventional (C) or deep-litter (DL) rearing pens in **Exp1b**(IP), and 80 OP pigs allocated to conventional (C) or deep-litter (DL) rearing pens in **Exp1b**(OP).

Additionally, information was obtained from the breeding company that indicated the progeny of boars used in the outdoor herd were expected to be up to 4.5 % slower-growing and 2.5 % leaner than indoor counterparts. In order to compare the performance of pigs from the two production systems, notwithstanding the possibility of under- or over-estimating the effects of genotypic differences, growth rate and backfat data of OP pigs were adjusted accordingly and re-analysed as a factorial experiment as originally intended.

3.4.1.3 Experiment 1b(IP)

Although IPC pigs grew 3.6% faster and were 0.9 kg heavier at 47 d than IPDL pigs (Table 3.3), the differences were not significant ($P = 0.371$) over the first seven weeks of the experiment. However, those housed in DL pens grew 5% faster from start to finish compared to those in conventional pens ($P < 0.001$). Consequently, DL pigs reached the target weight four days sooner ($P = 0.077$) than C pigs. Deep-litter pigs were 1.4 mm fatter at the P2 site ($P = 0.008$) and there was a trend for DL pigs to dress out slightly heavier than C pigs ($P = 0.095$). Pigs on deep-litter ate 10% more feed overall ($P = 0.044$), resulting in a 7% higher FCR despite their faster growth rate.

Table 3.3 Performance of pigs from an indoor production system (IP) reared in conventional (C) or deep-litter (DL) pens from 5 to 105 kg live weight without dietary antimicrobial products (Exp1b(IP))

	Housing system		s.e.d.	P - value
	Conventional	Deep-litter		
Start weight (kg)	5.6	5.6	0.07	0.978
47 d weight (kg)	25.9	25.0	0.89	0.369
Final weight (kg)	107.3	109.9	1.14	0.059
Days on experiment	144.4	140.6	2.06	0.077
Gain start - 47 d (g/d)	431	413	19.0	0.371
Gain start - finish (g/d)	708	744	6.4	<0.001
HSCW[1] (kg)	78.4	81.5	1.19	0.040
Dressing %	73.4	74.1	0.35	0.095
Carcass P2 (mm)	11.7	13.1	0.35	0.008
Feed disappearance				
Start - 47 d (kg/d)	0.58	0.71	0.024	0.011
Start - finish (kg/d)	1.63	1.79	0.049	0.044
Feed:gain ratio				
Start - 47 d	1.46	1.86	0.021	<0.001
Start - finish	2.33	2.50	0.022	0.004

[1]Hot standard carcass weight

3.4.1.4 Experiment 1b(OP)

Although DL pigs grew 6% faster and were 1.3 kg heavier than C pigs at 47 d (Table 3.4), the differences were not significant (P = 0.144) over the first seven weeks of the experiment. However, pigs in DL pens grew nearly 5% faster overall (P < 0.001) compared to those reared in C pens and reached the target weight 5 days sooner (P < 0.001). Deep-litter pigs were 1.5 kg heavier at slaughter than C pigs, and dressed out 1.6% heavier than C pigs (P = 0.005). Deep-litter pigs were over 1 mm fatter, although this difference was not significant (P = 0.237). Feed disappearance of DL pigs was

higher from start to 47 d (P = 0.014) and overall (P = 0.048). Consequently, the FCR of DL pigs was over 20% higher from start to 47 d (P = 0.038) and 4% higher overall (P = 0.033), despite having faster growth rates over these periods.

Table 3.4 Performance of pigs from an outdoor production system (OP) reared in conventional (C) or deep-litter (DL) pens from 5 to 105 kg live weight without dietary antimicrobial products (Exp1b(OP))

	Housing system		s.e.d.	P value
	Conventional	Deep-litter		
Start weight (kg)	5.6	5.6	0.302	0.978
47 d weight (kg)	24.6	25.9	0.74	0.141
Final weight (kg)	107.7	109.2	0.70	0.965
Days on exp.	153.3	148.0	0.74	<0.001
ADG 0-47 d (g/d)	405	431	15.8	0.144
Gain 0 – fin. (g/d)	671	703	6.27	0.002
HSCW[1] (kg)	80.0	82.8	1.04	<0.033
Dressing %	74.3	75.9	0.69	0.005
Carcass P2 (mm)	13.0	14.1	0.843	0.237
Feed disappearance				
0 - 47 d (kg/d)	0.56	0.72	0.031	0.014
0 - finish (kg/d)	1.64	1.75	0.034	0.048
Feed conversion ratio				
0 - 47 d	1.53	1.88	0.099	0.038
0 – finish	2.46	2.57	0.029	0.033

[1]Hot standard carcass weight

3.4.1.5 Experiment 1b(IP) and 1b(OP) combined

Adjusted growth and backfat measurements for OP pigs are presented in Table 3.5. Unadjusted data show that actual (P = 0.686) and adjusted (P = 0.346) gain of IP and OP pigs were similar from start to 47 d. However, while actual growth from start to finish of IP pigs was 5.7% faster than OP pigs (P < 0.001), adjusted values were not statistically different (P = 0.345). Actual and adjusted P2 backfat measurements (13.6

mm, P = 0.008, and 13.9 mm, P < 0.001, respectively) of OP pigs were both over 1 mm greater than for IP pigs. As in **Exp1a**, the carcass weight (P = 0.007) and dressing percentage (P = 0.007) were greater for OP than for IP pigs. Overall FCR was higher for OP than for IP pigs (P = 0.003), while feed disappearance (P < 0.001 and P = 0.002, respectively) and FCR (P < 0.001) were higher for DL than for C pigs from 0–47 d and from start to finish.

Table 3.5 Adjusted[1] growth performance of pigs from indoor (IP) or outdoor (OP) production systems reared in conventional (C) or deep-litter (DL) pens from 5 to 105 kg live weight without dietary antimicrobial products (pooled data from Exp1b(IP) and Exp1b(OP))

	Production (P)		Rearing (R)			Significance (P value)		
	IP	OP	C	DL	s.e.d.	P	R	PxR
Start weight (kg)	5.6	5.6	5.6	5.6	0.04	0.865	0.629	0.896
47 d weight (kg)	25.3	24.8	25.2	24.8	0.57	0.428	0.490	0.150
Final weight (kg)	107.0	107.6	107.3	107.3	0.84	0.522	0.976	0.140
Days on Exp.	143	151	149	149	0.89	<0.001	<0.001	0.683
Adjusted days on Exp.[1]	***143***	***145***	***146***	***142***	***1.29***	***0.052***	***0.002***	***0.763***
Gain start - 47 d (g/d)	418	412	418	412	13.6	0.686	0.657	0.107
Adjusted gain[1] (g/d)	***418***	***431***	***427***	***421***	***13.8***	***0.346***	***0.683***	***0.108***
Gain start - finish (g/d)	724	685	690	720	8.3	<0.001	<0.001	0.742
Adjusted gain[1] (g/d)	***724***	***716***	***705***	***736***	***8.5***	***0.345***	***<0.001***	***0.805***
HSCW[2] (kg)	79.7	81.4	79.1	81.9	0.6	0.007	<0.001	0.986
Dressing %	73.5	75.1	73.6	75.0	0.43	0.007	0.002	0.428
Carcass P2 (mm)	12.5	13.6	12.4	13.6	0.41	0.008	0.002	0.616
Adjusted P[1] (mm)	***12.5***	***13.9***	***12.5***	***13.8***	***0.41***	***<0.001***	***<0.001***	***0.643***
Feed disappearance								
0 - 47 d (kg/d)	0.64	0.64	0.57	0.71	0.02	0.834	<0.001	0.510
0 – finish (kg/d)	1.71	1.69	1.63	1.77	0.03	0.615	0.002	0.419
Feed:gain ratio								
0 - 47 d	1.66	1.70	1.49	1.87	0.04	0.306	<0.001	0.497
0 - finish	2.42	2.52	2.40	2.54	0.25	0.003	<0.001	0.240

[1]Values adjusted for expected 4.5% reduced growth and 2.5% reduced backfat of OP pigs due to differences between terminal sire lines of IP and OP pigs. [2]Hot standard carcass weight

3.4.2 Carcass composition of weaner piglets

The proportions of lean, fat and bone mineral in the bodies of newly-weaned, 21-day-old IP and OP piglets killed at the start of **Exp1a** were similar (Table 3.6).

Table 3.6 Effect of production system on body composition (by dual energy X-ray absorptiometry) of newly-weaned, 21-day-old piglets from indoor or outdoor production systems (Exp1a)

	Indoor	Outdoor	s.e.d.	P value
Number of carcasses	6	6		
Carcass weight (kg)	5.3	5.2	0.37	0.737
Lean %	77.4	76.6	2.34	0.715
Fat %	20.1	21.1	2.25	0.675
Bone mineral content %	2.4	2.3	0.19	0.627

The proportion of lean in the bodies of IPC pigs killed in **Exp1b**(IP) at 21, 28 or 42 days increased progressively (P = 0.005), with a corresponding decrease in the proportion of fat at each slaughter age (Table 3.7). The proportion of bone mineral was similar at 21, 28 and 42 d of age (P = 0.548), as was bone density (P = 0.216).

Table 3.7 Effect of age on body composition (by dual energy X-ray absorptiometry) at 21, 28 and 42 days of age of indoor-produced piglets reared in conventional pens (Exp1b(IP))

	21 d	28 d	42 d	s.e.d.	P value
Number of pigs	6	6	6		
Carcass weight (kg)	5.1	5.3	6.7	0.67	0.060
Lean %	68.8[a]	72.9[b]	78.9[c]	2.60	0.005
Fat %	28.3[a]	24.1[b]	18.1[c]	2.55	0.004
Bone mineral content %	2.9	3.0	3.0	0.11	0.548
Bone density (g/cm^2)	0.40	0.43	0.41	0.155	0.216

[a,b,c] Treatments with different superscripts within rows are significantly different (P < 0.05)

Bodies of OPDL pigs killed at 21 and 28 d in **Exp1b**(OP) contained similar proportions of lean in contrast to those pigs killed at 42 d, which contained proportionally more lean

(P < 0.001) (Table 3.8). Correspondingly, the proportion of fat was similar in pigs killed at 21 and 28 d but lower in those killed at 42 d (P < 0.001). The proportion of bone mineral in pigs was similar at 21 and 42 d, but was greater in bodies of pigs killed at 28 d (P = 0.047). However, there was a trend (P = 0.103) for bone density to be greater in pigs killed at 42 d compared to those killed at 21 or 28 d.

Table 3.8 Effect of age on body composition (by dual energy X-ray absorptiometry) at 21, 28 and 42 days of age of outdoor-produced piglets reared in deep-litter pens (Experiment 1b(OP))

	21 d	28 d	42 d	s.e.d.	P value
Number of pigs	6	6	6		
Carcass weight (kg)	4.65	4.32	7.12	0.987	0.025
Lean %	75.6[a]	74.2[a]	82.7[b]	1.57	<0.001
Fat %	21.6[a]	22.7[a]	14.5[b]	1.57	<0.001
Bone mineral content %	2.8[a]	3.2[b]	2.9[a]	0.14	0.047
Bone density (g/cm^2)	0.38	0.39	0.43	0.022	0.103

[a,b,c] Treatments with different superscripts within rows are significantly different (P < 0.05)

3.4.3 Experiment 1b(IP) and 1b(OP) combined

Analysis of pooled data from **Exp1b**(IP) and **Exp1b**(OP) indicated that bodies of OPDL piglets contained 6.8% more lean (P = 0.028) and 6.7% less fat (P = 0.028) than IPC pigs killed at 21 d (Table 3.9). Although the body composition was similar for IPC and OPDL pigs killed at 28 d, OPDL pigs killed at 42 d contained 3.8% more lean (P = 0.031) and 3.6% less fat (P = 0.035) than IPC pigs. At 23 weeks of age, half-carcasses of IPC pigs contained 5.1% more lean (P = 0.015) and 7.0% less fat (P = 0.015) than OP pigs. Bone mineral content and bone density were similar for IPC and OPDL pigs killed at 21, 28 or 42 d. The calculated bone density of OPDL pigs was greater (P < 0.001) than for IPC pigs at 161 d, although proportional bone mineral content was similar (P = 0.912).

Table 3.9 Body composition (by dual energy X-ray absorptiometry) of pigs killed at 21, 28, and 42 days of age and half-carcasses taken at 161 days of age from indoor-produced pigs reared in conventional pens (IPC) and from outdoor-produced pigs reared in deep-litter pens (OPDL) using pooled data from Exp1b(IP) and Exp1b(OP)

	Indoor	Outdoor	s.e.d.	P value
	Conventional (IPC)	Deep-litter (OPDL)		
21 d				
Number of pigs	6	6		
Carcass weight (kg)	5.2	4.9	0.28	0.247
Lean %	68.8	75.6	2.63	0.028
Fat %	28.3	21.6	2.62	0.028
Bone mineral content %	2.9	2.8	0.10	0.597
Bone density (g/cm^2)	0.40	0.38	0.010	0.104
28 d				
Number of pigs	6	6		
Carcass weight (kg)	3.3	3.2	0.55	0.809
Lean %	72.9	74.2	2.17	0.564
Fat %	24.1	22.7	2.11	0.498
Bone mineral content %	3.0	3.2	0.17	0.296
Bone density (g/cm^2)	0.43	0.39	0.020	0.099
42 d				
Number of pigs	6	6		
Carcass weight (kg)	6.9	7.4	12.23	0.737
Lean %	78.9	82.7	1.48	0.031
Fat %	18.1	14.5	1.46	0.035
Bone mineral content %	3.0	2.9	0.08	0.074
Bone density (g/cm^2)	0.41	0.43	0.24	0.465
Half carcasses taken at 161 d				
Number of carcasses	12	12		
Live weight (kg)	107.0	107.4	1.22	0.711
Trim 13[1] half carcass weight (kg)	35.0	37.3	1.53	0.011
Lean %	68.4	63.3	2.09	0.015
Fat %	14.1	21.1	2.09	0.015
Bone mineral content %	17.5	17.5	0.14	0.912
Bone density (g/cm^2)	0.8	0.9	0.01	<0.001

[1]Ausmeat Trim 13: head off, kidneys, flare fat, fore-trotters removed

3.4.4 Organ weights

3.4.4.1 Experiment 1a

At weaning (21 d), relative weight (percentage of empty bodyweight) of the heart (P = 0.062) and lung (P = 0.044) of OP pigs were heavier than those of IP pigs, while the stomach (P = 0.057), small intestine (P = 0.022) and caecum (P = 0.025) of IP pigs were heavier than those of OP pigs (Table 3.10).

Table 3.10 Relative weight (percentage of empty bodyweight) of visceral organs of 21 day-old newly weaned pigs from an indoor (IP) or outdoor (OP) production system (Experiment 1a)

	Indoor (IP)	Outdoor (IP)	s.e.d.	P value
No. of pigs	6	6		
Empty bodyweight (g)	6100	6280	474.0	0.708
Relative weight of organs (%)				
Heart	0.56	0.62	0.030	0.062
Lungs	1.32	1.45	0.059	0.044
Liver	2.83	2.81	0.225	0.929
Kidney	0.69	0.76	0.057	0.247
Spleen	0.22	0.24	0.027	0.426
Pancreas	0.12	0.10	0.018	0.318
Gastrointestinal tract	5.00	4.10	0.379	0.041
Stomach	0.53	0.47	0.030	0.057
Small intestine	3.51	2.75	0.274	0.022
Caecum	0.14	0.11	0.012	0.025
Colon	0.82	0.77	0.100	0.644

3.4.4.2 Experiment 1b

The effects, if any, of genotype differences between pigs used in **Exp1b**(IP) and **Exp1b**(OP) on organ weight are unknown. However, it was considered that genetic effects were likely to be small relative to production system effects, thus data from **Exp1b**(IP) and **Exp1b**(OP) were pooled for the purposes of examining production and

housing system effects on organ weights (Table 3.11). The relative weights of the liver (P = 0.007), kidneys (P = 0.078) and pancreas (P = 0.031) of OP were greater than those of IP pigs killed at 21 days of age (weaning).

Table 3.11 Relative weight (percentage of empty bodyweight) of visceral organs at 21, 28 and 42 days of age of indoor-produced (IP) pigs reared in conventional (C) pens or from outdoor-produced (OP) pigs reared in deep-litter (DL) pens using pooled data from Exp1b(IP) and Exp1b(OP)

	Age (d)	IPC	OPDL	s.e.d.	P value
Empty body weight (kg)	21	6.18	5.89	0.356	0.428
	28	4.59	5.65	0.790	0.209
	42	9.02	9.51	1.409	0.736
Relative organ weight (%)					
Heart	21	0.57	0.66	0.062	0.163
	28	0.87	0.62	0.071	0.005
	42	0.47	0.53	0.016	0.006
Lung	21	1.37	1.40	0.054	0.581
	28	2.00	1.62	0.163	0.043
	42	1.30	1.39	0.123	0.476
Liver	21	2.42	2.89	0.137	0.007
	28	4.02	2.72	0.324	0.003
	42	3.62	3.30	0.180	0.112
Kidney	21	0.54	0.66	0.061	0.078
	28	0.90	0.60	0.054	<0.001
	42	0.54	0.59	0.029	0.088
Spleen	21	0.22	0.22	0.025	0.843
	28	0.33	0.22	0.030	0.004
	42	0.24	0.23	0.024	0.803
Pancreas	21	0.16	0.19	0.013	0.031
	28	0.28	0.15	0.033	0.003
	42	0.28	0.29	0.021	0.542
GIT	21	5.06	4.76	0.322	0.368
	28	10.94	8.35	1.485	0.111
	42	11.1	10.9	2.02	0.901
Stomach	21	0.54	0.57	0.029	0.276
	28	1.05	0.81	0.109	0.047
	42	0.97	1.01	0.187	0.849
Small intestine	21	3.55	3.32	0.270	0.412
	28	7.24	5.43	1.140	0.143
	42	7.26	7.41	1.32	0.914
Caecum	21	0.14	0.12	0.016	0.252
	28	0.35	0.23	0.059	0.087
	42	0.33	0.32	0.097	0.891
Colon	21	0.84	0.75	0.084	0.334
	28	2.31	1.89	0.249	0.123
	42	2.55	2.12	0.471	0.385

The relative weights of heart (P = 0.005), lung (P = 0.043), liver (P = 0.003), kidney (P < 0.001), spleen (P = 0.004), pancreas (P = 0.003) and stomach (P = 0.047) of IPC pigs were greater at 28 d of age (seven days after weaning) than those of OPDL pigs. However, the relative sizes of the heart (P = 0.006) and kidneys (P = 0.088) of OPDL pigs killed at 42 d of age were larger than for IPC pigs.

3.4.5 Histology

3.4.5.1 Experiment 1b

Data from **Exp1b**(IP) and **Exp1b**(OP) were pooled to enable the effects of production system on villous height and crypt depth to be analysed (Table 3.12). Villous height and crypt depth of IPC and OPDL pigs were not statistically different. Villous height declined in pigs killed at 28 d compared to 21 d, and although villous height increased in pigs killed at 42 d, it was still lower than in pigs killed at 21 d (P < 0.001). Crypt depth increased (P < 0.001) at each slaughter age of 21, 28 and 42 days of age.

Table 3.12 Mean villous height (µm) and crypt depth (µm) at 21, 28 and 42 days of age of pigs from an indoor production system reared in conventional (IPC) pens or from an outdoor production system reared in deep-litter (OPDL) pens using pooled data from Exp1b(IP) and Exp1b(OP)

	Production (P)		Age (A)			s.e.d.	Significance		
	IPC	OPDL	21 d	28 d	42 d		P	A	P x A
No. of pigs	18	18	12	12	12				
Villous height	388	372	462	305	372	39.1	0.474	<0.001	0.101
Crypt depth	252	268	157	265	359	22.0	0.200	<0.001	0.332

3.4.6 Gut acidity (pH)

Data from **Exp1b**(IP) and **Exp1b**(OP) were pooled to enable the effects of production system on pH in various sections of the GIT to be analysed (Table 3.13). Duodenum (P = 0.003) and jejunum (P = 0.081) pH values were higher for OPDL than for IPC pigs.

Otherwise, treatment effects for other sections of the GIT were similar. The pH in all sections of the GIT decreased with age, although significant interactions occurred between production system and age for pH in the stomach and colon. Stomach pH declined progressively with age in IPC pigs, whereas for OPDL pigs it was lower at 28 d than at 21 and 42 d. In the duodenum, pH of OPDL pigs was similar at 28 and 42 d, while in the jejunum, pH values of IPC pigs were similar at 28 and 42 d, and higher for OPDL than for IPC pigs in the colon at 28 d.

Table 3.13 Acidity (pH) of digesta at 21, 28 and 42 days of age of pigs from an indoor production system reared in conventional (IPC) pens or from an outdoor production system reared in deep-litter (OPDL) pens (Exp1b(IP) and Exp1b(OP))

Age (A)	21 d		28 d		42 d		s.e.d.	Significance		
Production (P)	IPC	OPDL	IPC	OPDL	IPC	OPDL		P	A	P x A
Stomach	4.2	3.7	3.2	1.9	2.4	3.0	0.48	0.161	<0.001	0.027
Duodenum	6.0	5.9	5.2	5.5	4.0	5.4	0.42	0.030	<0.001	0.056
Jejunum	6.2	6.6	6.0	6.4	6.0	5. 8	0.20	0.081	0.003	0.060
Ileum	7.1	7.1	6.8	6.7	6.8	6.6	0.17	0.232	0.004	0.909
Caecum	6.5	6.4	5.9	6.0	5.6	5.8	0.16	0.885	<0.001	0.599
Colon	6.8	6.5	5.9	6.2	5.8	5.5	0.16	0.235	<0.001	0.041
Rectum	7.0	6.7	6.5	6.6	6.3	6.1	0.19	0.258	<0.001	0.403

3.4.7 Volatile fatty acid (VFA) production

3.4.7.1 Experiment 1a

The type of production system had only a minor effect on total faecal VFA concentration (Table 3.14). Total VFA concentrations in faecal samples from IP and OP pigs were not statistically different at 33 d (P = 0.327), 47 d (P = 0.283), 63 d (P = 0.058) and 145 d (P = 0.972). However IP pigs had higher molar proportions of valeric

acid (P = 0.021) and caproic acid (P = 0.008) than OP pigs at 33 d. Molar proportions of VFAs were similar in faecal samples collected at 47 d, but IP pigs had higher (P = 0.017) molar proportions of valeric acid at 63 d than OP pigs. At 145 d the molar proportion of butyric acid was higher (P = 0.033) while that for acetic acid was lower (P = 0.019). The branched-chain ratio (BCR) (the ratio of isobutyric, isovaleric, valeric, and caproic acids to acetic, propionic and butyric acids), was higher in faecal samples from IP compared to OP pigs at 33 d (P = 0.014) but similar in samples taken at 47, 68 and 145 d.

The type of rearing system had a greater effect on total VFA concentrations in faeces than did production system type. Pigs in C pens had higher total faecal concentrations of VFA than pigs in DL pens at all sampling ages. Total faecal VFA concentrations in samples from C pigs compared to DL pigs were 11% higher at 33 d (P = 0.055), 17% higher at 47 d (P = 0 003), 32% higher at 63 d (P < 0.001) and 14% higher at 145 d (P = 0.134). At 33 d, faecal samples from DL pigs contained a higher molar proportion of acetic acid (P = 0.020), but lower proportions of isobutyric (P = 0.003), isovaleric (P = 0.002), valeric (P = 0.004) and caproic (P < 0.001) acids than samples from C pigs. Higher molar proportions of acetic acid, and lower proportions of isobutyric, isovaleric, valeric and caproic acids (P values from < 0.001 to < 0.030) were found in samples taken from DL pigs at 47 and 63 d. Samples taken from DL pigs at 145 d contained higher molar proportions of acetic acid (P = 0.014), and lower molar proportions of isobutyric (P = 0.010), butyric (P = 0.015) and isovaleric (P = 0.013) than those from C pigs. Faecal BCRs were similar for C and DL pigs at all sampling ages.

No significant interactions ($P < 0.1$) between production and rearing system occurred for total faecal VFA concentration. However, significant interactions occurred in the molar proportion of butyric acid at 33 d when OPC pigs had higher levels than OPDL pigs. Significant interactions also occurred at 47 d for molar proportions of isobutyric ($P = 0.022$) and isovaleric ($P = 0.064$) acids with IPC and OPC pigs both having higher values than OPDL pigs which in turn were higher than for IPDL pigs. Significant production and rearing system interactions occurred at 63 d for isobutyric ($P = 0.004$) and isovaleric ($P = 0.002$) acids with molar proportions greater for IPC > OPC > OPDL > IPDL pigs. Different interactions occurred for the molar proportions of valeric acid ($P = 0.002$) and caproic acid levels which were higher for IPC pigs compared to OPC pigs, and compared to both IPDL and OPDL which were similar. At 145 d, there was an interaction for isovaleric acid when molar proportions were higher for IPC and OPC pigs compared to IPDL and OPDL pigs. Significant interactions ($P < 0.01$) for BCRs occurred at 47 and 68 d with DL rearing increasing the BCR of OP pigs above those for IP pigs.

Table 3.14 Faecal concentrations (molar proportions) of volatile fatty acids at 33, 47, 68 and 145 days of age from indoor (IP) or outdoor (OP) production systems reared in conventional (C) or deep-litter (DL) pens (Experiment 1a)

	IPC	IPDL	OPC	OPDL	s.e.d.	Significance		
						P[1]	R[2]	P x R
33 d of age								
Total VFA (mmol/L wet faeces)	111.7	96.5	114.1	111.4	7.7	0.327	0.055	0.124
Acetic acid	50	51	50	53	1.3	0.428	0.020	0.135
Propionic acid	22	23	23	24	1.3	0.532	0.280	0.960
Isobutyric acid	1.7	1.3	1.8	1.2	0.19	0.931	0.003	0.463
Butyric acid	17	18	18	17	0.86	0.803	0.522	0.057
Isovaleric acid	3.3	2.5	3.4	2.3	0.30	0.976	0.002	0.534
Valeric acid	4.0	3.0	3.3	2.2	0.37	0.021	0.004	0.860
Caproic acid	1.5	0.7	0.9	0.3	0.20	0.008	<0.001	0.514
BCR[3]	0.12	0.08	0.10	0.07	0.008	0.014	<0.001	0.703
47 d of age								
Total VFA (mmol/L wet faeces)	149	123	151	134	7.8	0.283	0.003	0.433
Acetic acid	49	53	50	53	1.6	0.917	0.014	0.869
Propionic acid	22	23	22	22	0.8	0.912	0.476	0.758
Isobutyric acid	2.1	1.2	2.0	1.6	0.15	0.248	<0.001	0.022
Butyric acid	18	18	18	17	1.3	0.710	0.321	0.412
Isovaleric acid	3.3	2.1	3.1	2.5	0.20	0.404	<0.001	0.064
Valeric acid	4.0	2.8	3.5	3.2	0.41	0.809	0.030	0.162
Caproic acid	1.0	0.4	1.0	0.7	0.17	0.322	0.004	0.249
BCR[3]	0.12	0.07	0.11	0.09	0.007	0.591	<0.001	0.009
68 d of age								
Total VFA (mmol/L wet faeces)	160	128	180	131	7.4	0.058	<0.001	0.142
Acetic acid	49	55	50	54	1.4	0.811	<0.001	0.467
Propionic acid	22	22	21	22	0.81	0.532	0.517	0.872
Isobutyric acid	2.2	1.1	2.0	1.3	0.10	0.860	<0.001	0.004
Butyric acid	18	18	20	18	1.04	0.169	0.388	0.399
Isovaleric acid	3.6	1.7	3.1	2.0	0.14	0.413	<0.001	0.002
Valeric acid	4.3	2.2	3.6	2.4	0.14	0.017	<0.001	0.051
Caproic acid	0.9	0.1	0.7	0.1	0.10	0.288	<0.001	0.085
BCR[3]	0.13	0.05	0.10	0.06	0.009	0.241	<0.001	0.008
145 d of age								
Total VFA (mmol/L wet faeces)	202	169	194	179	20.5	0.972	0.134	0.555
Acetic acid	56	58	58	61	1.0	0.019	0.014	0.437
Propionic acid	23	23	22	23	0.71	0.341	0.464	0.515
Isobutyric acid	1.5	1.4	1.7	1.3	0.10	0.708	0.010	0.118
Butyric acid	15	13	14	11	0.85	0.033	0.015	0.409
Isovaleric acid	2.3	2.2	2.6	2.1	0.16	0.583	0.013	0.092
Valeric acid	2.0	1.8	1.8	1.6	0.27	0.338	0.287	0.715
Caproic acid	0.6	0.5	0.6	0.4	0.17	0.723	0.348	0.801
BCR[3]	0.07	0.06	0.07	0.06	0.004	0.736	<0.001	0.137

P[1] = production system, R[2] = rearing system, BCR[3] = branched-chain ratio (isobutyric, isovaleric, valeric, caproic **:** acetic, propionic, butyric acids ratio)

3.4.7.2 Experiment 1b

The effects of genotype differences due to the use of semen from different terminal sire lines on digesta characteristics of indoor and outdoor piglets used in **Exp1b**(IP) and **Exp1b**(OP) were unknown. However, it was considered that genotype effects were likely to be negligible since intestinal microflora of neonatal piglets are sourced from their dams and undergo age related changes modulated by dietary and environmental factors (see Section 1.7.4). Thus, for the purposes of examining production and housing effects on digesta characteristics, data from **Exp1b**(IP) and **Exp1b**(OP) were pooled and analysed as a 2 x 2 factorial design (Table 3.15). Total faecal concentration of VFAs for IP pigs, compared to OP pigs, was 33% greater ($P = 0.029$) at 35 d, similar ($P = 0.677$) at 49 d, and 21% greater ($P < 0.001$) at 63 d. At 35 d, IP pigs had higher molar proportions of acetic acid ($P = 0.019$), while OP pigs had higher proportions of propionic ($P = 0.002$) and valeric ($P = 0.004$) acids. By 49 d, there was no difference in the molar proportion of acetic acid, but IP pigs had higher proportions of propionic acid ($P < 0.001$), whilst OP pigs had higher proportions of isobutyric ($P = 0.014$) and isovaleric ($P = 0.018$) acids.

The type of rearing system only affected the total concentration of faecal VFAs at 63 d when C pigs had a 31% higher ($P < 0.001$) total concentration of faecal VFAs than DL pigs. Molar proportions of VFAs in faecal samples taken at 35 d were similar for C and DL pigs, and differed only slightly at 49 d of age when the molar proportion of propionic acid was lower and that of caproic acid higher, for samples from C compared to DL pigs. However at 63 d, the molar proportion of acetic acid in samples from DL pigs was greater ($P = 0.001$), and lower for butyric ($P = 0.011$), valeric ($P = 0.005$) and

caproic ($P = 0.002$) acids than in samples from C pigs. The BCR in samples from C pigs was higher ($P < 0.001$) than those from DL pigs. No production and rearing system interactions occurred for total concentration of faecal VFA but there was an interaction for isobutyric acid at 49 d with IPDL having the lowest relative concentration of isobutyric acid ($P = 0.091$).

Table 3.15 Faecal concentration of volatile fatty acids at 35, 49, and 63 days of age of pigs from indoor (IP) or outdoor (OP) production systems reared in conventional (C) or deep-litter (DL) pens (Exp1b(IP) and Exp1b(OP))

	IPC	IPDL	OPC	OPDL	s.e.d.	P value		
						P[1]	R[2]	P x R
35 d of age								
Total VFA (mmol/L wet faeces)	214	203	175	138	28.6	0.029	0.275	0.537
Acetic (%)	71	64	58	61	4.0	0.019	0.438	0.103
Propionic (%)	11	11	19	17	2.5	0.002	0.386	0.592
Isobutyric (%)	1.5	1.9	1.6	1.1	0.70	0.505	0.880	0.458
Butyric (%)	13	20	16	16	3.0	0.825	0.096	0.156
Isovaleric (%)	2.8	3.2	2.8	3.0	1.87	0.857	0.579	0.810
Valeric (%)	1.2	1.1	2.4	2.0	0.86	0.004	0.455	0.537
Caproic (%)	0.1	0.2	0.4	0.2	0.16	0.191	0.416	0.178
BCR[3]	0.07	0.07	0.08	0.07	0.021	0.696	0.877	0.553
49 d of age								
Total VFA (mmol/L wet faeces)	138	137	146	133	7.1	0.677	0.193	0.248
Acetic (%)	57	57	59	57	1.2	0.215	0.518	0.521
Propionic (%)	22	24	20	22	0.5	<0.001	0.005	0.561
Isobutyric (%)	1.2	1.0	1.3	1.5	0.14	0.014	0.808	0.091
Butyric (%)	15	14	15	14	0.6	0.312	0.153	0.432
Isovaleric (%)	2.1	1.9	2.3	2.5	0.19	0.018	0.952	0.103
Valeric (%)	2.7	2.7	2.4	2.5	0.31	0.254	0.806	0.660
Caproic (%)	0.4	0.3	0.4	0.2	0.08	0.951	0.019	0.150
BCR[3]	0.07	0.06	0.07	0.07	0.007	0.334	0.743	0.295
63 d of age								
Total VFA (mmol/L wet faeces)	151	118	186	139	7.7	<0.001	<0.001	0.235
Acetic (%)	53	57	54	58	1.2	0.373	0.001	0.842
Propionic (%)	22	22	22	21	0.9	0.552	0.460	0.305
Isobutyric (%)	1.9	1.5	1.7	1.6	0.21	0.668	0.105	0.422
Butyric (%)	17	15	16	15	0.78	0.586	0.011	0.740
Isovaleric (%)	3.1	2.5	2.8	2.5	0.326	0.533	0.107	0.539
Valeric (%)	3.3	2.7	3.2	2.7	0.21	0.517	0.005	0.801
Caproic (%)	0.6	0.1	0.8	0.3	0.16	0.072	0.002	0.979
BCR[3]	0.10	0.07	0.10	0.08	0.007	0.878	<0.001	0.509

P[1] = production system, R[2] = rearing system, BCR[3] = branched-chain ratio (isobutyric, isovaleric, valeric, caproic **:** acetic, propionic, butyric acids ratio)

3.4.8 Haematological indices

3.4.8.1 Piglets at weaning (21 d) – Experiments 1a and 1b.

Haematological indices at weaning of IP and OP piglets are shown in Table 3.16. Haemoglobin (Hb) and haematocrit (HCT) levels for IP and OP pigs were similar (P = 0.781 and P = 0.499, respectively) in **Exp1a**, but were higher for OP pigs in **Exp1b** (P = 0.009 and P < 0.001, respectively). Mean cell volume (MCV) tended to be higher for IP pigs (61.5 vs. 57.8, P = 0.098). However, mean cell haemoglobin content was lower (P = 0.015) for OP pigs in **Exp1a** but tended to be higher (58.4 vs. 78.0 pg, P = 0.107) in **Exp1b**. Indoor pigs had higher (P < 0.001) mean cell haemoglobin concentrations in **Exp1a** and, although 4–8% higher in **Exp1b**, average values were not statistically different (P = 0.188). The white blood cell (WBC) count was similar for both IP and OP pigs in both experiments. Proportionally, IP pigs had more neutrophils (P < 0.001) but fewer lymphocytes (P = 0.003), monocytes (P = 0.041) and eosinophils (P = 0.017) than OP pigs in **Exp1a**. Values for IP and OP pigs followed similar trends in **Exp1b**. The neutrophil : lymphocyte ratio was over two times greater for IP than OP pigs in both experiments but was statistically different (P = 0.004) in **Exp1a** only. Serum haptoglobin (Ha) levels in both experiments were not statistically different despite being nearly three times higher for outdoor piglets (0.25 vs. 0.73 g/L and 0.07 vs. 0.19 g/L, P = 0.169 and P = 0.374 for IP and OP pigs for Experiments 1a and 1b, respectively).

Table 3.16 Haematological indices at weaning (21 days of age) of pigs from indoor (IP) or outdoor (OP) production systems

	Experiment 1a				Experiment 1b			
	IP	**OP**	**s.e.d.**	**P value**	**IP**	**OP**	**s.e.d.**	**P value**
Red blood cells (10^{12}/L)	5.6	6.2	0.36	0.127	5.3	5.4	0.38	0.718
Haemaglobin (g/L)	111	109	6.4	0.781	98	112	4.2	0.009
Haematocrit (L/L)	0.34	0.36	0.020	0.499	0.31	0.37	0.011	<0.001
Mean cell volume (fL)	61.5	57.8	1.98	0.098	58.4	70.2	6.52	0.107
Mean cell haemoglobin (pg)	19.9	17.7	0.73	0.015	18.5	21.1	1.44	0.117
Mean cell haemoglobin concentration. (g/L)	323	306	3.0	<0.001	317	303	10.0	0.188
White blood cells (10^9/L)	6.64	6.36	1.128	0.807	7.73	7.71	1.109	0.989
Neutrophils (%)	53	31	4.2	<0.001	38.9	25.8	10.68	0.253
Lymphocytes (%)	43	60	4.1	0.003	56	69	10.2	0.233
Monocytes (%)	1.6	3.0	0.59	0.041	2.9	3.0	0.82	0.882
Eosinosophils (%)	1.5	4.7	1.09	0.017	0.5	0.8	0.19	0.143
Basophils (%)	0.15	0.38	0.131	0.113	0.75	0.52	0.403	0.592
Lucocytes (%)	0.42	0.68	0.318	0.430	1.17	0.93	0.426	0.586
Neutrophil:Lymphocyte ratio	1.31	0.53	0.207	0.004	0.85	0.43	0.349	0.246
Haptoglobin (g/L)	0.25	0.73	0.321	0.169	0.07	0.19	0.132	0.374

3.4.8.2 Piglets at 28 and 42 days of age (7 and 21 d post-weaning) – Experiment 1b

Haemoglobin (Hb) values 7 days after weaning were greater for OPDL pigs than for IPC pigs ($P < 0.001$). However, 21 days after weaning, IPC and OPDL pigs had similar levels of Hb (101 vs. 110 g/L). Mean cell volume for OPDL pigs was higher at both 7 and 21 d post-weaning ($P = 0.064$ and $P < 0.001$, respectively). Mean cell haemoglobin for OPDL pigs was also higher at both 7 and 21 d post-weaning (15.9 vs. 22.7, $P = 0.242$ and 15.6 vs. 18.9, $P < 0.001$, respectively).

Table 3.17 Haematological indices at 28 and 42 days of age of pigs produced indoors (IP) or outdoors (OP) and reared in conventional (C) or deep-litter (DL) pens (Experiment 1b)

	28 days				42 days			
	IPC	OPDL	s.e.d.	P value	IPC	OPDL	s.e.d.	P value
Red blood cells (10^{12}/L)	5.9	6.2	0.88	0.751	6.5	5.8	0.32	0.056
Haemaglobin (g/L)	94	118	4.0	<0.001	101	110	7.3	0.261
Haematocrit (L/L)	0.29	0.35	0.034	0.097	0.32	0.34	0.022	0.284
Mean cell volume (fL)	48.0	59.4	5.52	0.064	48.6	58.7	1.44	<0.001
Mean cell haemoglobin (pg)	15.9	22.7	5.42	0.242	15.6	18.9	0.55	<0.001
Mean cell haemoglobin concentration (g/L)	332	362	44.8	0.520	321	321	4.1	1.000
White blood cells (10^9/L)	8.6	13.9	1.11	<0.001	18.6	14.1	1.85	0.033
Neutrophils (%)	44.4	35.9	7.37	0.275	48.2	50.1	5.04	0.714
Lymphocytes (%)	48.3	57.4	7.59	0.258	44.9	42.7	5.76	0.717
Monocytes (%)	4.0	3.8	0.64	0.743	4.20	3.70	0.553	0.387
Eosinosophils (%)	0.52	1.12	0.301	0.074	1.02	1.83	0.642	0.232
Basophils (%)	0.65	0.43	0.218	0.344	0.28	0.25	0.097	0.739
Lucocytes (%)	2.15	1.40	0.423	0.107	1.43	1.33	0.575	0.865
Neutrophils : Lymphocytes ratio	0.97	0.71	0.219	0.261	1.19	1.27	0.320	0.803
Haptoglobin (g/L)	1.16	1.45	0.345	0.415	1.34	0.53	0.390	0.064

The WBC for pigs of OPDL pigs was greater at 7 days but lower at 21 d post-weaning (P = 0.033). There were no statistical differences between treatments for lymphocyte, monocyte, eosocyte, basocyte and leucocyte percentages. Serum haptoglobin (Ha) levels at 7 days post-weaning were similar for IPC and OPDL pigs (P = 0.415), but values for OPDL pigs were 60% lower (P = 0.064) at 21 days post-weaning.

3.4.9 Health

The overall health status of pigs was good throughout Exp1a. No pigs died and only 12 pigs from all treatments were treated individually for swollen joints and received medication additional to in-feed antimicrobial products. However, it was necessary to treat many pigs in Exp1b for swollen joints, post-weaning diarrhoea (PWD) and conjunctivitis.

The numbers of pigs treated for swollen joints in **Exp1a** were similar for production and rearing systems (P = 0.720), with seven IP pigs compared to five OP pigs, and seven C

pigs compared to five DL pigs, treated for swollen joints. However, non-parametric analysis of data from **Exp1b** showed that nine IP (22.5%) compared to two OP (5%) pigs (P = 0.029) were treated therapeutically with antibiotics and anti-inflammatory drugs for lameness and swollen joints. The numbers of C or DL pigs treated for lameness or swollen joints were similar (P = 0.755).

No pigs were treated for PWD in **Exp1a**, but there was a severe outbreak of PWD in **Exp1b** with 18 (23%) OP compared to four (5%) IP pigs (P = 0.001), and five (6.3%) C compared to 17 (21.3%) DL pigs (P = 0.006) treated for PWD. One IPC, one OPC and one OPDL pig died of PWD in the first week of the experiment.

There was an outbreak of conjunctivitis in Exp1b with over 50% of pigs treated topically with oxytetracycline hydrochloride.

A cluster of rectal prolapses occurred in Exp1a following a change of diet around 50 kg live weight, with two IP pigs, two OP pigs, three C pigs and one DL pig experiencing prolapses; however the incidence was not statistically different between production or rearing systems (P = 0.562). Prolapsed pigs were removed from the experiment and subsequently sold as porkers at 60–70 kg live weight. No other pigs were removed prematurely from Exp1a or 1b. There were no deaths after the first week in either part of the experiment.

3.5 Discussion

3.5.1 Performance indices

As there were no statistically significant interactions between production and rearing systems for growth parameters other than carcass backfat, production and rearing system effects are discussed separately.

3.5.1.1 Production system effects

The reasons for the faster growth of OP piglets during the first seven weeks but not overall in **Exp1a** are unclear. Post-weaning growth has been positively correlated to birth-weight (Quiniou et al., 2002) and weaning weight (Dunshea et al., 2002). It has been suggested that improved post-weaning growth of outdoor compared to indoor pigs weaned at the same age may simply reflect heavier weaning weights of outdoor piglets (Miller et al., 2007). This is likely to be the case where higher pre-weaning mortality reduces litter size, resulting in sow milk production being divided between fewer piglets with consequently higher weaning weights (Miller et al., 2007). Lower survival rates for low birth-weight piglets in outdoor systems (Edwards, 1994) may also contribute to higher weaning weights in outdoor systems by raising the average birth-weight, and hence average weaning weight of surviving litter mates. However, it is unlikely that these factors influenced early growth in the current experiment, since starting weight and age of IP and OP piglets were similar. Furthermore, the age, weaned weight, and body composition of 21-day-old IP and OP piglets killed at the start of **Exp1a** were also similar despite probable differences in sucking behaviour, thermal environment and exercise levels experienced by piglets in the indoor or outdoor production systems. Villous height and crypt depth for IP and OP pigs were also similar at weaning,

precluding gut maturity as the possible cause of the early superiority in performance. The health status of IP and OP pigs in **Exp1a** as indicated by the number of pigs treated and the duration of treatments was also similar, suggesting that differences in enteric health did not impact on early growth. However, as previously discussed, it is possible that OP pigs carried a higher sub-clinical disease burden, the effects of which were suppressed by antimicrobial products (APs) in the first-stage weaner diet but which started to affect performance when dietary APs were withdrawn from the second-stage diet onwards, causing OP pigs to grow more slowly in the latter part of the experiment.

Faster early growth may have been due to the enriched pre-weaning environment experienced by the outdoor pigs, the benefits of which diminished with age. In particular, OP pigs may have been less stressed at weaning as a result of co-mingling and the development of foraging behaviour prior to weaning that resulted in higher feed intake in the critical week after weaning, as described by Cox and Cooper (2001). However, overall feed disappearance and FCR were similar for both IP and OP pigs, indicating that the effect of any increase in feed intake that may have occurred in the first one or two weeks did not persist throughout the experiment.

The inadvertent use of different terminal sire lines confounded results from **Exp1b**, making it difficult to separate genetic effects from the effects of removing APs from the diets. It cannot be determined with certainty whether the similarity in early growth of IP and OP piglets was due to genetic differences that negated any benefits of outdoor production seen in **Exp1a**, or whether the removal of APs from the diets more severely affected OP than IP piglets after weaning. Likewise, the faster overall growth of IP pigs

may have been due to genetic differences or a more severe long term impact on OP pigs following the withdrawal of APs from second-stage diets onwards.

The similarity in lifetime growth performance of IP and OP pigs when the results of **Exp1a** and **1b** were considered together, notwithstanding possible confounding effects of genotype, contrasted with Gentry et al. (2002a and 2004) who reported that pigs produced outdoors had greater ADG at all growth intervals after weaning, but agreed with Rudine et al. (2007) who reported similar rates of gain for pigs produced indoors or outdoors.

Surprisingly, OP pigs in **Exp1a** had higher carcass weights and dressing percentages than IP pigs, indicating that environmental differences in the first three weeks of life affected carcass characteristics at 23 weeks of age. Similar results were obtained from pooled data from **Exp1b**(IP) and **Exp1b**(OP), not withstanding possible differences due to genotype, with OP pigs having higher average carcass weights and dressing percentages than IP pigs ($P = 0.007$). Gentry et al. (2002a) also reported that pigs farrowed outdoors had heavier carcass weights and dressing percentages than those farrowed indoors.

The higher carcass weights and dressing percentages of OP pigs at similar final live weights to IP pigs are of considerable interest because of their impact on financial returns to producers. Factors known to influence carcass weight and dressing percentage of animals of similar genotype and live weight at slaughter include time off feed prior to slaughter, time in transportation and in lairage, the weight of viscera removed, carcass composition and carcass management after slaughter. With the exception of weight of viscera removed and carcass composition, these factors were

similar for all treatments and therefore considered unlikely to have caused the observed differences in carcass weight. However, the weight of viscera removed and (or) carcass composition might have been affected by treatment and may have affected carcass weight. Although prolonged consumption of roughage has been shown to increase GIT weight (Stanogias and Pearce, 1985), it is unlikely the amount of roughage ingested by OP pigs before weaning was sufficient to increase GIT weight. Lighter relative GIT weights of OP piglets eviscerated at 21 d of age support this supposition (Table 3.10). Furthermore, the relative weights of other organs from OP piglets, with the exception of the heart and lungs, were lighter than those from their IP counterparts (Table 3.10). Therefore it can be speculated that lower viscera weights may have contributed to higher dressing percentages of the OP pigs. The higher fat content of OP pigs also may have contributed to their higher dressing percentages. Every increase of 1% total body fat in market weight pigs has been shown to increase dressing percentage by 0.1% (Kauffman & Breidenstein, 1994). Thus it can be calculated that the 11% higher average subcutaneous backfat of OP pigs may have been associated with a 1% increase in dressing percentage, or about half of the observed difference, assuming a strong correlation exists between P2 backfat measurement and total body fat. It is also speculated that increased bone weight may have accounted for some of the increase in carcass weight. Pre-weaning access to trace elements in soil, exposure to sunlight, and higher levels of spontaneous activity have been associated with increased lifetime development of bone mass. Higher spontaneous activity of pigs reared in large pens has been shown to increase total bone mass (Petersen et al., 1998), although the bone mineral content and bone density of 21-day-old IP and OP pigs were similar in this experiment.

The higher backfat measurements for OP pigs in both parts of the experiment, particularly in **Exp1b** when sires expected to produce leaner progeny were used, indicated that piglets produced outdoors were slightly fatter than their indoor counterparts regardless of rearing treatment, in agreement with Gentry et al. (2002) who reported similar trends.

3.5.1.2 Rearing system effects

Pigs reared in DL pens consistently grew faster than those in C pens in **Exp1a**, **Exp1b**(IP) and **Exp1b**(OP), in agreement with other reports (Lyons et al., 1995; Guy et al., 2002). However, a large MLC (2004) study conducted in identical environmentally-controlled buildings to compare performance in fully-slotted or deep-litter pens produced inconsistent results with either similar growth rates or faster growth in straw-based pens. In the current study, pigs in DL pens consumed more feed which resulted in higher feed : gain ratios regardless of associated faster growth rates. This result is consistent with industry experience in Western Australia, but is contrary to other reports in the literature. Guy et al. (2002a) found that pigs in straw yards had lower FCRs than pigs in slatted pens, whereas Lyons et al. (1995) and the MLC (2004) reported no differences in FCR between straw-based and slatted pens. In North America, FCR tends to be similar in the warm months but worsens significantly in the winter (Connor et al., 1994; Honeyman et al., 2003). Despite consuming more food in **Exp1a**, DL pigs were not fatter than C pigs, suggesting that DL pigs possibly had an additional food requirement to support either an increased energy demand for thermogenesis and (or) for increased activity. The effect of housing systems on the relationship between thermal comfort, feed intake and feed efficiency of pigs is well documented (Bruce, 1981; Close,

1989). Pigs reared below their lower critical temperature (LCT) either eat more to maintain thermal homeostasis, in which case growth rate is maintained but FCR worsens, or they eat the same quantity but use a greater proportion of energy consumed for thermogenesis resulting in a deterioration in growth rate which also worsens FCR. The LCT for pigs reared on deep-litter is not well defined. Sallvik and Wejfeldt (1993), using a robotic pig, estimated the LCT for groups of grower pigs (34 kg LW) at 70% embedding in straw to be -22ºC, well below temperatures cited by Bruce and Clarke (1979). However, Sallvik and Wejfeldt (1993) did not take into account heat losses during other activities such as eating, drinking, voiding, play and exploration, or heat produced during composting processes in the deep litter. It is considered unlikely that feed intake of DL pigs was influenced by sub-LCT temperatures, given the experiments were conducted from late October to early April. It is more likely that feed intake of DL pigs was depressed by temperatures above their evaporative critical temperature (Kruger et al., 1992), although this cannot be assumed with certainty.

Several authors have reported increased activity of pigs in straw-based compared to conventional pens (Beattie et al., 1993; Lyons et al., 1995; Guy et al., 2002a; MLC, 2004). The level of activity may also increase energy requirement, either directly or by stimulating appetite. It is possible that ingestion of straw by DL pigs may have increased the rate of passage of digesta through the GIT (Wenk, 2001), thereby decreasing the digestion and absorption of nutrients, resulting in decreased feed efficiency.

The variable effect of rearing system on backfat in the current experiment was consistent with commercial experience. Some producers within a grower group that use

similar genetics and nutritional programmes report increased backfat in deep-litter facilities compared to those using conventional facilities within the same grower group, while others within the same group achieve similar results in both conventional and deep-litter facilities on the same farm.

Dietary fibre has been shown to influence the growth of the GIT (McDonald et al., 2001). The ingestion of straw by DL pigs may have diverted nutrients away from carcass gain or increased feed intake to support additional growth of the GIT. However, in **Exp1a** and **Exp1b** the relative weights of the stomach, small intestine, caecum and colon of IPC and OPDL pigs at 42 days of age were similar, suggesting that increased growth of the GIT was not a factor in the inferior FCR of DL pigs.

The higher carcass weights and dressing percentage of DL finisher pigs was probably due to greater bone density. Although bone mineral content and bone density of the two extreme treatments of IPC and OPDL pigs were similar at 21, 28 and 42 days of age, the bone density in half-carcasses was significantly greater ($P < 0.001$) in OPDL than for IPC pigs at the end of the experiment. However, the extent to which outdoor production and (or) rearing in deep-litter pens contributed to the increase in bone density in OPDL pigs cannot be determined from these results. Both the outdoor and the deep-litter environments provided: (1) a source of trace elements in soil either directly from the paddock or from straw contaminated with soil, (2) exposure to sunlight and (3) higher levels of spontaneous activity. Any of these factors singly or in combination may have resulted in greater bone development seen in OPDL pigs as previously discussed. The other common causes of higher dressing percentage are lower gut content and viscera

weights, both of which seem unlikely in this instance as ingestion of fibre tends to increase the weight of the GIT and its contents (Whittemore et al., 2003).

3.5.2 Organ weights

The greater relative weights of the heart of OP compared to IP pigs at 21 days of age (weaning) in Experiments 1a and 1b can most likely be explained by higher levels of spontaneous exercise in the paddock environment, although activity level was not quantified in our experiments. Cox and Cooper (2001) reported that outdoor pigs spent almost twice as much time moving than indoor piglets prior to weaning. Similarly, Johnson et al. (2002) found that outdoor piglets spent nearly twice as much time walking and nearly three times more time playing than did indoor piglets. Petersen et al. (1998) reported that exercising pigs by walking on a treadmill at 6 kph for 15 minutes a day induced cardiac hypertrophy. It is likely that OP piglets in this study were more active than IP piglets which induced a similar hypertrophic effect on the heart. The relative weight of other visceral organs increased with age as expected, with the exception of the lung, kidney and spleen which for no obvious reasons were heavier at 28 d compared to 21 and 42 d in Experiment 1b.

Odle et al. (1996) suggested that the weight of the small intestine may depend on the nutritional status of the pig. Therefore, higher relative weights of gastrointestinal organs at weaning (21 d) of IP pigs in Experiments 1a and 1b suggest that more nutrients may have been available for GIT growth, either because IP pigs consumed more sow milk than OP pigs, or if intake of sow milk was similar, IP pigs expended fewer nutrients in support of maintenance and activity. Alternatively, an associated increase in the intake of growth factors and enzymes contained in sow milk known to promote the growth of

the GIT may have stimulated development of the GIT in IP pigs. If this was the case, however, it would be reasonable to expect differences in gut morphology at weaning but villous height and crypt depth were similar between IP and OP pigs. The rate of increase in the relative weight of gastrointestinal organs was higher in the first week after weaning than in the subsequent two weeks, possibly reflecting the requirement of the weaned pig for a larger digestive system than a sucking pig (Cranwell, 1995). Overall, the relative weights of the stomach, small intestine, caecum and colon of IPC pigs were greater than those of OPDL pigs which were slightly heavier at 28 and 42 days.

Production environment appears to have little effect on intestinal maturity (Miller et al., 2007). The similarity in villous height of IP and OP pigs at weaning noted in the current experiment agreed with Miller et al. (2007) who found that indoor and outdoor piglets had similar gut morphology when weaned at 28 or 42 days. Likewise, the significant villus atrophy and crypt hyperplasia that occurred in the week after weaning regardless of pre-weaning treatment in the current experiment was typical of other reports in the literature (Hampson, 1986; Pluske et al., 1996; Bruininx et al., 2004; Verdonk et al., 2007). However, the effect of post-weaning feed intake on villous architecture is equivocal. Bruininx et al. (2004) demonstrated that the function of the gut is not affected by the latency period between weaning and onset of feeding or subsequent rate of increase in daily feed intake, whereas Verdonk et al. (2007) found that high levels of dry feed intake after weaning alleviated but did not prevent negative changes to gut morphology. Thus any increase in immediate post-weaning feed intake by OP pigs, attributable to more developed feeding and foraging behaviours as observed by Cox and Cooper (2001), was insufficient to prevent changes to gut morphology.

3.5.3 VFA production

Production system did not affect total faecal VFA concentration in **Exp1a** when olaquindox and zinc oxide were included in the first-stage weaner diet. Exact mechanisms for effects of dietary APs on pig performance have not been established, although it is generally accepted that APs reduce adverse effects of ammonia concentration in the gut by suppressing microbial activity (Burrin & Stoll, 2003). The same authors also suggest that enteric infection increases intestinal nutrient requirements, thus more dietary nutrients are likely to be available for growth in situations where APs suppress enteric infection. Dietary APs may also help maintain a balance between bacteria that promote and those that impede digestion in the gut (Baynes & Varley, 2001; Cromwell, 2001). Therefore, the use of APs in **Exp1a** may have increased nutrient digestion and reduced the amount of undigested feed present in faeces, thus explaining why total faecal VFA concentrations in 35 day faecal samples in Exp1a were about 60% lower than those in **Exp1b** when averaged across all treatments. However, total faecal VFA concentrations increased for IP compared to OP pigs when APs were omitted.

Antimicrobial treatment of piglets at weaning has also been shown to reduce microbial diversity and concentration of VFA in the small intestine (Thyman et al., 2007). Thus the use of dietary APs in the first-stage weaner diet in **Exp1a** may have been sufficient to establish and maintain similar bacterial populations, and hence similar faecal VFA concentrations in IP and OP pigs throughout their lifetime. Alternatively, the similarity in VFA production by IP and OP pigs in **Exp1a** may have simply reflected a similarity in gut microbiota at the start of the experiment, although this would appear to have been

unlikely given the different substrates available to IP and OP piglets prior to weaning. Conversely, omitting dietary APs from post-weaning diets fed in **Exp1b** may have created more diverse microbiota in IP and OP pigs which in turn may have affected VFA production. Pigs farrowed indoors and weaned into flat-deck weaner pens had more diverse microbiota at weaning and 21 days after weaning than pigs that were farrowed outdoors and weaned into deep-litter pens (Pluske et al., 2007). However, Pluske et al. (2007) found outdoor pigs on deep-litters had a more diverse microbiota 7 d after weaning that continued to diversify with time which did not occur in conventionally-housed indoor pigs.

Although total VFA production was similar for IP and OP pigs at all sampling ages in **Exp1a**, differences in molar proportions of valeric and caproic acids at 33 days of age and of valeric acid at 63 days, which were all higher for IP compared to OP pigs, suggest that differences in microbiota between IP and OP pigs influenced fermentation processes sufficiently to change the ratios of VFA produced, and that the differences persisted until at least 145 days of age when OP pigs had higher molar proportions of acetic but lower levels of butyric acids.

Type of rearing system appeared to have a much greater effect on faecal VFA concentrations than production systems, with C pigs having higher total VFA concentrations than DL pigs at all sampling ages in **Exp1a**. Pigs on both rearing treatments were provided with feed from the same commercially-prepared batches, thus diets of C and DL pigs were similar apart from the ingestion by DL pigs of unknown quantities of straw provided for bedding on which they were housed continuously, and soil to which they had access for about 15 minutes per week when moved into dirt yards

for weighing. The quantity of these substrates ingested may have increased the rate of digesta flow, resulted in greater microbial and fermentation activity in the large intestine of DL pigs, or diluted the total and relative faecal VFA concentrations in the faeces of DL pigs. Feeding high fibre diets to sows increases ileal flow of nutrients, in particular carbohydrates, the excretion of faecal materials, CH_4 production and fermentation in the large intestine (Serena et al., 2008). Alternatively, faeces of DL pigs may have contained less dry matter because of water-holding properties of undigested fibre, which may have diluted the concentration of faecal VFA (McDonald et al., 2001). Higher molar proportions of acetic acid and lower proportions of isobutyric and isovaleric acids in faeces of DL compared to C pigs at 33, 47, 63 and 145 days of age suggest a greater supply of carbohydrate relative to protein entering the large intestine because of a faster rate of passage of digesta through the small intestine attributable to a higher dietary fibre content (Serena et al., 2008). Additionally or perhaps alternatively, increased microbial activity resulted in the production of acetic acid. Differences in faecal VFA composition were not as marked when dietary APs were omitted in **Exp1b**, with only minor differences occurring between rearing treatments at 35 and 49 days of age. However at 63 days, total faecal VFA concentration was higher for C than for DL pigs but, contrary to **Exp1a**, there were no differences in relative isobutyric or isovaleric molar proportions. It is possible that the production of VFA was affected by the incidence of PWD in **Exp1b** or by a reduced straw intake resulting from the use of straw of inferior quality. Drought in the preceding year resulted in a shortage of straw in Western Australia, and only substandard straw was available for use in **Exp1b** which may have inhibited intake.

3.5.4 Blood characteristics

Neutrophil numbers have been shown to increase and lymphocyte numbers to decrease in response to specific stressors such as castration and marketing of pigs (Widowski et al., 1989), suggesting that in controlled situations an increase neutrophil : lymphocyte (N:L) ratio is a reliable indicator of stress. It is therefore possible that the higher neutrophil and lower lymphocyte numbers and corresponding higher N:L ratio experienced by IP piglets at weaning were indicative of a stress response to indoor farrowing accommodation, or conversely OP piglets were less stressed by their outdoor farrowing environment. In contrast, Kleinbeck and McGlone (1999) found that at 28 days of age, outdoor piglets had higher blood neutrophil and decreased lymphocyte numbers, higher N:L ratios and lower natural killer cell (NK) activity while exhibiting superior growth and higher Hb levels compared to indoor pigs. Although these findings might have been interpreted as a stress response by outdoor piglets, Kleinbeck and McGlone (1999) suggested that lower microbial exposure causing lower WBC numbers and NK activity in outdoor piglets was a more plausible explanation than stress-induced immunosuppression. However, WBC numbers of IP and OP piglets in the current experiment were similar, thereby discounting lower microbial exposure rather than a stress response by IP piglets to their housing system as a possible explanation for their higher N:L ratios, but this cannot be concluded with certainty. The nearly threefold higher serum Ha levels recorded for OP piglets, although not statistically significant different ($P = 0.17$, **Exp1a**; $P = 0.37$, **Exp1b**), suggested there may have been a difference in health and hygiene status and hence, microbial exposure of IP and OP piglets. Haptoglobin is an acute phase protein synthesised by the liver and released in response to bacterial and viral infections, and local inflammation. It is a sensitive

indicator of infection and tissue injury and has been used to assess hygiene and health status of rearing systems (Gymnich & Petersen, 2004). Other authors have established relationships between elevated Ha levels and disease (Petersen et al., 2002), and sub-clinical disease and growth performance (Clapperton et al., 2005). Thus, although the health status of IP and OP pigs was deemed to be similar at weaning in **Exp1a** and **Exp1b**, the higher Ha levels of OP pigs indicate that in fact outdoor pigs may have been exposed to unknown sub-clinical challenges, possibly explaining why OP pigs grew slower and had more PWD than IP pigs in **Exp1b** when no dietary antimicrobial products were used.

Lower WBC counts caused by lower numbers of neutrophils have been found in iron-deficient anaemic piglets (Egeli et al., 1998), but this does not appear to have been the case in the current experiment. Supplementary iron was provided to IP but not to OP pigs in accordance with standard management practices for indoor and outdoor pig production in Western Australia. In **Exp1a**, WBC, RBC, Hb and HCT levels were similar for IP and OP pigs at weaning and all were within normal ranges for non-anaemic pigs (Egeli et al., 1998), indicating that OP piglets derived sufficient iron from soil to maintain haematological indices equivalent to those of IP piglets that received 200 mg of iron dextran within 48 hours of birth. This is in agreement with Brown et al. (1996) and Kleinbeck and McGlone (1999) who reported little or no benefit from administering supplementary iron to piglets born and reared outdoors until weaning. However, in **Exp1b**, conducted a year later, the Hb value for IPC piglets (94 g/L) was significantly lower than for OPDL piglets (118 g/L) and approached the threshold of 80 g/L indicative of anaemia (Egeli, 1998), while Hb levels of OPDL pigs remained above the generally accepted adequate level of 100 g/L (ARC, 2002). Potentially, the parity of

some sows in IP and OP breeding herds may have increased by two litters in the intervening year between **Exp1a** and **1b** with consequences for their iron reserves. Increasing parity has been associated with depletion of iron reserves of sows housed indoors as a result of inadequate mineral nutrition (Close, 2005; Peters, 2008a and 2008b). Mineral recommendations and allowances are generally determined per unit weight of diet and do not take into account actual requirement based on feed intake, body weight and parity of sows. Close (2005) calculated that at recommended inclusion rates, the iron intake of a third parity sow was 23% less than of a first parity sow after accounting for differences in feed intake and metabolic body weight. This process of gradual depletion of iron reserves of indoor sows may explain why IPC piglets, despite receiving parenteral iron supplementation, had lower Hb levels at weaning than OPDL piglets in **Exp1b**, since outdoor sows with access to soil would not be expected to experience a decline in iron intake.

3.5.5 Health

Treatment had little effect on pig health in **Exp1a**. The health status of IP and OP pigs appeared similar on arrival and abattoir health checks indicated that it remained so during the experiment (see Section 2.3 Slaughter procedures). The cluster of rectal prolapses that occurred in **Exp1a** following a change in diet around 50 kg live weight could not be attributed to either the production or the rearing system. Three C pigs compared to only one DL pig suffered rectal prolapses, suggesting that perhaps the combination of more space and access to straw may have reduced the occurrence of rectal prolapses. However, this could not be concluded with certainty because of the

lack of statistical difference due perhaps to the low numbers of affected pigs on each treatment.

The reasons why more IP than OP pigs were treated for lameness and swollen joints in this study were not clear. It is possible that IP pigs had a higher incidence of limb injuries at weaning from being accommodated in slotted-floor farrowing crates as occurred in the study of Kelly et al. (2000b), who reported that 24.1% of newly-weaned piglets produced in slotted-floored farrowing crates had foot injuries at the start of their experiment.

The incidence of lameness was similar between C or DL pens in both experiments, in disagreement with Lyons et al. (1995), Kelly et al. (2000b) and Guy et al. (2002b) who reported fewer injuries and less adventitious bursitis in pigs kept on deep-straw compared to those on bare-concrete or slotted floors. The contrasting results may have been due to differences in the depth and type of straw used, or between the methods used to assess lameness or swollen joints. Lyons et al. (1995) and Guy et al. (2002b) restrained pigs in a crate for examination of feet by veterinarians which presumably was a more sensitive measure of limb injury than a simple count of pigs treated for lameness as performed in the current experiment. However, it is likely that the incidence of limb injury and adventitious bursitis would only have affected growth performance in the first month of the experiment and would have had little impact on overall performance. Kelly et al. (2000b) found that although pigs with foot injuries at weaning recovered quickly on deep-straw and initially worsened in small flat-deck pens, there was no difference due to floor types after one month and that growth rate differences appeared unrelated to foot injuries.

Several factors additional to the omission of dietary APs may have contributed to the higher incidence of PWD in **Exp1b**. Conditions for outdoor pig production were more favourable in the winter and spring of the year when OP pigs in **Exp1a** were farrowed, with mild conditions and exceptionally low rainfall compared to the following year when average conditions prevailed. Furthermore, continuous use of farrowing paddocks from which OP pigs were sourced for **Exp1b** increased by a year, bringing the total time in use to more than three years, thus potentially increasing the pathogen load, particularly the levels of *E. coli* present. The producer reported that pre-weaning mortality for the batches of weaners from which OP pigs were sourced were 15% and 25% for **Exp1a** and **Exp1b**, respectively, suggesting that OP pigs in **Exp1b** may have carried higher levels of sub-clinical disease. Thus a combination of increased sub-clinical disease and the omission of dietary APs may have caused the outbreak of PWD in OP pigs in **Exp1b** and their subsequent poor performance relative to OP pigs in **Exp1a**. Responses to dietary APs are notoriously variable (Lee et al., 1995) and are generally greater when offered to pigs reared in sub-optimal conditions. It is also possible that OP pigs in **Exp1a** were infected with higher levels of subclinical disease than IP at the start of **Exp1a** and may have benefited to a greater extent than IP pigs from the inclusion of APs in the first stage weaner diets. Interestingly, not only was there a lower incidence of PWD in IP pigs in **Exp1b**, but growth performance of IP pigs was similar to **Exp1a**, suggesting that IP pigs were not disadvantaged by the omission of dietary APs to the same extent as OP pigs in **Exp1b**. This also suggests that the health status and hygiene levels of IP pigs were similar in **Exp1a** and **Exp1b** and high enough to preclude a response to antimicrobial products in **Exp1a**. The higher incidence of PWD in DL pens in **Exp1b** may also have been exacerbated by inclement weather in the

first week of the experiment. The use of oaten straw due to the short supply of barley straw following a drought the previous year may also have contributed to the incidence of PWD in DL pigs in **Exp1b**. The oaten straw was coarse, brittle and dusty compared to the barley straw previously used and appeared to provide less thermal comfort to the pigs. The outbreak of conjunctivitis in DL pigs in **Exp1b** was also attributed to poor straw quality.

3.5.6 Limitations to the study

There were some limitations to this study arising from the use of pigs from two sources and the use of separate structures to accommodate the conventional and deep-litter pens. The following limitations should be kept in mind when interpreting the results of this experiment.

Firstly, it was assumed that IP and OP pigs were of similar genotype. Both IP and OP herds were re-populated two years before the start of the experiment with breeding stock sourced from the same multiplier herd. It was also assumed that the parity structure of the two herds was similar. Therefore, the rate of genetic improvement arising from the introduction of replacement animals into the herds would also have been similar in both herds. However these assumptions could not be verified, and thus small genetic differences may have existed between IP and OP pigs, possibly contributing to some of the differences observed in growth and carcass characteristics of IP and OP pigs additional to those that may have resulted from the use of different terminal sire lines in **Exp1b**.

Secondly, undetected differences in the pre-existing health and injury status of IP and OP pigs may also have contributed to observed performance differences in the experiment. Faecal samples taken from IP and OP weaners at the start of **Exp1a** and **Exp1b** yielded similar results, as did abattoir health checks conducted at slaughter, suggesting that the gross health status of IP and OP pigs was similar throughout the experiment. However, more detailed examination may have revealed subtle differences in the health status of IP and OP pigs.

Thirdly, ventilation and air-quality characteristics inside the conventional structure containing the C pens and inside the Eco-Shelter® containing the DL pens were dissimilar. It is extremely difficult to measure ventilation rate in naturally-ventilated buildings, but the smaller size of the Eco-Shelter® in association with larger air inlets were conducive to greater ventilation rates and higher air quality than would have been the case in the conventional building. Conversely, ambient temperatures in the conventional building may have been higher than in the Eco-Shelter®, although this may have had little effect on overall performance. Pigs with access to deep-litter are generally well able to maintain themselves within their thermal comfort zone in a wide range of ambient temperatures by varying the degree to which they embed themselves in the litter.

Fourthly, the types of feeders and drinkers used in the two housing systems were different. Although the resources provided were considered not to have limited feed intake or growth performance, wastage from the different types of feeders may have varied. Different wastage rate could have affected feed disappearance, apparent feed intake and feed efficiency recorded for C and DL pigs.

Fifthly, the pre- and post-weaning housing systems were not replicated. Thus the results apply only to the conditions of this experiment, and need further verification in different indoor and outdoor housing systems.

3.5.7 Future work

The reasons for increased feed intake and inferior feed efficiency of pigs on deep-litter warrants further investigation, given the importance of feed efficiency to the profitability of pig production. Further work is required to determine if pigs reared on deep-litter in commercial situations experience similar increases in carcass weight and dressing percentage seen in DL pigs on this project, and to determine the mechanisms responsible for any increases. The unexpected difference in bone density of outdoor-born pigs reared on deep-litter compared to indoor-born pigs reared in conventional pens, which may be related to higher carcass weights and dressing percentage, also warrants further investigation. These results require confirmation and additional work to establish the impact, if any, on carcass value and the yield of retail cuts of meat which may be affected by increased bone density. If it is proven that a combination of outdoor and deep-litter housing system increases the bone density of grower/finisher pigs, investigations should be extended to breeding animals. Currently about 50% of animals in the Australian breeding herd are replaced annually (Australian Pork Ltd, 2005), of which about 18% are culled for locomotive problems (Patterson et al., 1997). It is possible that increasing the bone density of animals entering the breeding herd could reduce the incidence of leg problems and increase sow longevity.

The effects of the ingestion of substrates available to pigs in outdoor and deep-litter housing systems on immunity and bacterial diversity of the GIT also warrants more detailed investigation than was possible in this project.

3.6 Conclusions

The results of this experiment did not support the first hypothesis that '*Piglets farrowed outdoors have more developed gastrointestinal tracts at weaning than piglets farrowed indoors*' as there was no measurable difference in gut development between indoor and outdoor piglets weaned at 21 days of age. The second hypothesis that '*Piglets farrowed outdoors adapt more readily to rearing in deep-litter housing than piglets farrowed indoors, as indicated by higher post-weaning feed intake and growth rate*' was supported when APs were included in the first stage weaner diet in **Exp1a** but not when APs were omitted in **Exp1b**, but whether this was associated with the use or non-use of APs or other factors cannot be concluded with certainty because of limitations to the experimental design. Elements of the third hypothesis that '*Pre- and post-weaning housing environments affect lifetime growth performance, production efficiency and carcass composition*' were supported. Pre-weaning environment had little effect on whole of life growth rate or days to market weight, but rearing pigs in deep-litter pens after weaning increased feed intake and growth rate but reduced feed efficiency. However, outdoor production and deep-litter housing both increased P2 backfat. Furthermore, dressing percentage and bone density of finisher pigs were increased by unidentified factors associated with outdoor production and (or) deep-litter rearing systems. The fourth hypothesis that '*Piglets farrowed outdoors remain healthier after weaning than indoor piglets*' was only supported when APs were included in the

weaner diets when piglets produced outdoors grew faster than their indoor counterparts in the four weeks after weaning. Morbidity and mortality was similar for indoor and outdoor weaners in both rearing systems when APs were included in first stage weaner diets, but there was a greater incidence of PWD in pigs from the outdoor system, and also when reared in deep-litter pens regardless of production systems when APs were not used in the second part of the experiment. However, there was a higher incidence of lameness in piglets farrowed indoors in both rearing systems, suggesting that outdoor piglets experience fewer foot and leg injuries than indoor piglets.

In summary, under the conditions of this experiment, it appears that production system did not affect gut development or whole-of-life growth, but deep-litter housing increased growth at the expense of feed efficiency and carcass quality. Thus, producer reports of robustness and superior post-weaning performance of outdoor piglets are unlikely to be the result of enhanced gut development at weaning, and that any initial advantage may not persist over the entire grow-out period. Overall, the results of this experiment indicate that different substrates available in various pre- and post-weaning housing systems may affect the microbiota in the GIT, health, patterns of growth and carcass composition of grower-finisher pigs.

CHAPTER 4: EXPERIMENT 2

PRE- AND POST-WEANING GROWTH, HEALTH AND GUT PHYSIOLOGY OF INDOOR PIGLETS OFFERED DIFFERENT SUBSTRATES PRIOR TO WEANING

4.1 Introduction

In Part 1 of **Exp1a** (Chapter 3), piglets born outdoors grew significantly faster than indoor counterparts during the first seven weeks after weaning compared to piglets born indoors whether reared in conventional or deep-litter pens. This result concurs with those of Gentry et al. (2002a) who also found that piglets born outdoors grew faster after weaning than those born indoors regardless of the accommodation type. However, these authors did not provide a definitive explanation for the superior performance of outdoor- compared to indoor-born piglets.

Major differences between indoor and outdoor production systems and their possible impact on piglet growth and development are described at length in Chapter 1. The significance and effects of specific differences in physical and social conditions that exist between indoor and outdoor production systems do not appear to have been reported. It appears the contributions of individual environmental factors to the superior post-weaning growth and health status attributed to outdoor piglets have yet to be determined. Typically, when comparing pig behaviour and performance in diverse production systems, authors describe differences in physical and social environments without explaining the effect of these differences on various aspects of piglet performance. For example, Rudine et al. (2007) listed a number of factors that differed

between the indoor and outdoor production systems considered in their experiment, but failed to elucidate or even speculate which of these factors within each production system caused the observed effects.

Given the dearth of information on the impact of specific differences in the pre-weaning environment on subsequent growth, the general hypothesis from Experiments 1a and 1b that post-weaning growth performance and gut development of the weaned pig are affected by its pre-weaning rearing environment was investigated further by providing substrates (soil, pasture residues, straw and sow feed), generally only available to outdoor piglets during lactation, to piglets of indoor sows farrowed in conventional crates. This enabled one factor specific to outdoor production, i.e. the ingestion of common substrates, to be studied in the absence of other environmental and behavioural differences in the outdoor milieu. Furthermore, it would be relatively easy for the wider industry to feed similar substrates to piglets in intensive housing systems if found to be beneficial.

Therefore, the specific hypothesis tested in Experiment 2 was that *'gut development and health could be enhanced, and post-weaning anorexia and associated depression in growth could be reduced by offering straw, pasture residue, soil and sow-feed (the outdoor mélange) to piglets reared indoors from birth to weaning'*, with the following aims:

1. To compare the intake of an outdoor mélange with that of a high quality creep diet when offered to piglets of indoor sows farrowed in conventional crates.

2. To measure the pre- and post-weaning performance, morbidity and mortality of piglets offered an outdoor mélange, a high quality creep diet, or no creep feed.

3. To compare digesta and tissue samples taken from the gastrointestinal tract of pigs offered an outdoor mélange, a high quality creep diet, or no creep feed.

4.2 Materials and Methods

4.2.1 Animals and experimental design

Twenty-four pregnant multiparous Large White x Landrace crossbred sows were used in the experiment. The sows were farrowed in two batches of 12, with each batch regarded as a block. Litters were equalised at ten piglets per sow within 24 hours of birth by cross-fostering piglets between test litters and litters of four additional sows that farrowed around the same time. However, insufficient piglets were available to balance litters for birth weight and sex. Sows and litters within each block were stratified by parity and farrowing date before being randomly allocated to one of three pre-weaning nutritional treatments: (1) no creep feed (NC), (2) a commercial pelleted creep feed (CF) and (3) an outdoor mix (OM). The outdoor mix consisted of 1 part straw, 5 parts sow feed and 25 parts soil by weight to approximate the substrates available to outdoor piglets. The soil used was topsoil taken from the paddocks in which outdoor piglets used in Experiments 1a and 1b were farrowed. Dietary treatments were introduced at seven days and each litter of piglets weaned at 28 days of age in the expectation that creep feed intake would be high enough, particularly in weeks 3–4, to significantly affect performance.

4.2.2 Housing, management and nutrition

Sows were loose-housed in small, part-slatted pens in a naturally-ventilated building for the remainder of gestation prior to farrowing in conventional crates in an environmentally-controlled room. After weaning, piglets were housed in weaner kennels in an insulated, naturally-ventilated building for five weeks, and then moved into part-slatted grower/finisher pens within the same building. The accommodation is described in detail in Chapter 2, Sections 2.2.5–7. Pigs were penned in litter groups throughout the experiment. The number of pigs per pen was adjusted to maintain equal group size in each pen following the removal of pigs for euthanasia tissue and digesta sampling at 28 and 35 d of age.

Sows at 56–63 d of gestation were transported to Medina Research Station in two equal batches. On arrival, sows were weighed and penned in groups of two according to weight. Sows were floor-fed once daily 2.5–3.0 kg per sow of commercial dry sow pellets according to their live weight and condition. When the first sow in a batch reached 112 days of gestation, all sows in the batch were weighed, washed and moved into the farrowing accommodation. Sows were then fed 1.0 kg of commercial lactating-sow pellets and 0.5 kg of bran at 0730 and 1530 hrs daily from entry into the crates until farrowing. Thereafter, sows were continued to be fed twice daily according to appetite, with the amount of feed offered per meal increased or decreased by 0.5 kg per feed depending on whether the previous allocation had been consumed. Residual feed was removed and feeders cleaned before addition of fresh feed at 0730 hrs.

Sows were injected intra-vulvally with 5 mg dinoprost tromethamine (*Lutalyse*, Pfizer Animal Health) at 08:00 and 14:00 hrs on day 113 of gestation to induce parturition the

following day. Piglets were weighed, ear-notched, tooth-clipped, tail-docked and injected intramuscularly with 200 mg of iron dextran (1 ml *Feron 20*, distributed by Pharm Tech Pty Ltd, West Pymble, NSW) on day 2 after birth. Dietary treatments were introduced to piglets on day 7 and continued until litters were weaned at 28 days of age. Diets were offered in plastic feeding troughs (600 mm long by 100 mm wide by 75 mm deep) positioned against the side wall of the creep area opposite the sow feeder. To encourage piglets to eat, feed was also sprinkled on the solid floor in front of the feeder for the first two days after treatments began. The commercial creep feed (CF) and the outdoor mix (OM) were fed daily after residues were removed for weighing, and the troughs cleaned. Spillage was retrieved from under the crates and from the solid creep area, and daily feed intake per litter calculated by deducting the residue and spillage from the amount offered. Water was provided from a nipple drinker fitted below the sow drinker.

No antimicrobial products were used in any of the diets (supplied by a commercial feed-mill) which were based on wheat, barley, triticale and de-hulled and whole-lupin seed (Table 4.1). The straw, sow pellets and long straw contained in each litter's daily supply of OM diet were hand mixed in a bucket before being added to the feeding trough to allow piglets to ingest substrates separately or in combination as preferred. The creep diet was in crumble form, while the follow-on diets were pelleted. After weaning, all treatments were similarly fed ad libitum according to a six diet, phase-feeding program. Pigs were offered 7 kg of creep diet, 35 kg of weaner diet, 35 kg of grower diet 1, 56 kg of grower diet 2, 63 kg of the finisher diet, and finally a pre-sale diet as required (approx. 50 kg) to reach the target market weight of 105 kg. Pigs were

removed from their pens on attaining 105 kg live weight and slaughtered within 24 hours at a commercial abattoir. Slaughter procedures, and the determination of carcass weight, backfat and dressing percentage are described in Chapter 2.3

4.2.3 Measurements and observations

Piglets were weighed on the second day after birth and weekly thereafter until the end of the experiment. Creep feed usage was recorded daily on a per litter basis for treatments 2 and 3 from day 8 until weaning and, for all treatments, daily from days 29–42 and weekly thereafter. The average amount of feed used per pig and feed conversion ratio (FCR) were calculated on a pen basis for the weaner, grower and finisher phases, and from the start to the finish of the experiment. Representative samples of the dry sow, lactating sow and creep diets, soil and straw were analysed for iron content.

Pigs were observed at least twice daily and the incidence of mortality and of morbidity as indicated by the number and duration of treatments administered to sick or injured pigs, recorded on a pen basis. Blood, organs, tissue and digesta samples were taken from a median-weight piglet from each of six randomly selected litters per treatment at 28 days (average live weight 8.2 kg, ± 0.83 SD) and at 35 days of age (average live weight 10.0 kg, ± 0.95 SD) for examination as described in Chapter 2.4. In accordance with the requirement of DAFWA's Animal Ethics Committee to use the minimum number of animals necessary to ensure scientific and statistical validity, six piglets per treatment at each slaughter age were deemed sufficient to establish treatment differences in blood characteristics, organ weights, villus height and crypt dept, gut acidity and volatile fatty acid production.

Table 4.1 Composition of diets

Ingredient (g/kg as fed)	Dry sow	Lac. Sow	Creep (CF)	Outdoor mix (OM)*	Weaner	Grower 1	Grower 2	Finisher	Pre-sale
Straw				32					
Soil				806					
Barley	111.5	287		18	248.6	426.5	512.7	499.5	499.3
Breadcrumbs			59.6						
Fishmeal			10		40				
Full fat Soya			120		50				
Fishmeal			10						
Groats			200		99.3				
Lupins	261.5			43			114	300	196.7
Lupin Kernel		250			100	200	86		
Lupin Bran	16			3				19	100
Canola Meal						100	80		
Mill Mix	50			8	50	47			79
Oat Hulls	50			8					30
Reworks	60			10				50	50
Soya Bean Meal			232		70		24		
Triticale	299.5	150		47.2	50	150	130	82	
Wheat	100	242	25	16	169				
Meat and Bone Meal					54				
Bloodmeal					10	20			
Tallow press	10	30	20	2	38	20	20	20	20
Vegetable oil			20						
Skim milk powder		0.5	125						
Sugar			38						
Whey powder			100						
Dicalcium phosphate	17.0	14.5	9.5	2.7		10.0	10.5	11.0	9.0
Limestone	18.5	16.5	10.0	3.0	7.5	15.0	14.0	9.5	9.5
Salt	3.1	2.8		0.5	1.4	2.8	2.5	2.8	4.0
Vit. & min. pre mix**	2.5	2.5	3.8	0.4	2.5	2.5	2.5	2.5	1.3
Choline chloride	0.2	0.2	0.5	0.1	0.3	0.1	0.1	0.1	0.1
Lysine		3.0	1.3		4.3	4.4	2.6	2.2	0.7
Methionine	0.2	0.5	1.8	0.1	0.8	1.2	0.8	1.1	0.4
Threonine		0.5	0.5		0.8	0.5	0.3	0.3	
Zinc oxide			3.0		2.5				
Porzyme			10.0		1.0				

* Outdoor mix contained 1 part straw (87% av. DM), 5 parts lactating sow pellets and 25 parts soil (89% av.DM). All ingredients, other than straw and soil, listed for the OM diet were contained in the sow pellet fraction of the mix.

** Pre-mix included in dry and lactating sow diets supplied the following micro-nutrients per kg of air-dried diet:
Vitamins; A 1000 IU, D_3 200 IU, E 40 mg, K_3 0.5 mg, Thiamine 1 mg, Riboflavin 3 mg, Niacin 15 mg, Pyridoxin 1mg, Folic acid 0.5 g, Pantothenic acid 10 mg, Biotin 0.1 mg, B12 0.020 mg; Minerals; Manganese 40 mg, Zinc 100 mg, Iron, 80 mg, Copper 10 mg, Iodine 1 mg, Selenium 0.1 mg , Cobalt 0.2 mg.

** Pre-mix included in creep, weaner, and grower/finisher diets supplied the following micro-nutrients per kg of air-dried diet: Vitamins; A 1100 IU, D3 220 IU, E 35 mg, K3 1 mg, Thiamine 1 mg, Riboflavin 3 mg, Niacin 15 mg, Pyridoxin 1 mg, Folic acid 0.5 g, Pantothenic acid 10 mg, Biotin 0.08 mg, B12 0.02 mg; Minerals; Manganese 40 mg, Zinc 100 mg, Iron 125 mg, Copper 100 mg, Iodine 1 mg, Selenium 0.2 mg, Cobalt 0.5 mg.

Table 4.1 Composition of diets (continued)

Calculated nutrient content	Dry sow	Lac. Sow	Creep (CF)	Outdoor mix (OM)*	Weaner	Grower 1	Grower 2	Finisher	Pre-sale
Digestible energy (MJ/kg)	12.60	14.50	16.23	0.72	15.01	13.99	13.82	13.40	12.08
Crude protein (g/kg)	162	169	25	8	220	193	171	164	140
Available lysine (g/MJ DE)	0.42	0.54	0.90	0.20	0.79	0.67	0.59	0.55	0.44
Crude fibre (g/kg)	100	45	24	34	40	57	65	88	117
Total iron (g/kg)	0.2	0.1	0.1	32.5					

* Outdoor mix contained 1 part straw, 5 parts lactating sow pellets and 25 parts soil. Nutrients listed for the OM diets included those contained in the sow pellets, straw and soil.

4.2.4 Statistical analysis

Data were analysed using the ANOVA procedures of Genstat Release 6.1, Lawes Agricultural Trust (Rothamsted Experimental Station). Growth and carcass characteristic responses to treatments were compared using one-way ANOVA, whereas treatment and age effects on the GIT and haematological indices at 28 and 35 days of age were compared using two-way ANOVA. The main effects in the model were creep feeding treatment and age at sampling which were considered fixed effects. Fisher's Protected-LSD comparisons were used (at 5% significance level) to compare treatment means of variables. Morbidity and mortality data were compared using the Chi-square test. The litter was the experimental unit for performance indices and the individual pig for blood, tissue, organ and carcass composition comparisons. Statistical significance was accepted at $P < 0.05$.

4.3 Results

4.3.1 Production performance

Live weight (LW) at birth, 28 d, 35 d and at the end of the experiment, and pre-weaning and whole-of-life growth rates, were similar between treatments (Table 4.2). However, NC pigs tended to grow slower ($P = 0.089$) in the week after weaning compared to CF and OM pigs. Carcass weight ($P = 0.017$) and dressing percentage ($P = 0.047$) of OM pigs were greater than for NC or CF pigs, but P2 thickness was similar for all treatments.

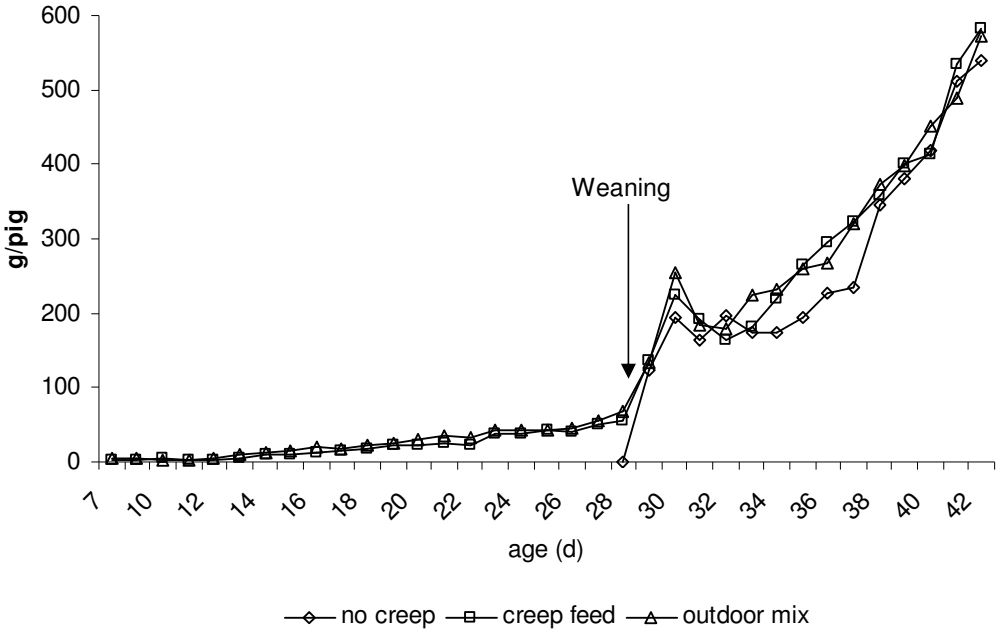

Figure 4.1 Average feed disappearance (g/pig) for pigs offered no creep (NC), creep feed (CF), or outdoor mix (OM - comprised of 1 part straw, 5 parts sow feed and 25 parts soil) from day 7 to weaning at 28 days of age

Feed disappearance from 7–28 d was similar (P = 0.171) between CF and OM pigs, and between any of the treatments from 28–35 d (P = 0.257) and from 28 d to the finish of the experiment (P = 0.974). The pattern of solid feed disappearance during lactation was similar for CF and OM pigs, with about 8% of total feed disappearance occurring from d 7–14, 30% from d 15–21 and 62% from d 21–28. Feed disappearance for all treatments increased for two days after weaning before declining for another two to three days and taking a further four to five days to recover to previous levels (Figure 4.1). Feed usage was similar for all treatments by day 42. Surprisingly, the wean-to-finish FCR of pigs that received creep feed (CF) prior to weaning was higher than for the other two treatments (P = 0.009) (Table 4.2).

Table 4.2 Growth and carcass characteristics of pigs offered no creep feed (NC), creep feed (CF) or outdoor mix (OM - comprised of 1 part straw, 5 parts sow feed and 25 parts soil) from day 7 to weaning at 28 days of age

	NC[1]	CF[2]	OM[3]	s.e.d.[4]	P value
Number of litters per treatment	8	8	8		
Birth weight (kg)	1.55	1.48	1.53	0.079	0.713
28 d live weight (kg)	8.75	8.88	9.01	0.279	0.655
35 d live weight (kg)	9.50	9.92	10.03	0.252	0.096
98 d live weight (kg)	50.20	49.52	50.96	0.977	0.341
Final live weight (kg)	106.9	106.8	107.5	0.48	0.260
Final age (d)	157	156	154	2.9	0.425
Gain 0–28 d (g/d)	265	268	272	10.6	0.764
Gain 28–35 d (g/d)	70[a]	118[b]	112[b]	13.7	0.011
Gain 28–98 d (g/d)	339	319	341	12.0	0.136
Gain 98 d–finish	1,019	1,000	1,042	20.5	0.122
Gain from 28 d–finish (g/d)	774	764	785	9.6	0.104
Gain birth–finish (g/d)	677	677	693	17.0	0.238
Carcass weight (Ausmeat Trim 13[5]) (kg)	70.4	70.3	71.8	0.39	0.055
Dressing % (Ausmeat Trim 13)	66.0[a]	65.9[a]	66.7[b]	0.36	0.047
Carcass P2 (mm)	12.5	12.8	13.2	0.49	0.357
Feed disappearance					
7–28 d *(kg/pig[6])*	nil	0.45	0.53	0.053	0.171
28–35 d *(kg/pig[6])*	1.22	1.38	1.47	0.145	0.257
28–98 d *(kg/pig/d)*	1.06	1.05	1.08	0.030	0.630
98 d–finish *(kg/pig/d)*	2.55	2.63	2.59	0.061	0.416
28 d–finish *(kg/pig/d)*	1.82	1.85	1.82	0.037	0.633
Feed conversion ratio					
28–98 d	1.62	1.66	1.63	0.028	0.347
98 d–finish	3.02	3.18	3.05	0.071	0.084
28 d to finish	2.42[a]	2.53[b]	2.41[a]	0.037	0.009

[1] No Creep Feed, [2] Commercial Creep Feed, [3] Outdoor Mix, [4] standard error of difference,
[5] Head off, flare fat removed, fore trotters off, hind trotters on,
[6] Feed disappearance per pig over the entire periods from 7-28 d and 28-35 d, respectively.
[ab] Means in the same row with different superscripts differ significantly ($P < 0.05$).

4.3.2 General Health

All pens of pigs, regardless of treatment, were water-medicated after an outbreak of respiratory disease in the grower shed. The underlying cause of the respiratory disease was not established, but there was no evidence of enzootic or actinobacillus pleuropneumoniae infection in the lungs of pigs at slaughter. The number of pigs treated individually for lameness or swollen joints was similar between treatments ($P = 0.158$). Fewer OM pigs were treated for post-weaning diarrhoea ($P = 0.020$) with nine NC pigs, 14 CF and three OM pigs receiving individual medication (12.5 mg apramycin per kg live weight) for the condition.

4.3.3 Organ weights

There were no significant ($P < 0.010$) interactions between treatment and age except for the pancreas as reported later, thus only main effects are shown in Table 4.3. The average LW and empty bodyweight (EBW) of median-weight piglets selected from each litter for sampling were heavier for OM than for NC and CF piglets at both 28 and 35 d. Average LW and EBW were also greater for all treatments at 35 compared to 28 d. Treatment did not have a significant effect ($P > 0.05$) on relative organ weights although CF pigs tended to have a heavier relative pancreas weight than NC or OM pigs ($P = 0.069$). The relative weights of the heart ($P = 0.073$) and lungs ($P < 0.001$) were lower at 35 than at 28 d, whereas the relative weights of the pancreas, gastrointestinal tract (GIT), stomach, small intestine, caecum and colon were all greater ($P < 0.001$) for pigs killed at 35 compared to 28 d. An interaction ($P = 0.083$) occurred between treatment and age for the relative weight of the pancreas ($P = 0.069$) of CF pigs which, compared

to NC and OM piglets, was similar at 28 d but significantly higher at 35 d (relative pancreas weights 0.17, 0.16, 0.16 and 0.21, 0.27, 0.19 for NC, CF and OM pigs at 28 and 35 days, respectively).

Table 4.3 Main effects of pre-weaning nutrition on the visceral organ weights of 28 and 35 day old piglets offered no creep feed (NC), creep feed (CF), or outdoor mix (OM - comprised of 1 part straw, 5 parts sow feed and 25 parts soil) from day 7 to weaning at 28 days of age

	Treatment (T)			Age (A)		s.e.d.[5]	P value		
	NC[1]	CF[2]	OM[3]	28 d	35 d		T	A	T x A
No. of pigs	12	12	12	18	18				
Live weight	9.31[ab]	9.02[a]	9.87[b]	8.82	9.99	0.454	0.041	<0.001	0.970
EBW[4] (kg)	8.84	8.48	9.31	8.57	9.18	0.465	0.057	0.033	0.869
Relative organ weight (%EBW)									
Heart	0.61	0.51	0.52	0.59	0.50	0.082	0.159	0.073	0.587
Lung	1.25	1.17	1.93	1.28	1.13	0.066	0.191	<0.001	0.508
Liver	2.38	2.44	2.30	2.48	2.27	0.344	0.851	0.296	0.684
Kidney	0.56	0.57	0.54	0.56	0.55	0.035	0.348	0.568	0.724
Spleen	0.21	0.19	0.19	0.21	0.18	0.033	0.580	0.092	0.994
Pancreas	0.19	0.21	0.18	0.16	0.22	0.021	0.069	<0.001	0.083
GIT	5.94	6.22	5.63	4.66	7.20	0.474	0.238	<0.001	0.895
Stomach	0.72	0.70	0.64	0.61	0.76	0.061	0.161	<0.001	0.898
Small intestine	3.78	3.98	3.64	3.03	4.57	0.349	0.397	<0.001	0.893
Caecum	0.24	0.25	0.21	0.18	0.29	0.028	0.085	<0.001	0.891
Colon	1.21	1.29	1.15	0.85	1.58	0.138	0.374	<0.001	0.965

[1] No Creep Feed, [2] Commercial Creep Feed, [3] Outdoor Mix, [4] Empty Body Weight, [5] standard error of difference.
[ab] Means in the same row with different superscripts differ significantly ($P < 0.05$).

4.3.4 Morphology of the small intestine

Villus height and crypt depth at 28 and 35 d are shown in Table 4.4. Villus height was higher for CF than for NC and OM piglets at 28 d and at 35 d ($P = 0.047$), and significantly higher for all treatments at 28 compared to 35 d ($P < 0.001$). Crypt depth was similar between treatments at 28 and at 35 d, but significantly greater at 35 compared to 28 d ($P < 0.001$).

Table 4.4 Mean villus height and crypt depth of 28 and 35 day old piglets offered no creep feed (NC), creep feed (CF), or outdoor mix (OM - comprised of 1 part straw, 5 parts sow feed and 25 parts soil) from day 7 to weaning at 28 days of age

	28 days of age			35 days of age			s.e.d.[4]	Significance		
	NC[1]	CF[2]	OM[3]	NC[1]	CF[2]	OM[3]		T	A	T x A
Villus height (μm)	428[a]	509[b]	461[ab]	280[c]	357[d]	279[c]	44.7	0.047	< 0.001	0.840
Crypt depth (μm)	173[a]	175[a]	187[a]	319[b]	308[b]	322[b]	31.1	0.839	< 0.001	0.950

[1] No Creep Feed, [2] Commercial Creep Feed, [3] Outdoor Mix, [4] standard error of difference
[ab] Means in the same row with different superscripts differ significantly ($P < 0.05$).

4.3.5 Gut acidity values

Average pH values were not statistically different between treatments ($P > 0.05$) in any section of the GIT (Table 4.5). However, a significant interaction ($P = 0.009$) occurred for treatment and age of CF pigs where the jejunum pH was lower for CF pigs at 28 d but higher at 35 d (jejunum pH 6.4, 6.1, 6.5 and 0.6.1, 6.5, 6.2 for NC, CF and OM pigs at 28 and 35 days, respectively). The average pH in the ileum ($P = 0.008$) was lower for pigs killed at 35 compared to 28 d of age, with a tendency also to be lower in the duodenum ($P = 0.088$) and colon ($P = 0.063$) at 35 d.

Table 4.5 Main effects for acidity (pH) of digesta from 28 and 35 day old piglets offered no creep feed (NC), creep feed (CF), or outdoor mix (OM - comprised of 1 part straw, 5 parts sow feed and 25 parts soil) from day 7 to weaning at 28 days of age

	Treatment (T)			Age (A)		s.e.d.[4]	Significance		
	NC[1]	CF[2]	OM[3]	28 d	35 d		T	A	T x A
Stomach	3.8	4.1	3.3	3.7	3.7	0.58	0.181	0.856	0.831
Duodenum	5.4	5.3	5.2	5.5	5.1	0.32	0.580	0.088	0.696
Jejunum	6.3	6.3	6.3	6.3	6.3	0.17	0.959	0.500	0.009
Ileum	6.8	6.9	7.1	7.2	6.7	0.33	0.534	0.008	0.990
Caecum	6.2	6.1	6.1	6.2	6.0	0.25	0.605	0.107	0.755
Colon	6.4	6.4	6.2	6.5	6.2	0.25	0.364	0.063	0.292
Rectum	6.4	6.5	6.4	6.5	6.5	0.20	0.888	0.972	0.558

[1] No Creep Feed, [2] Commercial Creep Feed, [3] Outdoor Mix, [4] standard error of difference

4.3.6 Volatile fatty acid (VFA) production

There were no significant ($P < 0.010$) interactions between treatment and age for total concentrations and molar proportions of VFA in digesta except for the molar proportion of butyric acid (as discussed later), thus only main effects are shown in Table 4.6. The total and molar proportions of VFA in digesta from the caecum and distal colon were similar ($P > 0.05$) for all treatments. However, there were differences in the characteristics of digesta samples taken at 28 or 35 d. While the total concentrations of VFA in the caecum were similar at 28 and 35 d, the molar proportion of propionic acid was higher at 35 than at 28 d ($P = 0.011$) whereas molar proportions were lower for isobutyric ($P < 0.001$), isovaleric ($P < 0.001$), valeric ($P = 0.023$) and caproic ($P = 0.060$) acids. The total concentration of VFA ($P < 0.001$) and molar proportion of propionic acid ($P < 0.001$) were higher in digesta taken from the distal colon at 35 d; the

molar proportions of isobutyric ($P = 0.077$), butyric ($P = 0.013$) and isovaleric ($P = 0.045$) acids were lower. The branch-chain ratios (BCR) were similar between treatments but were lower in digesta from the caecum ($P < 0.001$) and distal colon ($P = 0.065$) at 35 compared to 28 d. Significant interactions ($P = 0.077$) occurred between treatment and age for butyric acid at 28 d when its molar proportion was higher for CF than for NC piglets, and at 35 d when OM piglets had a lower proportion of butyric acid than NC and CF piglets (butyric acid % 12.3, 14.7, 8.5 and 11.6, 12.0, 13.1 for NC, CF and OM pigs at 28 and 35 days, respectively).

Table 4.6 Total and relative concentration (% of total VFA) of VFA in digesta from the caecum and distal colon of 28 and 35 day old piglets offered no creep feed (NC), creep feed (CF), or outdoor mix (OM - comprised of 1 part straw, 5 parts sow feed and 25 parts soil) from day 7 to weaning at 28 days of age

	Treatment (T)			Age (A)		s.e.d.[4]	Significance		
	NC[1]	CF[2]	OM[3]	28 d	35 d		T	A	T x A
Caecum									
Total VFA (mmol/L wet digesta)	81	95	110	91	100	23.1	0.227	0.508	0.710
Acetic %	67.6	59.6	66.0	66.2	62.6	7.10	0.225	0.389	0.217
Propionic %	17.1	22.6	19.4	15.9	23.5	4.87	0.300	0.011	0.408
Isobutyric %	0.72	0.65	0.80	1.40	0.04	0.580	0.931	<0.001	0.979
Butyric %	12.0	13.4	10.8	11.8	12.3	2.24	0.276	0.738	0.077
Isovaleric %	1.24	1.58	1.36	2.18	0.60	0.727	0.803	<0.001	0.596
Valeric %	1.15	1.91	1.55	2.12	0.95	0.839	0.453	0.023	0.674
Caproic %	0.20	0.34	0.06	0.40	0.00	0.350	0.545	0.060	0.545
BCR[4]	0.03	0.05	0.04	0.07	0.02	0.023	0.680	<0.001	0.664
Distal colon									
Total VFA (mmol/L wet digesta)	83	103	91	70	115	16.7	0.254	<0.001	0.269
Acetic %	64.7	61.8	61.5	64.2	61.1	3.51	0.383	0.139	0.818
Propionic %	16.1	18.5	17.8	12.9	22.0	2.63	0.432	<0.001	0.347
Isobutyric %	1.13	0.65	0.68	1.03	0.61	0.389	0.174	0.077	0.642
Butyric %	13.7	15.0	13.6	15.4	12.8	1.58	0.394	0.008	0.496
Isovaleric %	2.63	1.75	4.35	4.44	1.38	2.563	0.359	0.049	0.356
Valeric %	1.68	1.96	1.85	1.88	1.77	0.556	0.778	0.723	0.850
Caproic %	0.13	0.42	0.28	0.20	0.35	0.223	0.204	0.239	0.226
BCR[4]	0.06	0.05	0.09	0.09	0.04	0.040	0.429	0.065	0.396

[1] No Creep Feed, [2] Commercial Creep Feed, [3] Outdoor Mix, [4] BCR = branched-chain ratio (isobutyric, isovaleric, valeric, caproic : acetic, propionic, butyric acids ratio).

4.3.7 Haematological indices

Pigs fed the outdoor mix (OM) had the highest values for RBC (P = 0.026), Hb (P < 0.001) and HCT (P < 0.001) (Table 4.7). Values for these parameters were also significantly higher at 35 d than at 28 d for all treatments. The WBC for all treatments were approximately 30% higher at 35 d than at 28 d (P = 0.006), with NC pigs tending (P = 0.097) to have higher WBC at 28 and 35 d compared to CF and OM pigs. The NC pigs also had a higher proportion of neutrophils (P = 0.001), a lower proportion of lymphocytes (P = 0.001), and a higher N:L ratio (P = 0.001) than CF and OM pigs at 35 compared to 28 d. Serum Fe levels were higher (P = 0.101) for OM than for NC and CF piglets at 28 but not at 35 d.

Table 4.7 Haematological indices of 28 and 35 d old piglets offered no creep feed (NC), creep feed (CF), or outdoor mix (OM - comprised of 1 part straw, 5 parts sow feed and 25 parts soil) from day 7 to weaning at 28 days of age

	Day 28			Day 35			s.e.d.[4]	P value		
	NC[1]	CF[2]	OM[3]	NC[1]	CF[2]	OM[3]		T[5]	A[6]	T x A
Serum Fe (umol/L)	13.2	11.4	33.0	18.0	20.8	21.0	8.10	0.101	0.880	0.167
RBC[7] (10^{12}/L)	5.37^{a}	5.59^{a}	6.16^{b}	6.97^{c}	7.20^{cd}	7.42^{d}	0.308	0.026	<0.001	0.646
Hb[8] (g/L)	80^{a}	87^{ab}	110^{c}	97^{b}	105^{bc}	112^{c}	7.7	<0.001	0.012	0.288
HCT[9] (L/L)	0.27^{a}	0.30^{a}	0.37^{c}	0.33^{b}	0.36^{bc}	0.38^{c}	0.022	<0.001	0.001	0.198
WBC[10] (10^{9}/L	9.4^{a}	6.4^{b}	6.5^{b}	12.6^{c}	10.2^{ac}	10.1^{ac}	1.98	0.097	0.006	0.990
Neut[11] (%)	21.3^{a}	32.3^{b}	32.4^{b}	42.8^{c}	35.0^{b}	$39.0b^{bc}$	5.03	0.594	0.001	0.033
Lymph[12] (%)	70.5^{a}	61.7^{b}	59.1^{b}	49.8^{c}	55.3^{bc}	53.4^{bc}	5.28	0.582	0.001	0.095
Neut:Lymph[13]	0.31^{a}	0.58^{b}	0.55^{b}	0.91^{c}	0.67^{b}	0.76^{bc}	0.146	0.899	0.001	0.054

[1] No Creep Feed, [2] Commercial Creep Feed, [3] Outdoor Mix, [4] standard error of difference, [5] Treatment, [6] Age,
[7] Red blood cells, [8] Haemaglobin, [9] Haematocrit, [10] White blood cells, [11] Neutrophils %, [12] Lymphocyte %,
[13] Neutrophil : Lymphocyte ratio.
[ab] Means in the same row with different superscripts differ significantly (P < 0.05).

4.4 Discussion

4.4.1 Pre-weaning substrate disappearance

The current experiment was designed to investigate the lifetime impact of providing substrates (soil, sow feed and straw) generally only available to piglets farrowed outdoors to those farrowed indoors in conventional crates, and to study the nutritional effects of the outdoor milieu on post-weaning growth and development independently of environmental and behavioural factors. Thus, consumption of normal quantities of CF and OM during lactation was critical to the outcomes of the study. Both the patterns and quantities of CF and OM that disappeared pre-weaning agreed with values for creep feed disappearance in published studies. The majority of feed disappearance occurred from d 21-28 of lactation, in agreement with data from Fraser et al. (1994), Bruininx (2001) and Pluske et al. (2007). Disappearance of CF was similar to the average of 468 g per piglet from d 10–28 of lactation reported by Pajor et al. (1991) but considerably higher than average intakes of 385 g per piglet from d 11–28 (Fraser et al., 1994), 377 g per piglet from d 10–28 of lactation (Bruininx et al., 2002) and 230 g per piglet from d 14–28 (Wattanakul et al., 2005).

Creep feed disappearance during lactation is known to be influenced by feeder design and diet complexity as well as other as yet unidentified factors. Disappearance has been found to be higher when feed is presented in shallow trays (Wattanakul et al., 2005) and when the diet is of a high complexity and readily digestible by young pigs (Fraser et al., 1994). In the present study, use of 600 mm long troughs mounted above a wide mat from which spilt feed could be recovered by piglets may have enhanced feed intake.

The creep feed used in the present study was not as complex as some diets used in other experiments (Pajor et al., 1991; Fraser et al., 1993; Pluske et al., 2007), and was unlikely to have had a stimulatory effect on intake. Furthermore, the consumption of both CF and OM was considerably lower than the average of over 700 g of creep feed per piglet from d 12–31 of lactation reported by Pluske et al. (2007) in an experiment conducted in the same facility using the same genotype, which can be explained by the earlier ages at which creep feeding started and finished and (or) by the use of a less complex diet in the current experiment.

It is difficult to relate the consumption of OM mix in this experiment to consumption of similar materials by outdoor pigs in the field. Estimates of soil intake by outdoor piglets during lactation are lacking (Edwards, 2003). Indications of the amount of soil can be found in reports of the role of soil in the prevention of iron-deficiency anaemia. For example, the gut contents of a 21 day-old outdoor piglet contained 513 mg of iron which, based on soil Fe analysis, required ingestion of at least 40 g of soil from the paddock in which it was raised (Venn et al., 1947). Other estimates of soil consumption can be derived from calculating the amount of soil of known Fe content required to supply the necessary 6 g of Fe per day to prevent iron-deficiency anaemia (Venn et al., 1947). Using this logic, Venn and Davies (1965) calculated that over a three-week period from birth to weaning, piglets must ingest a minimum of 60 g of soil containing 4,000 ppm Fe or 480 g of soil containing 500 ppm Fe, assuming a 50% absorption rate for soil Fe as apparent in Ullrey et al. (1959 and 1960). Similarly, outdoor piglets in lactation paddocks with soil iron contents from 4.1–30.8 g per kg (4,100–30,800 ppm) showed no signs of anaemia (Brown et al., 1996) and therefore were assumed to have

eaten a minimum of 60 g of soil from d 1–22 in order to meet Fe requirements to avoid anaemia. However, estimating the amount of soil ingested in this manner is likely to grossly underestimate consumption by outdoor piglets because of variation in Fe status of piglets at birth which determines subsequent Fe requirement and absorption, differences in soil composition, and in the form and digestibility of the Fe it contains. The soil component of the total feed disappearance for OM pigs from d 9 to d 28 of about 430 g was in the range of estimates cited above for soil intakes by outdoor piglets. Thus, it appears the amount of OM mix ingested by indoor piglets in the current study was representative of the quantity of solid material that outdoor piglets might be expected to consume over a similar period, and sufficient to have an effect on growth and development.

The similar feed disappearance recorded for CF and OM treatments contradicted the common belief that highly-digestible creep diets are necessary to maximise intake (Fraser et al., 1994). Studies on the development of feeding and investigatory behaviour in free range pigs partly explain the contradiction. Rooting behaviour, defined as 'repeated thrusting the snout along and into the surface of the earth and digging into it', and chewing earth, commences in the first week of life and increases significantly in the fourth week of age (Petersen, 1994). In contrast grazing, defined as repeatedly biting-off, chewing and swallowing plant material, is not apparent until the fourth week of life when ingestion of solid food in significant quantity usually begins (Petersen et al., 1989). The later onset of eating compared to rooting behaviours in the young piglet may be due to immature dentition (Widowski et al., 2008). That is, deciduous premolars do not erupt until around three weeks of age and a series of developmental processes must

occur before the transition to solid food can be properly and fully achieved (Widowski et al., 2008). Thus rooting and chewing behaviours may be integral to the development of anatomical and neurological systems necessary for mastication. Alternatively or perhaps coincidentally, rooting and chewing by very young piglets may be explorative behaviours motivated by an intrinsic need to investigate their environment rather than to satisfy hunger needs (Studnitz et al., 2007). Pigs prefer more complex and compound rooting materials such as compost and peat (Jensen et al., 2007). Characteristics such as structure, particle size, complexity and destructibility are more likely to stimulate rooting behaviour than the nutritional value of the substrate which may be immaterial to the piglet when consumption is not motivated by appetite. It is therefore plausible that physical characteristics of the OM stimulated rooting and investigative behaviours resulting in a similar intake of OM compared to more homogenous CF crumbles.

4.4.2 Production indices

Apparent creep feed disappearance during lactation did not significantly influence weaning weight. Evidence that creep feed consumption and weaning weight are positively correlated is equivocal. Positive correlations within litters between solid feed intake (measured for individual piglets within litters by combining weight of feed removed from feeders – determined electronically and video records of piglet activity at the feeders) and individual piglet weight gain during the creep feeding period were reported by Pajor et al. (1991). Similarly, positive correlations between solid feed intake and pre-weaning weight gain between litters of more than eight piglets were reported by Klindt (2003). Other between-litter comparisons failed to demonstrate a positive effect of creep feeding on litter weights at weaning (Okai et al., 1976; Barnett et

al., 1989). In the current experiment, the use of sows of a genotype recognised for its milking ability, together with standardising litter size at ten piglets per litter, may have ensured that milk supply was sufficient to meet the requirement for growth and to satisfy appetite, thereby reducing the need to ingest solid food to an extent whereby ingestion of CF and OM was insufficient to affect performance.

No exposure to creep feed during lactation inhibits feed intake in the first few days after weaning (Pluske et al., 2007), thus it was unsurprising that piglets not offered creep feed during lactation ate 12–17 % less feed and grew slower than CF and OM pigs in the first week after weaning. Post-weaning growth is positively-related to pre-weaning growth (Klind, 2003), so again it was unsurprising that growth rate for all treatments was similar at every stage thereafter, given the similarity in pre-weaning growth.

There were no obvious physiological reasons why CF pigs had a higher wean–finish FCR than NC and OM pigs. Feed disappearance was higher and weight gain lower for CF pigs over this period, although the differences were not statistically different ($P > 0.05$). However, when these parameters were used to calculate FRC, their small differences in magnitude were sufficient to generate statistically-different treatment means for FCR.

Higher carcass weights and dressing percentages of OM pigs were presumably caused by the ingestion during lactation of outdoor substrates contained in the OM mix, since all other management factors were held constant for the three treatments. Possible mechanisms for the increase in carcass weight and dressing percentage can only be speculated upon, but the most plausible explanation appears to be greater bone size and

(or) weight due to increased bone mineralisation resulting from enhanced mineral nutrition, Fe in particular, of the OM-fed pigs. Some evidence exists to support the notion that access to additional minerals may have caused increased bone mineralisation to occur in OM pigs. Supplementation of Ca and P above normal concentrations found in sows' milk has been found to increase bone mineral content of piglets from 5 to 28 d of age (Atkinson et al, 1993). A positive relationship between dietary Fe intake and bone mineralisation has been reported in rats and humans (Parelman et al., 2006). Stern et al (2003) reported higher dressing percentage and femur bone weight in outdoor pigs compared to pigs reared indoors on deep-litter.

4.4.3 Organ weights

The consumption of CF and OM had little effect on organ weights, probably because of the small amounts consumed. The similarity between treatments in the relative weight of the GIT and various sections of the GIT at 28 and at 35 d adds weight to the argument that differences in killing-out percentage were unlikely to be the result of differential gut fill and development. The lack of difference in small intestine weight suggests that intestinal health was similar between treatments.

Substrates in the creep feed, starch for example, consumed by CF pigs may have stimulated enzyme production which could account for the trend ($P = 0.069$) to heavier pancreas weights in CF pigs (Pluske et al., 2003).

4.4.4 Morphology of the small intestine

Villus height and crypt depth measurements for 28 d old piglets from all treatments were within normal ranges cited for a healthy intestinal tract (van der Klis & Jansman, 2002). The significant villus atrophy and crypt hyperplasia seen in all treatments a week after weaning was also in agreement with other studies (Hampson, 1986; Bruininx, 2002). However, it appears that creep consumption during lactation may have beneficially affected gut morphology as average villus height was greater for CF compared to NC and OM piglets at weaning and at d 35. Alternatively, soil mineral particles may have abraded the villi of OM piglets. Interestingly, although the OM contained few nutrients, villus height for OM piglets at 28 d was intermediate between those for NC and CF piglets at 28 d but not at 35 d, possibly reflecting higher energy retention as a result of higher Hb levels as discussed later in section 4.4.6. It is significant that weaning at four weeks, nearly a week later than current industry practice, did not prevent major disruption to gut architecture, indicating that four-week-old piglets are still highly vulnerable to enteric diseases caused by interruption to normal gut function.

4.4.5 Acid production

Consumption of commercial CF or the OM had little effect on VFA concentrations in digesta taken from the caecum or distal colon at 28 d, indicating that either the intake of solid material was not high enough to cause any treatment differences in VFA production and/or that microbial populations were insufficiently diverse between treatments to significantly influence fermentation processes in the gut. Therefore, it was

not surprising that VFA production in the caecum and distal colon was also similar between treatments at 35 d, given that piglets on all treatments consumed similar quantities of the same diet between 28 to 35 d. However, the differences in VFA production at 35 d compared to 28 d which occurred in all treatments during the current experiment following the cessation of sow milk and total dependence on plant-based solid food was in contrast to Konstantinov et al. (2006). These authors found no differences ($P > 0.05$) in total VFA production and the molar proportions of acetic, propionic and butyric acids in ileum and colon of 21-day weaned piglets at 19, 23, 27 and 32 d, even though significant changes in bacterial composition occurred after weaning. There is no obvious explanation why post-weaning differences in VFA production occurred in the current experiment and not in Konstantinov et al. (2006). No antimicrobial products were used in either experiment, and no creep feed was used while piglets were on the sow in Konstantinov (2006), but it can be speculated that differences in weaning age, diet composition and possibly feed intake in the post-weaning period may have influenced results in the respective experiments.

4.4.6 Fe status

The nearly threefold increase in serum iron levels seen in OM compared to NC and CF piglets at weaning was an important finding with major implications for the mineral nutrition of sows and their litters. Two thirds of NC and CF piglets had serum Fe values within or below a marginal band of 2.7 – 10.7 μmol/l suggested by Underwood and Suttle (1999) for assessing the risk of Fe deficiency, while half of the Hb values were below a threshold of 80 g/L used by Egeli et al. (1998) to differentiate between normal and anaemic piglets.

High Hb status within the physiological normal range has been associated with increased energy metabolism and retention in 28 d weanling piglets (Gentry et al., 1997), but this did not appear to be the case in the current experiment as growth rates were similar between treatments.

These results suggest that, under the conditions of this experiment, the Fe supplement administered in accordance with current industry practice did not prevent Fe deficiency in all piglets. However, OM piglets apparently derived sufficient additional Fe from soil in the OM to prevent Fe deficiency and to maintain haematological indices within normal ranges. These results are in disagreement with numerous other studies, e.g. Hill et al. (1999), who found that one injection of 200 mg of Fe dextran was sufficient to maintain adequate growth and Hb concentration of greater than 100 g/L at weaning (21 d). However, the piglets in the present study were derived from sows with an average parity of 6.3 litters, so it is possible that piglet Fe stores were depleted at birth as a consequence of their dams having low Fe reserves.

Current guidelines for sow mineral nutrition are largely based on experimental work conducted over 20 years ago. Modern genotypes have increased in mature body size and fecundity and it is likely that demand for more micro-nutrients has increased over this period. Furthermore, sows increase in body size until the sixth parity (McGlone et al., 2004) and have an increased requirement for micro-nutrients to support additional tissue metabolism associated with the extra tissue mass accrued (Boyd, 2006). Unless the supply of micro-nutrients increases with parity to meet the extra demand, stores of some minerals may be depleted. Close (2005) calculated that sows from parity three onwards may be receiving 23% less Fe, Zn, Cu, Mn and Se per kilogram of body weight

compared to parity one sows receiving similar diets. Thus it is highly probable that some if not all of the high parity sows used in this experiment were Fe deficient at parturition, resulting in piglets with low reserves of Fe.

4.5 Conclusions

The quantity of solid food consumed during lactation was within the normal range reported in the literature. Pre-weaning consumption of commercial creep feed (CF) or the outdoor mix (OM) did not increase weaning weight, but positively affected feed consumption and growth during the first week after weaning. However, the increase in post-weaning feed intake was insufficient to prevent significant villous atrophy and crypt hyperplasia. The effects of creep feed and outdoor substrate ingestion during lactation persisted until slaughter around 22 weeks of age. Specifically, piglets offered CF had a poorer FCR from weaning to slaughter, while piglets that received the OM had heavier carcasses and higher dressing percentages than piglets that did not receive solid food or were offered commercial creep feed during lactation. It is suggested that the increase in carcass weight was due to increased bone mass.

It appears from the results of this experiment, the current industry practice of administering a single injection of 200 mg Fe dextran within 1-2 days after birth may be insufficient to prevent Fe deficiency anaemia in piglets in all situations. Although it was not possible to determine the cause of the unexpected rate of Fe deficiency anaemia found in this experiment, it may have been due to depleted Fe stores in the piglets at birth, a possible consequence of using high parity dams whose Fe reserves were low because of inadequate mineral nutrition in later parities.

In summary, this experiment demonstrated that the reported difference in post-weaning growth and development of indoor and outdoor weaners may in part be attributed to ingestion of substrates normally available only to outdoor pigs rather than solely to differences in their physical and social environments.

CHAPTER 5: GENERAL DISCUSSION

The general hypothesis for this thesis, that '*gut structure and function, and lifetime performance of the weaned pig are affected by its pre- and post-weaning rearing environments*, was examined in two experiments. The first experiment compared the post-weaning growth performance, gut structure and health of piglets from indoor and outdoor production systems when reared under diverse housing conditions. The second experiment was conducted under uniform housing conditions to examine the lifetime effects of providing substrates similar to those available to the outdoor piglets used in **Experiment 1** to indoor piglets prior to weaning in the absence of other differences in the outdoor rearing milieu. For the purposes of this discussion, 'pre-weaning environment' is defined as including the physical environments as in **Experiment 1** and the indoor environment with or without enhancement by the provision of outdoor substrates as in **Experiment 2**.

The general hypothesis was partly supported by results from both experiments. Pre-weaning environments in **Experiment 1** (indoor and outdoor production systems) and provision of outdoor substrates to indoor piglets in **Experiment 2**, appeared to have little effect on gut structure and overall growth rate but significantly affected carcass composition, whereas post-weaning environment (conventional or deep-litter pens) affected both overall growth rate and carcass composition (**Experiment 1**). Specific hypotheses from both experiments, that ingestion of outdoor substrates prior to weaning would enhance gut structure at and after weaning, were not supported. Morphology of the small intestine was similar for indoor and outdoor piglets at weaning in **Experiment**

1 and for all treatments in **Experiment 2**. Likewise, the decrease in villous height seven days after weaning was similar in both experiments and in agreement with other published results. Furthermore, there was inconsistent support for the specific hypotheses tested in both experiments that piglets whose pre-weaning environment provided access to outdoor substrates would experience less of a growth check after weaning.

The specific hypothesis in **Experiment 1** that outdoor piglets might adapt better to deep-litter housing from weaning to sale was not supported, since growth rate of OP and IP pigs was similar over this period. Although OP piglets did grow faster in DL pens during the first seven weeks after weaning, this advantage was not apparent at the end of the experiment. Furthermore, piglets that received creep feed (CF) and the outdoor-mix (OM) during lactation also grew faster in the week after weaning, but overall growth was similar regardless of pre-weaning environment in **Experiment 2**.

Access to consumable substrates during lactation appeared to have relatively little effect on whole-of-life growth rate. Although pigs produced outdoors experienced enhanced growth for at least three weeks after weaning in **Exp1a**, this advantage was not evident at the end of the grow-out period. A similar effect was seen in **Experiment 2** in which CF and OM piglets grew faster than NC piglets in the first week after weaning, but not from weaning to 14 weeks, nor from birth to slaughter. Presumably, in both experiments, the faster growth in the first few weeks after weaning was the result of higher feed intake and (or) enhanced feed utilisation.

Factors that may have influenced CF and OM disappearance during lactation and its effects on growth before and after weaning were discussed in Sections 4.4.1 and 4.4.2. However, access to CF and OM during lactation may also have provided other intangible benefits regardless of the digestibility and nutrient content of the substrates offered. Williams (2003) suggested that creep feeding may help piglets learn how to access dry food from a feeder, drink water, accustom the GIT to dry food, induce the necessary enzymes for its digestion and assist the piglet to cope with potential allergens in plant foods. In the absence of direct evidence, it cannot be determined with certainty which, if any, intangible attribute(s) of creep feeding suggested by Williams (2003) were beneficial. Enhanced structure of eating behaviours and (or) ingestion of dry material which may have accustomed the GIT to solid material are the most likely possibilities. Perhaps the early and continuous ingestion of small quantities of plant material during lactation mitigated piglet response to any allergens present. Likewise, exposure to low levels of antigens may have primed the mucosal immune system without producing excessive, energy-consuming immune responses, thereby rendering more energy available for growth. Similar mechanisms may also account for some of the performance differences between indoor and outdoor weaners in **Experiment 1**.

The similarity in pre- and immediate post-weaning feed disappearance and growth of CF and OM treatments in **Experiment 2** suggests the nutritional quality of ingredients used in the pre-weaning diet may not be overly important, given that the OM mix comprised mostly of indigestible soil and straw. This supposition, although based on results from **Experiment 2**, is contentious and contradicts conventional wisdom that advocates the

use of highly palatable and digestible ingredients in creep feed, such as those included in the commercial creep feed provided in **Experiment 2** (see Table 4.1).

Pre-weaning environment effects on carcass composition were seen in both experiments. Pigs that were housed outdoors until weaning had higher carcass weights and dressing percentages than pigs produced and reared indoors (Experiment 1), as did pigs that received outdoor substrates compared to those that received no creep or a commercial creep feed during lactation (**Experiment 2**). Reasons for the differences in carcass weight and dressing percentage of indoor and outdoor pigs could not be elucidated after the completion of **Experiment 1** because of the number of variables within the production and rearing environments. The most plausible explanation at the time appeared to be an increase in bone mass ensuing from ingestion of trace elements contained in soil (from paddocks, contaminated straw or incidental access during weekly weighings), greater exposure to sunlight, higher levels of spontaneous exercise or a combination of all three factors before or after weaning. However, when exposure to sunlight and the opportunity for spontaneous exercise were standardised across treatments in **Experiment 2**, carcass weight and dressing percentage of pigs from the OM treatment were higher than for the NC and CF treatments. Access to outdoor substrates during lactation was the only common factor between the two experiments. Therefore, ingestion of outdoor substrates appears to be the most likely reason for the higher carcass weights and dressing percentages observed in both experiments. Since soil was the predominate substrate, it follows that soil from the paddocks in which the OP pigs were farrowed and which was used in the OM mix, contained the causal agent(s) for the higher carcass weights and dressing percentages seen in these

treatments. Evidence from these experiments and from the literature suggest Fe as the most likely causal agent for increased bone mineralisation (see Section 4.4.2), although the role of other minerals that may have been present in the soil, specifically Ca, P, Cu and Zn, cannot be discounted.

While it has been argued that higher dressing percentages seen in pigs from treatments with access to soil prior to weaning were caused by increased bone weight, limited carcass composition data from **Experiment 1** provide only equivocal support for this notion. Bone mineral content and bone density of IPC and OPDL piglets were similar at 21, 28 and 42 days, although bone density was significantly higher in half-carcasses taken from OP pigs at 161 days. It is difficult to explain the lack of treatment differences in bone mineral content and bone density in the young piglets. Phosphorus deficiency has been shown to increase relative bone weight of 6-week-old piglets, whereas deficiencies of Ca, Mg and vitamin D do not change relative bone weight (Miller et al., 1967). Thus the effects of individual nutrient deficiencies on relative bone weight may not be apparent when the deficiencies are marginal and concurrent, as may have been the case in these experiments. The possibility of measurement error also cannot be disregarded.

The unexpected finding of low haemoglobin (Hb) and serum iron (Fe) levels at weaning in piglets that did not have access to outdoor substrates in lactation (**Experiment 2**) was particularly interesting as it provided a possible explanation for some of the health differences and the higher dressing percentage seen in pigs produced outdoors and on deep-litter. Low Fe reserves in piglets at birth may have rendered the standard parenteral supplementation of 200 mg Fe Dextran within 1–2 days of birth insufficient

to sustain Hb levels within the normal range. The average parity of sows from which the piglets were derived was 6.3 litters so it is possible their Fe reserves were depleted through inadequate mineral nutrition during later parities (see Section 4.5). A similar effect may have been present in **Experiment 1** as a result of an increase in average herd parity that occurred during the intervening year between the conduct of the two parts of the experiment. Indoor piglets in **Exp1b** experienced lower average Hb levels compared to those in **Exp1a**, which was consistent with a possible decline in both sow and piglet reserves of Fe at parturition. In contrast, Hb levels of outdoor piglets were similar in both parts of the experiment, suggesting that Fe stores of outdoor sows and piglets did not decline with increasing parity (see Section 3.5.5).

Findings on health status may have been confounded by differences in Fe reserves at birth and the Fe supplementation afforded by the various environments. Resistance to disease is generally lower and enteritis more common in piglets with chronic Fe deficiency anaemia (Miller & Ullrey, 2007). Conversely, unbound Fe promotes bacterial growth (Klasing et al., 1980; Knight et al., 1983; Kadis et al., 1984), thus parenteral and oral administration of Fe in excess of requirement may encourage proliferation of diarrhoea-inducing *E. coli*. Enteric health of indoor (IP) and outdoor (OP) piglets after weaning was similar when antimicrobial products (APs) were included in the first-stage weaner diet in **Exp1a**, whereas OP piglets experienced more PWD when APs were omitted in **Exp1b** (see Section 3.5.1). However, in the absence of dietary APs in **Experiment 2**, there was a lower incidence of PWD in piglets that received the OM during lactation. The increased prevalence of PWD in **Exp1b** may have been due to a greater level of sub-clinical disease in OP pigs which manifested as

PWD in the absence of the suppressive effect of APs (see Section 3.5.1). In contrast, the lower incidence of PWD in piglets on the OM treatment in **Experiment 2** may have been due to normal Hb levels and consequent absence of anaemia. Presumably, the amount of Fe ingested by piglets that received the OM mix was sufficient to prevent chronic anaemia and maintain a competent immune status and (or) without stimulating enteric disease.

Sub-clinical disease affects microbial populations in the GIT, thereby altering fermentation processes and VFA production. Therefore, lower VFA concentrations and differences in the molar proportions of some acids in 35 day faecal samples of OP compared to IP pigs may have been indicative of differences in the sub-clinical disease status of OP compared to IP piglets at weaning. These effects may have persisted until at least seven weeks of age (see Section 3.4.5). There were also age-related changes to total VFA found in colonic but not caecal digesta in **Exp1b** when no APs were used. In contrast, when APs were used in the first-stage weaner diet in **Exp1a**, type of production system appeared to have little effect on VFA production throughout the grow-out period as faecal VFA concentrations were similar at all sampling ages, suggesting that APs may have decreased microbial populations and diversity. Molar proportions of individual VFAs differed at various ages however, indicating fermentation processes were influenced either by changing microbial populations and (or) changes to diet composition that occurred throughout the grow-out period.

With regard to the effects of rearing system on enteric health, piglets in deep-litter pens were more susceptible to PWD in **Exp1b** when a combination of adverse weather and poor straw quality rendered their environment sub-optimal during the first few weeks

after weaning (see Section 3.5.1). Even so, piglet growth was similar in both rearing environments during the weaner phase of the experiment, indicating that overall, piglets tended to fare better in the DL compared to C pens. Otherwise, there were no noticeable differences in the health status of pigs in the two rearing systems.

In summary, the only measurable effects of pre-weaning environment on lifetime performance were increased carcass weight and dressing percentage in pigs produced and raised outdoors until weaning, and for those pigs that received outdoor substrates during lactation. These effects were thought to be due to the effect of enhanced mineral nutrition (increased Fe intake in particular), on bone mineralisation. Ingestion of solid substrates during lactation appeared to increase feed intake and growth in the first few weeks after weaning, but had little effect on changes to gut morphology that occurred after weaning or on lifetime performance. Pigs reared on deep-litter, under the conditions of these experiments, grew faster with an inferior FCR, were fatter and had higher carcass weights and dressing percentages than those reared in conventional pens. A number of mechanisms were proposed to account for the production differences observed, the most important of which was the role of Fe which may have increased bone mineralisation in pigs produced outdoors and those raised on deep-litter. It should be noted that these findings may be valid only under the conditions under which the experiments were conducted and should not be extrapolated more generally until tested under a wider range of indoor and outdoor production systems.

5.1 Further Work

Causes of increased feed intake and inferior FCR seen in pigs on deep-litter warrant further investigation. Increased carcass weight and dressing percentage seen in pigs of similar live weight and P2 backfat that were derived from the outdoor herd or reared in deep-litter pens also has important implications for the pig industry if comparable increases occur under commercial conditions. Further work is therefore required to investigate whether carcass composition and dressing percentage can be manipulated by housing system and to determine causal mechanisms. The use of creep feed low in plant material and digestible nutrient content to stimulate eating behaviour without adverse consequences also deserves further consideration. Lastly, the finding of surprisingly low Hb levels in piglets from high-parity dams requires confirmation in further studies on commercial farms to determine whether Fe reserves of piglets at birth decline with increasing dam parity.

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