THE EFFECT OF GROUP SIZE AND FLOOR-SPACE ALLOWANCE ON THE EFFICIENCY OF LYSINE UTILISATION BY GROWING PIGS

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PREFACE

The experimental work described in this dissertation was carried out in the Discipline of Animal and Poultry Science, School of Agricultural Sciences and Agribusiness, University of KwaZulu-Natal, Pietermaritzburg, from January 2002 to May 2005, under the supervision of Professor Rob Gous.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others it is duly acknowledged in the text.

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ABSTRACT

Two experiments were conducted for this thesis, to determine whether an animal should be fed to its genetic potential in spite of this not being achievable due to an on-farm constraint.

The first experiment was designed to compare the response of pigs housed either individually or in groups to a range of feeds limiting in lysine between 40 and 85 kg live weight. Two hundred and eighty-eight entire male Large White × Landrace pigs were used. The experiment was divided into two growth periods, i.e. from 40 to 60 kg and from 60 to 85 kg. In each period, pigs were subjected to feed containing one of four dietary lysine concentrations. In Period 1, the lysine concentrations were 11.03 (L1); 9.54 (L2); 8.00 (L3) and 6.51 (L4) g/kg, while in Period 2 these were 7.82 (T1); 6.71 (T2); 5.55 (T3) and 4.40 (T4) g/kg. Pigs fed an L1, L2, L3 or L4 diet in Period 1 were fed a T1, T2, T3 and T4 diet in Period 2, respectively. Three buildings provided the following group sizes and floor-space allowances: House 1 contained eight pigs per pen at 1.94 m^2/pig; House 2 contained four or eight pigs per pen at 1.72 or 0.86 m^2/pig; and House 3 contained one pig per pen at 1.72 m^2/pig. The individually-housed pigs were divided into three feeding levels, i.e. *ad libitum*, or pair-fed so that feed intakes would match those of *ad libitum*-fed pigs housed in groups of either 4 (restricted-4) or 8 (restricted-8) pigs per pen in House 2. For all group sizes, feed intake increased linearly as the dietary lysine content increased. However, this increase was significantly lower for 8, when compared with 1 and 4 pigs per pen. The linear increase in feed conversion efficiency with dietary lysine content was similar for all group sizes. However, at any dietary lysine concentration, pigs housed in groups of 8 had significantly higher efficiencies than the pigs housed individually or in groups of 4. Average daily gain increased linearly as lysine intake increased, this increase being the same for all group sizes. However, pigs in smaller groups grew significantly faster than those in larger group sizes for any lysine intake. Protein and lysine retention were unaffected by group size, increasing linearly as lysine intake increased. The efficiency of lysine utilisation (0.45) was not impaired by group size. The pair-fed pigs housed individually (restricted-4 and -8) consumed significantly less feed than the individually-housed pigs fed *ad libitum*, and this was reflected in their average daily gains, which increased linearly as lysine intake increased, but with the restricted-8 growing significantly slower than the *ad libitum* or restricted-4 pigs. In all three treatments feed

conversion efficiency increased linearly with dietary lysine content, although the restricted-4 and -8 had significantly higher efficiencies than the *ad libitum*-fed pigs at any dietary lysine content. Protein and lysine retentions were unaffected by feeding level and increased significantly with lysine intake. However, at any lysine intake the restricted-8 pigs had a significantly lower efficiency of lysine utilisation than the *ad libitum* or restricted-4 pigs. The pigs with floor-space allowances of 0.86 and 1.94 m^2/pig consumed significantly less and grew slower than the pigs with floor-space allowances of 1.72 m^2/pig at any dietary lysine content. Feed conversion efficiency was unaffected by floor-space allowance and increased significantly with dietary lysine content. Similarly, protein and lysine retentions were unaffected by floor-space allowance and increased linearly as lysine intake increased. The efficiency of lysine utilisation (0.45) remained unaffected by floor-space allowance. It was concluded that when animals are socially stressed, feeding according to the requirement for maximum protein growth produces the best biological performance and carcass composition, with the corollary that, if profitability and biological efficiency is to be maximised, pigs housed in stressful conditions, or those whose future performance is predicted to be below potential because of external stressors, should not be given feed of an inferior quality.

The second experiment was designed to determine the extent to which grouping or floor-space allowance would alter the nutrient content of feed chosen by pigs given a choice of two feeds differing in protein: energy ratio between 40 to 85 kg live weight. Three hundred and eighteen entire male Large White × Landrace pigs were used. Two buildings provided the following group sizes and floor-space allowances: House 1 contained nine and eighteen pigs per pen at 1.72 or 0.86 m^2/pig; House 2 contained four, nine and fourteen pigs per pen at 1.72; 0.86 or 0.49 m^2/pig. Animals were given simultaneous *ad libitum* access to a high (236 g protein/kg as fed) and a low crude protein feed (115 g protein/kg as fed) in two hardened plastic self-feeder bins placed side-by-side. A training period of six days was used prior to the start of the trial, during which the two feeds were alternated daily. The reduction in the proportion of high protein feed chosen over time was significantly higher for the groups of four and eight, in comparison to the groups of nine and eighteen, contrasting with the steady increase for the groups of fourteen pigs. Similarly, the significant increase for pigs with floor-space allowances of 0.49 m^2/pig differed from the significant decrease for pigs with floor-space allowances of 0.86 and 1.72 m^2/pig. Pigs housed in larger group sizes and smaller floor-space allowances consumed

significantly less and grew slower than pigs housed in smaller group sizes and larger floor-space allowances. However, the feed conversion efficiency remained unaffected by group size and floor-space allowance. The non-significant effect on protein retention with increasing group size contrasted with the significant increase associated with increasing floor-space allowance. The results of the two studies were compared to determine whether pigs chose differently depending on the degree of stress and the implication of this choice. Average daily gain was significantly reduced as the group size increased for pigs fed a fixed lysine content and choice-fed. However, this reduction was less severe with choice-feeding than when feeding a fixed lysine content. Increasing the group size significantly reduced the feed intake in pigs fed a fixed lysine content only. The efficiency of protein utilisation remained unaffected as the group size increased for the pigs fed a fixed lysine content. However, at any group size pigs fed lower lysine contents had higher efficiencies than pigs fed higher lysine contents. On the contrary, increasing the group size significantly increased the efficiency of protein utilisation in choice-fed pigs. The average daily gain and feed intake was significantly improved as the floor-space allowance increased but was similar for pigs fed a fixed lysine content and choice-fed. Although the efficiency of protein utilisation remained unaffected by increasing the floor-space allowance for the pigs fed a fixed lysine content and pair-fed, at any floor-space allowance pigs fed higher lysine contents had higher efficiencies than pigs fed lower lysine contents. The results indicate that providing socially stressed pigs a choice between an appropriate pair of feeds differing in protein: energy ratio, does not overcome the reduction in potential growth, but does result in performance similar to that of pigs fed a fixed lysine content. It was concluded that the social stress of grouping or floor-space allowance has no influence on the ability of the animal to select an appropriate dietary combination allowing the expression of potential growth within the constraint(s) of the production system.

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CHAPTER 1

GENERAL INTRODUCTION

The intensive and competitive nature of pig production is reliant upon genetic selection programmes to improve productive traits such as growth rate, feed conversion efficiency and the proportion of lean in the gain, whilst minimising feed intake and facility cost per unit of pork produced. The potential growth rate of an animal is determined by genotype, nutrition and environment and despite genetic improvement and progress, this is still not often realised. It is highly unlikely that the environment remains non-limiting throughout the production cycle, as disease challenges, environmental temperature, feeder space, social stresses and stocking density impinge on feed intake and ultimately divert nutrients from maintenance and growth. It is well established that group-penned pigs fail to satisfy their inherent growth potential, as they consume less feed and grow more slowly in relation to individually-penned pigs housed under similar conditions. Consequently, it has sometimes been suggested that under circumstances in which the potential of the animals is likely to be constrained in some way the amino acid content of the feed offered should be reduced thereby cutting back on feed costs and perhaps salvaging a little more profit from the enterprise.

However, another school of thought maintains that even though performance is likely to be reduced through environmental insults, the pigs would perform better and more efficiently on the best quality feed. Hence, these contradictory and inconsistent views have established the need for further research on the nutritional management of commercially housed pigs.

In an attempt to reduce the inherent growth potential of an animal in a non-evasive and non-threatening manner using the existing infrastructure, current management practices and relatively disease-free environment, group size and floor-space allowance were chosen as stressors. Two investigations were conducted. The first was to determine whether it was economically feasible to reduce the amino acid content of a feed when the genetic potential is unlikely to be realised due to an on-farm constraint. The response to increasing intakes of an essential amino acid, using the summit-dilution technique, was used to measure the consequences of housing growing animals in increasingly stressful conditions.

The responses measured were used to calculate the efficiency of utilisation of the test amino acid, thereby determining the effect of the stressor on this efficiency. The second area of investigation was designed to determine to what extent the social stresses of grouping and floor-space allowance would alter the combination of feeds chosen by pigs given a choice of two feeds differing in protein: energy ratio.

The reduction in the potential growth rate associated with increasing group size and decreasing floor-space allowance in growing-finishing pigs has been extensively researched. However, the lack of informed knowledge on whether nutritional management might counteract or negate this effect, or whether a feeding programme should be adjusted to account for such stresses, highlights the need for research on this topic. This thesis was designed to investigate if a pig should be fed according to its genetic potential even if this is not achievable due to one or more on-farm constraints. The results of this investigation should provide the basis for informed nutritional management of socially-stressed pigs.

CHAPTER 2

LITERATURE REVIEW

2.1 AMINO ACIDS IN PIG NUTRITION

Proteins are complex organic compounds of high molecular weight containing carbon, hydrogen and oxygen (McDonald *et al*., 1995). Nitrogen is the major functional element in protein and links amino acids together to make up protein (Whittemore, 1998). The provision of proper nutrients is essential as the construction of absorbed dietary amino acids into pig protein is an energy expensive process (Whittemore, 1998).

Pigs obtain amino acids from the proteins in the feedstuffs consumed, released during digestion and absorption (Lewis, 2001). The protein content of a feed is estimated from its nitrogen content, as proteins contain nitrogen in fixed proportions (SCA, 1987). Although proteins are considered essential dietary constituents, it is not the proteins *per se*, rather their components, amino acids, that are essential ingredients (Lewis, 2001). This distinction is important, as young pigs fed on a feed containing no protein but appropriate amino acid mixtures still gain weight (Chung and Baker, 1991).

Amino acids are required in the body: to replace proteins lost as a result of protein tissue turnover (maintenance); manufacture body enzymes and replace intestinal epithelial cells and synthesise various gut secretions; and for the deposition and retention in lean tissue growth (Whittemore, 1998).

2.1.1 Essentiality of amino acids

Twenty primary amino acids occur in proteins and not all of these are essential dietary components (NRC, 1998). The chemically reactive groups characterising the various amino acids and synthesis of non-essential amino acids by simple transamination or more complex reactions of metabolites, from oxidation products of glucose or, as arginine from the urea cycle is illustrated in Figure 2.1 (Boisen, 2003).

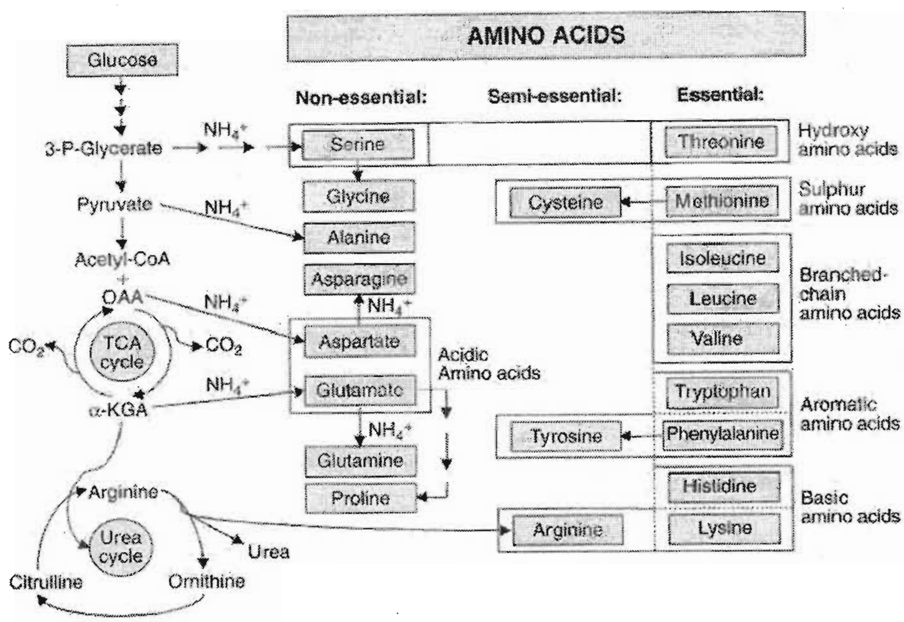

Figure 2.1 *Essential amino acids and synthesis of semi-essential and non-essential amino acid (after Boisen, 2003).*

2.1.2 Essential, non- and semi-essential amino acids

Nine core amino acids (essential or indispensable) are required for maintenance and productive purposes by higher animals, which are unable to synthesise the corresponding carbon skeleton or keto acid, making the provision of these nutrients mandatory (D'Mello, 2003a). The remaining amino acids (non-essential or dispensable) are synthesised using carbon skeletons derived primarily from glucose and other amino acids present in excess of the requirement (NRC, 1998).

In certain situations, but not others, semi-essential amino acids are essential dietary components (Lewis, 2001). Arginine is synthesised at an inadequate rate to meet the requirement of the rapidly growing young pig, resulting in only 0.6 of the maximum growth rate being achieved (Fuller, 1994). Dietary supplementation is required, as the vast majority of arginine synthesis in the urea cycle is catabolised in the liver by active arginase within this pathway, resulting in insufficient arginine being exported for the rapid growth of extra hepatic tissue (D'Mello, 2003a). The dietary supply of arginine appears to be used in surplus to requirement in practical piglet feeds and a possible insufficiency is no cause for concern (Boisen, 2003). Tyrosine and cysteine are considered conditionally essential as pigs have the enzymes present for the hydroxylation of phenylalanine to form tyrosine and for more complex trans-sulfuration pathways, by which cysteine is formed from methionine and serine (Fuller, 1994). An undersupply of cysteine and tyrosine is compensated by an oversupply of methionine and phenylalanine, but cysteine and tyrosine cannot compensate for an undersupply of methionine and phenylalanine respectively (Boisen, 2003).

Dietary nitrogen, supplied exclusively in the form of essential amino acids, results in high-yielding animals failing to achieve their genetically determined potential and although animals have specific dietary requirements for essential amino acids, some combination of dispensable amino acids should be provided to maximise performance (D'Mello, 2003a).

2.1.3 Amino acid balance (protein quality)

The single most important factor affecting the efficiency of protein utilisation is the dietary balance of amino acids (Van Lunen and Cole, 2001). The ideal protein concept was a major breakthrough in understanding the amino acid requirements, as it contained all the essential amino acids in the correct balance or proportions and correct ratio of essential to non-essential amino acids (Batterham, 1994).

The major difference between pigs of different classes (i.e. breed, sex and live weight) was thought to exist in the amount of protein required relative to potential lean meat deposition. However, the relative amounts of the different essential amino acids required for 1 g protein deposition would be the same in each instance (Van Lunen and Cole, 2001). Although different quantities of protein would be required for pigs of different classes, the quality would be the same in each case (Cole, 1980). This relationship only applies if the composition of the ideal protein is not influenced by the relative needs of maintenance, growth or a changing composition of lean tissue deposited (Cole, 1980).

Lysine was chosen as a reference, as it is required in large amounts for protein deposition and often the first limiting amino acid in cereal based pig feeds (Batterham, 1994). The necessity for lysine, together with leucine is higher than for any other amino acids, since lysine does not contribute quantitatively to any specific functions other than protein synthesis (Boisen, 2003). According to Batterham (1994) the ideal ratio of essential amino acids relative to lysine is much easier to estimate than the individual requirements of nine essential amino acids for different growth phases. This improved the accuracy of amino acid research, as experimental feeds were unlikely to be limiting in amino acids other than test amino acids, providing common ground when comparing estimates of amino acid requirements worldwide, which prevented misleading results (Batterham, 1994).

Precisely translating the animal's tissue requirements to the dietary level requires nutritional evaluation of dietary ingredients expanded to include protein digestibility and availability of all essential amino acids (Campbell *et al.*, 1988a).

2.1.4 Amino acid disproportions

Reduced animal performance is sometimes due to deviations from the pattern of amino acids of ideal protein (Lewis, 2001). Apart from amino acid deficiencies and excessive protein intake, three types of disproportions exist namely: amino acid toxicities, antagonisms and imbalances, resulting in adverse effects (Harper *et al.*, 1970). Amino acid toxicity is rare in pig nutrition and may be precipitated by ingesting excess quantities of individual amino acids by virtue of particular structural or functional properties (Lewis, 2001; D'Mello, 2003b). Antagonisms are deleterious interactions between structurally similar amino acids (D'Mello, 2003b). Imbalances are characterized by excessive intake(s) of (an) amino acid(s), with lesser disproportion and no specified toxic features, which are usually caused by the exacerbation of the deficiency of the most limiting amino acid, and corrected by the appropriate addition of the amino acid (Lewis, 2001).

The single largest cost in producing pork is feed, influencing both biological and economic efficiency (Close, 1994). Appropriate feeding strategies need to be employed to ensure optimum feed utilisation, requiring knowledge about the growth and development, requirements for and responses to nutrients by pigs (Close, 1994). Protein-amino acid metabolism and nutrition studies demonstrate that protein and amino acid requirements are functions of the metabolic demand of the animal's tissue and processes within them, which will determine how efficiently or inefficiently the feed satisfies metabolic demand (Bequette, 2003). Amino acids play an important role in pig nutrition as the final amount deposited and retained by the pig is greatly influenced by the balance contained in the feedstuff protein (Whittemore, 1998).

2.2 AMINO ACID REQUIREMENTS OF GROWING PIGS

The animal nutritionist seeks to maximise the productivity in growing, lactating and egg laying animals and consequently amino acid requirements are largely focused on the composition of protein accreted or secreted (Bequette, 2003). A 'nutrient requirement' may be described as the point on a dose-response curve relating a level of nutrient intake and some measure of productivity or indicator of metabolism (Moughan and Fuller, 2003). Generally, they pertain to animals of specific ages and specific physiological functions, thus their accurate evaluation and determination is essential to economic and productive efficiency (Baker, 1986; Lewis, 2001). The simple flow diagram (Figure 2.2) describes the amino acid requirements of the pig (or any other species).

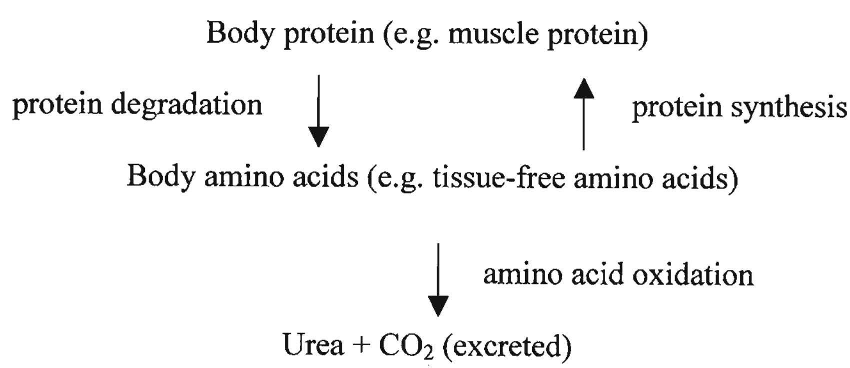

Figure 2.2 *Amino acid requirements showing protein degradation, protein synthesis and amino acid oxidation (after Baker, 1993).*

Protein degradation, protein synthesis and amino acid oxidation are continuous processes and 0.6 (young animal) to 0.8 (adult animal) of the amino acid requirement for body protein synthesis comes from endogenous protein degradation, with the remainder requiring supplementation in the feed (Baker, 1993). Individual amino acids are depleted via amino acid oxidation from tissue pools at varying rates (lysine - slow and methionine - fast) and the assumption that the amino acid composition of muscle tissue is predictive of dietary amino acid patterns is invalid (Baker, 1993).

Ultimately the amino acid requirements should be expressed as a rate (g/d) instead of a dietary concentration (g/kg), which is only relevant when some rate of feed intake is assumed (Fuller and Wang, 1987). The amino acid requirements of growing pigs are determined by many factors such as protein quality, feed intake and feed composition, genotype, sex, body composition and criterion of response, and various approaches have been employed to address these.

2.2.1 Protein quality

The adequacy of a dietary protein concentrate is determined by the quantity and quality of the protein (digestibility and availability), the latter being a function of the amino acid profile (NRC, 1998).

The perception that amino acid requirements increase as a linear function of protein content is well illustrated in the literature (Becker *et al.*, (1957); McWard *et al.*, (1959); Klay (1964); Sowers and Meade (1972); Boomgaardt and Baker (1973a, b)), despite most of the studies upon which this was based, feeding protein from sub-adequate to super-adequate levels (Boomgaardt and Baker, 1973a).

Morris *et al.* (1999) using chicks, re-evaluated this hypothesis in an attempt to explain the observed response in terms of known nutritional effects and considered the following possibilities: (1) response to a critical amino acid limited by an energy deficit, (2) heat disposal by chicks limited by the experimental environment, (3) use of live weight gain rather than protein retention as a response measure, (4) available amino acid content lower than assumed, (5) nutrient(s) other than the amino acid under investigation limiting performance, and (6) amino acid imbalance.

The papers reviewed by Morris *et al.* (1999) suggested that the excessive supply of protein in the feed (i.e. imbalance) resulted in the efficiency of utilisation of the first limiting amino acid being impaired and the degree being dependent on the protein concentration. They proposed that unless a proportional adjustment to the prescribed minima for amino acids likely to be present in limiting proportions is made, feed formulation programmes need to be modified to prevent surplus protein being included in the solution. In developing countries where a variety of protein and amino acid supplements are scarce, this is especially important.

Kyriazakis and Emmans (1992a) demonstrated the efficiency of protein utilisation at low protein intakes was independent of energy intake and at high protein intakes significantly affected by the level of energy intake, decreasing as the amount of energy in the feed decreased i.e. when energy is limiting, the efficiency of protein utilisation is directly proportional to the energy: protein ratio in the feed.

Commercially, nutritionists formulate 'balanced' feeds using the least-cost feed formulation principle, which predetermines the minimum levels for certain amino acids and crude protein, ignoring any surpluses as they are uneconomical and biologically wasteful (Morris *et al.*, 1999).

2.2.2 Feed intake and feed composition

Kyriazakis and Emmans (1999) posed the dilemma of whether the pig grows because it eats or eats because it grows, in a review of existing approaches to predict feed intake. It is well established that the animal's inherent growth plan (size, potential lipid-free empty body growth rate and desired fatness) motivates its feed intake, providing a mechanism for animals to achieve their requirements for a number of resources e.g. energy and other nutrients (Kyriazakis, 1994).

Emmans and Oldham (1988) proposed desired feed intake as the rate at which an animal seeks to eat in order to meet its requirement for the first limiting resource. The feed and environment must be conducive to the desired feed intake if the animal is to achieve the potential rate of protein gain. If energy is the first limiting resource, desired fatness is attained; if not (e.g. protein or an amino acid) and desired feed intake is achieved, extra energy eaten is converted to excess lipid and excess protein deaminated. In addition to feeding regime (restricted and pair-feeding) impinging on feed intake, two other constraints operate: the feed's bulk or other properties and the "hotness" of the environment limiting the rate at which the animal can eat and lose heat respectively, resulting in the actual feed intake being achieved. This approach in predicting growth and voluntary feed intake in different species is summarised in Figure 2.3.

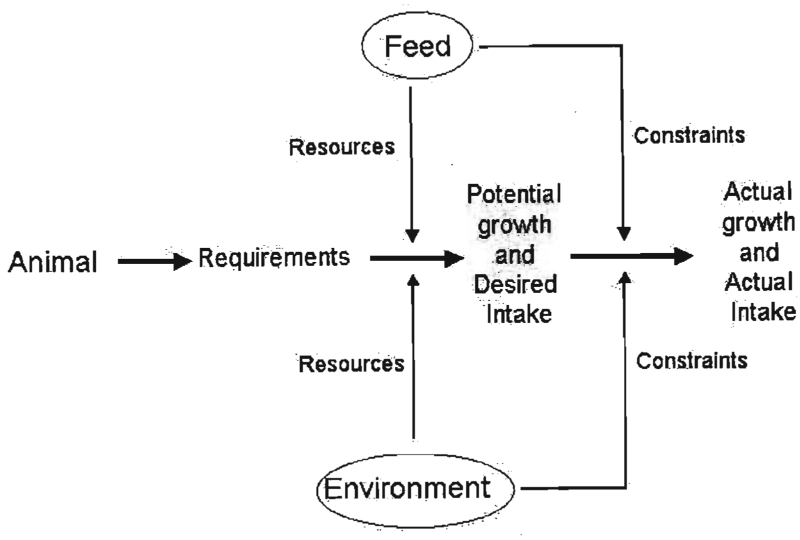

Figure 2.3 *A systems approach for predicting growth and voluntary feed intake in growing pigs (after Ferguson, 2001).*

As the growth period progresses, energy requirements increase faster than protein requirements, if dietary amino acid concentrations are not decreased to match this change in nutrient requirements, amino acid intakes will be in excess of the requirement (Bradford and Gous, 1991a). Once the requirement for a nutrient has been satisfied, there is no merit for further intake as this is a wasteful, costly means of providing energy, overloading the deaminating system of the animal causing heat stress in hot environments (Kyriazakis *et al.*, 1990; Bradford and Gous, 1991a).

Formulating feeds to satisfy the daily requirements of a growing pig would be ideal in meeting the systematic changes for maintenance and growth, yet impossible to implement successfully and economically (Bradford and Gous, 1991a, b). Production units generally feed a grower and finisher feed from weaning to slaughter with the composition remaining constant, this results in the young pig being unable to obtain sufficient limiting nutrients to satisfy its needs without over-consuming other nutrients (Bradford and Gous, 1991a).

As the dietary protein concentration is decreased, the animal increases its feed intake, in an attempt to meet its amino acid requirement (Wyllie *et al.*, 1969; Campbell and Biden, 1978; Baker, 1986; Kyriazakis and Emmans, 1990; Kyriazakis *et al.*, 1990; Kyriazakis and

Emmans, 1991; Kyriazakis *et al.*, 1991). If the increase in intake is insufficient, the growing animal fails to achieve its full growth potential and after a period of inadequate nutrition it usually has a lower protein weight with lipid weight varying, compared to a similar pig treated in a non-limiting way at the same protein weight (Kyriazakis *et al.*, 1991).

In order to achieve its inherent growth plan, the immature animal has a set of requirements for a number of resources satisfied through its feed intake (Kyriazakis, 1994). In addition to the feed and environment (inter-related) providing resources enabling the animal to successfully achieve its growth potential, they are also sources of constraints preventing this (Emmans and Oldham, 1988). Therefore, the pig seeks to eat because it seeks to grow, but if unsuccessful it will grow according to what it eats (Kyriazakis and Emmans, 1999).

2.2.3 Body composition

Growth is fuelled by the provision of sufficient nutrients and large differences exist between genotypes in successfully growing and efficiently converting dietary nutrients (energy, protein and amino acids) into carcass gain (Close, 1994). Genetic improvements and stricter control over all aspects of pig production have resulted in animals being fed more precisely, according to improved estimates of nutrient requirements for particular populations (Fuller, 1994). In order to accurately determine amino acid requirements and hence predict responses, an interaction between the dietary nutrients and genetic potential of the animal needs to be addressed (Close, 1994).

It is widely accepted the requirement for most essential amino acids, expressed as a proportion of the feed, decreases as the animal gets older and subsequently protein requirements for maximal growth decrease with age (Boomgaardt and Baker, 1973b). In growing animals, feed consumption is largely associated with increments in protein and lipid formation, unlike mature animals, where variations cause changes in body composition largely confined to fat content (Close *et al.*, 1978). The linear increase in protein retention to feed intake occurs until a maximum is attained and plateaus thereafter (Whittemore, 1998).

The potential for maximum protein retention is influenced by the sex and genotype of the animal concerned (Van Lunen and Cole, 2001). Sex differences in the ability to retain dietary nitrogen result in the capacity for muscle synthesis of the boar being higher than the gilt, which is, in turn, higher than the castrated male, leading to increased protein requirements (Yen *et al.*, 1986a). Improved genotypes, possessing the ability to deposit protein tissue at a higher rate than conventional genotypes, respond to increasing dietary protein levels, in comparison to unimproved genotypes (Baker and Speer, 1983). Thus, restricting the intake of dietary protein hinders the protein retention (Baker and Speer, 1983; Van Lunen and Cole, 2001).

Prior to improved genotypes, restricted feeding was employed especially during the finisher phase in an attempt to reduce growth rate, maximise protein content and carcass quality as *ad libitum* feeding resulted in increased lipid retention with no further increase in protein retention (Van Lunen and Cole, 2001). Genetic improvements have modified previously accepted theories and feeding strategies, discouraging feed restriction as voluntary feed intake has declined and improved genotypes have lower appetite levels compared to conventional genotypes (Van Lunen and Cole, 2001).

Whittemore (1998) attempted to explain the growth response to feed supply through the following propositions: Under non-limiting conditions, the animal prefers to target for protein whilst maintaining a minimum level of fat in normal live weight gain and during the linear phase for protein growth, lipid deposition is limited to a minimum level. Animals with higher lean tissue growth potentials are capable of consuming more feed, thus improving feed efficiency, with no increase in fatness. Entire males of an improved genotype will not fatten, as their appetite in relation to protein growth rate is low. Initially growth and not fatness is enhanced through selecting for greater appetite, but as the lean potential is approached further selection for appetite results in fat pigs.

The intensive and competitive nature of pork production demands that the producer maximise body weight gain in specific facility and period, minimising the facility cost per unit of pork produced (Kornegay and Notter, 1984). The use of improved genotypes capable of high lean tissue growth rates at lower voluntary feed intakes has changed the nutritional and environmental management of growing pigs (Schinckel, 2001).

2.2.4 Criteria of response

Protein quality, feed intake and feed composition, genotype, sex and body composition have all been implicated in determining the amino acid requirements of growing pigs thus far. From this it is established that the 'requirement' for an amino acid can be defined in numerous ways: maximum protein growth, maximum growth rate, maximum feed conversion efficiency, body composition, metabolic response and ultimately maximum profit.

To be able to use any of these criteria, the nutritionist requires information on the rate an animal in a given class and well-defined nutritional and environmental context responds to incremental inputs of the amino acid (Morris, 1983). In addition, the effect on voluntary feed intake and protein retention also needs to be considered. This knowledge enables the nutritionist to determine the marginal cost and value of extra output, enabling the optimum dose to be calculated (Morris, 1983).

Therefore, in order to accurately determine amino acid requirements and develop feeding strategies for growing pigs within their appetite potential, a quantification of potential growth and protein retention is required (Close, 1994). Although this is adequately described by biological constants and mathematical equations, it must acknowledged that actual growth and protein retention are directly influenced by level of nutrient intake achieved at any particular time (Whittemore, 1998).

2.3 FACTORS INFLUENCING THE RESPONSE IN GROWING PIGS TO DIETARY AMINO ACIDS

The nutritionist strives to formulate a 'balanced' feed, allowing the animal to utilise the nutrients (energy, protein and amino acids) provided efficiently for maintenance and growth. However, under commercial conditions it is highly unlikely that the growing conditions remain non-limiting, with constraints impinging on feed intake, ultimately diverting nutrients from maintenance and growth.

In attempting to determine the response of growing pigs to dietary amino acids, several approaches have been employed namely: empirical (graded supplementation or diet dilution technique) and factorial methods. D'Mello (2003c) suggested that the factors influencing the response of an amino acid separate into those influencing the feed intake and those reducing the efficiency of utilisation with the difference evident when the response is compared in relation to intake. If a smooth and full response curve is to be generated in determining optimum performance, the consequence of undersupply and oversupply needs to be established when examining the response to an individual amino acid (Taylor *et al.*, 1979).

The previous section highlighted the importance of accurately evaluating and determining the amino acid requirements of growing pigs, if economic and biological efficiency for both producer and animal is to be achieved. Likewise, the factors influencing the response of growing pigs to dietary amino acids are equally important. This knowledge has significant implications for the nutritional and environmental management of growing pigs, enabling the producer to maximise the response of the animal within the limit of the constraint(s) present.

2.3.1 Feed-intake mediated factors

2.3.1.1 Environmental temperature

In addition to environment influencing the voluntary feed intake and growth of an animal (through heat exchange), the prevailing thermal environment also affects the energy partitioning between that retained as growth and that dissipated as heat and ultimately lost to production by the animal (Close, 1981).

The range of ambient temperatures, where heat loss is minimal and energy retention maximal (thermoneutral zone - lower limit defined as lower critical temperature) should be determined, as variation on either side results in the activation of thermoregulatory mechanisms affecting energy metabolism (Noblet *et al.*, 2001). The reduction in ambient temperature below the lower critical temperature results in energy expenditure increasing and voluntary feed intake increasing (delayed) to balance additional heat loss, whereas temperatures above the evaporative critical temperature results in voluntary feed intake decreasing (Black *et al.*, 1999). Thus animal, nutritional and environmental factors all influence the thermoneutral zone (Close, 1981). The extent to which temperatures below the critical level cause increases in energy required for maintenance and thermoregulation is informative in indicating what reduction in growth can be expected (Close, 1981).

According to Verstegen *et al.* (1973) the rate of heat loss from an animal is not only associated with body size and thermal insulation, but plane of nutrition and environmental temperature as well. They explained that the environmental temperature determines which of the two factors is important: in the zone of thermoneutrality the plane of nutrition is important and higher heat losses occur at higher levels of feeding, whereas below the critical level, heat loss is dependent on environmental temperature, and the plane of nutrition has no bearing.

The results of Ferguson and Gous (1997) and Ferguson *et al.* (2000a, b) demonstrate that, as environmental temperature decreases, pigs on poor quality feeds increase their feed intake in an attempt to maintain an adequate dietary protein intake, which may or may not be sufficient to allow the expression of genetic potential because of their increased ability to lose heat. However, a point is reached as protein concentration decreases still further, where the animal is no longer capable of compensating (heat loss dependent on environmental temperature) for the decrease by increasing voluntary feed intake (Ferguson and Gous, 1997). Ferguson *et al.* (2000b) observed feeding severely deficient feeds resulted in reduced feed intakes, irrespective of environmental temperature, suggesting intake reached a maximum, then declined as lysine levels decreased. They attributed this to maximum physical gut capacity (at low temperatures) and/or maximum heat loss (at high temperatures).

Kyriazakis and Emmans (1991) suggested that the use of high environmental temperatures, both commercially and experimentally for *ad libitum*-fed pigs, may constrain growth rates. Hence, the importance of knowing how the thermal environment influences voluntary feed intake, nutrient utilisation and performance cannot be reiterated further.

2.3.1.2 Immunological stress

Throughout their natural life, pigs are susceptible to infection by pathogenic microorganisms causing reductions in voluntary feed intake and ultimately growth as nutrients are redirected to support the defence against them (Johnson *et al.*, 2001).

An earlier experiment by Webel *et al.* (1997) indicated that stimulating the immune system of the pig resulted in the plasma cytokines and cortisol levels to increase implicating them in the reduction of feed intake, protein retention and growth in immunologically-stressed animals. A subsequent increase in the plasma urea nitrogen following the increase in cytokines and cortisol led them to conclude that immunological challenge induces protein degradation.

Williams *et al.* (1997a, b, c) demonstrated that pigs with a low level of chronic immune system activation (healthy) had greater feed intakes, body growth rates, efficiency of feed utilisation and protein retentions compared with counterparts with a high level of chronic immune system activation (sick). Although healthy pigs required higher dietary lysine concentrations and greater lysine intakes to achieve maximum protein retention compared to sick pigs, this was the result of a greater capacity for protein retention and not changes in the efficiency of lysine utilisation.

Thus the challenge herein lies to try and minimise immunological stress throughout the lifespan of the pig to allow it to express its inherent growth potential by ensuring that it is fed according to its biological potential irrespective of its immune status.

2.3.1.3 Sex and Genotype

The sex and genotype of an animal determine the extent to which an increase in feed allowance will influence growth and fattening (Whittemore, 1998). A series of experiments by Batterham *et al.* (1985), Giles *et al.* (1986) and Giles *et al.* (1987) demonstrated that females have a lower capacity for protein retention in comparison to males. Restricting feed intakes, and consequently amino acid and energy supply, resulted in both sexes being unable to attain maximum protein retention. Although *ad libitum* feeding resulted in both sexes being able to consume sufficient nutrients to satisfy maximum protein retention, the marginal response of females to increasing lysine concentration suggested a lower capacity for protein retention. Campbell *et al.* (1988b) suggested that production efficiency for maximum growth in both sexes throughout the growing-finishing period could be improved through adjustments in protein and amino acid concentrations.

Whittemore (1998) explained that at any feed intake allowance castrates are inherently fatter than entire males and pigs selected for their lean capacity will be less fat than unselected pigs. Consequently the pig inherently discriminating against fat deposition is more efficient, requiring less feed (higher lysine requirement) for a given growth rate response (maximum protein retention) in comparison to a counterpart, which is less efficient, requires more feed (greater amount of lysine) and has a predisposition to fatten.

Although Giles *et al.* (1986) suggested the potential for separate sex feeding and lowering the lysine (and other amino acid) concentration in female feeds, ultimately this decision is determined by practicality and economic efficiency.

2.3.1.4 Energy intake

Maintenance and growth require energy and protein, and excesses are stored as fat and deaminated, respectively (Van Lunen and Cole, 2001). A deficiency in dietary protein and energy will result in lean tissue growth responding to increasing protein and energy intake, respectively. The nutritionist should seek to formulate a feed supplying adequate proportions of protein and energy for lean and lipid gain to be maximised and minimised, respectively (Batterham, 1994).

Schinckel (1999) alluded to the widely accepted perception of a linear relationship between protein retention and energy intake, which is apparent when other nutrients are non-limiting. This suggests that energy intake is greater than that needed for maintenance and less than that required for maximum protein retention. Lean growth efficiency increases linearly at increasing energy intake until a maximum is reached, whereafter a plateau occurs, which is achieved when the energy requirement for maximum growth is attained (Schinckel, 2001). Energy intakes above the maximum protein retention requirement will result in a quicker decrease in lean growth efficiency, unlike those below the maximum protein retention requirement (Schinckel, 1999).

During the growing phase (up to 50 kg live weight) the inherent capacity for protein retention exceeds the ability to consume sufficient feed to satisfy protein synthesis (Lewis, 2001). However, during the finishing phase, feed and energy intake exceeds the necessity for protein retention and thus amino acid requirements for tissue synthesis are independent of energy intake (Lewis, 2001).

Whittemore (1998) explained that a narrow protein: energy ratio hinders lean growth especially at low feed intakes, although widening the ratio positively influences lean growth this can only be maximised once the correct ratio has been determined. An inadequate protein supply or excess feed allowance induces fatness, which may be corrected by widening the ratio or decreasing feed allowance (Whittemore, 1998). Providing feed intakes higher than required at any ratio results in pigs becoming fat (Whittemore, 1998).

The reduction in the lean growth rate at maturity and change in partitioning of energy intake results in the ratio of lean to fat gain decreasing at moderate energy intakes (Schinckel, 2001). Improved genotypes with high lean growth rate potentials respond to higher energy intakes by increasing their lean growth rate at lower live weights tend to have more fat and less lean deposition at moderate feed intakes (Schinckel, 2001).

If the pig is to attempt to express its inherent lean growth rate potential, then the feed intake and feed composition needs to be considered, especially under commercial conditions (Schinckel, 2001). Likewise, such pigs should be able to maintain high lean growth rates at heavier live weights improving the lean efficiency over the growing-finishing period (Schinckel, 2001).

2.3.2 Factors reducing the efficiency of lysine utilisation

The quantity of dietary amino acids supplied during any period is not all absorbed as body protein retention by the pig partly due to obligatory losses occurring (Fuller, 1994). In spite of all requirements being satisfied and amino acid supply increased, a 100% efficiency of amino acid utilisation is biologically impossible (Fuller, 1994).

The efficiency of lysine utilisation is less than 100% because lysine is lost during normal physiological processes of growth, conversion of lysine to methylated and hydroxylated derivatives, absorption of lysine in forms unsuitable for protein synthesis and lysine oxidation (Adeola, 1995).

If the pig is to retain one gram of body protein the feed needs to supply amino acids contained in the protein, as well as compensate additional amino acid losses occurring and collectively reducing the efficiency of amino acid utilisation (Fuller, 1994). The efficiency of protein utilisation provides no understanding about the efficiency with which individual amino acids are utilised or whether the efficiency of utilisation is equal to or better than that of individual amino acids (Chung and Baker, 1992).

Adeola (1995) explained that the efficiency of lysine utilisation could be expressed in two ways: the gross efficiency of lysine utilisation for carcass growth is the proportion of lysine consumed retained as carcass lysine plus that used for carcass maintenance and the net efficiency involves quantitative estimates of lysine concentration and digestibility.

The results of an experiment by Batterham *et al.* (1990) using Large White males and females from 20 to 45 kg live weight reported a 86% efficiency of lysine utilisation (ileal digestible lysine basis) indicating 14% of the apparently absorbed lysine was catabolised. Later, Adeola (1995) using crossbred (Yorkshire-Landrace-Hampshire-Duroc) castrates and gilts from 10 to 20 kg recorded a 72% efficiency of lysine utilisation (lysine intake basis) suggesting 28% of the dietary lysine was either undigested or catabolised after absorption. In trying to compare the efficiency of lysine utilisation, Adeola (1995) expressed the results of Batterham *et al.* (1990) on a total dietary lysine basis assuming 85% ileal lysine digestibility and found the efficiency to be 73%.

Additional research into the efficiency of lysine utilisation is required to improve the accuracy of predicting pig performance because of variation in the estimates of the efficiency of lysine utilisation (Adeola, 1995).

2.3.3 Effects of dietary lysine on carcass composition

It is well established that the dietary lysine concentration has variable responses on the carcass fat composition of growing pigs affected by factors such as: methodology of response (graded supplementation or diet dilution technique), physiological state, breed, strain, sex or environment (D'Mello, 2003c; Fuller, 1994).

The results obtained by Yen *et al.* (1986a - 50 to 90 kg live weight and 1986b - 25 to 55 kg live weight) of the dissection of the ham joint demonstrated significant differences in the tissue composition of fat between sexes (entire males, castrated males and gilts) in response to dietary lysine supply. In both experiments, the increase in dietary lysine concentration led to a subsequent decrease in the proportion of fat up to a maximum of 9.2, 7.3 and 8.7 g lysine/kg feed (1986a) and 10.4, 9.9 and 10.3 g lysine/kg feed (1986b) for entire males, castrated males and gilts respectively. Thus entire males had lower proportions of fat than castrated males whilst gilts were intermediate.

An experiment undertaken by Giles *et al.* (1986) established that the dietary lysine concentration, sex (entire male and female) and feed intake (*ad libitum* and restricted) significantly influenced the fat content in dissected carcasses examined. The *ad libitum*-fed males and females over the 20 to 50 and 50 to 85 kg live weight periods recorded the lowest fat content at 11.0 and 8.8 and 12.2 and 9.8 g lysine/kg feed, whilst the lowest fat contents in the restricted males and females were at 12.2 and 9.8 and 9.8 and 7.8 g lysine/kg feed respectively. However, Giles *et al.* (1987) noted a significant influence in fat content under *ad libitum* feeding with cereal (barley or wheat) and sex (entire male or female) but not dietary lysine concentration. With restricted feeding the carcass fatness decreased to a minimum with 12 g lysine/kg feed.

In contrast, Batterham *et al.* (1990), who also observed that increasing the dietary lysine concentration decreased the fat content, found the minimum fatness occurred at 10.7 g lysine/kg feed, with no difference between the sexes (entire male and female).

Thus, the response to amino acid concentration on carcass fatness is dependent on the extent of the deficiency, and any interpretation of this response requires the knowledge of the factors used in the determination (D'Mello, 2003c).

The amino acid requirements of growing-finishing pigs should be based on the potential protein growth rate of the genotype concerned. However, from the literature reviewed it is well established that the feed and environment provide resources and constraints, permitting or preventing the animal from achieving its inherent growth potential resulting in feed intake (lower requirement for amino acid) and potential protein growth rate being positively or negatively influenced. The potential protein growth rate is limited by a reduced amino acid intake and a physiological constraint. Commercially it is highly unlikely that the environment remains non-limiting throughout the growing finishing period with the exposure of 'stressors' such as disease challenges, environmental temperature, feeder space, social stress and stocking density. The next part of this literature review will focus on two such stressors, namely group size and floor-space allowance and their impact on the performance during the growing-finishing period. Thus, the challenge facing nutritionists and producers is how to work within the constraint(s) present in order to maximise the inherent growth potential from a financial and biological perspective.

2.4 EFFECTS OF KEY MANAGEMENT FACTORS ON GROWTH PERFORMANCE AND CARCASS CHARACTERISCTICS IN GROWING PIGS

Knowledge and understanding of the relationships between the environment, growth performance and carcass characteristics is fundamental to the production of quality pork. This information enables the nutritionist and producer to devise appropriate feeding and management strategies in making informed decisions for the production system to operate efficiently and profitably.

From the previous section it is clear that nutrition and the environment determine whether the potential growth rate of an animal is attained. From a behaviour and welfare standpoint, 'stress' is perceived to be another constraint in intensive production systems (Whittemore, 1998). Moberg (2000) defined stress "as the biological response elicited when an individual perceives a threat (stressor) to its homeostasis". The biological response to stress is divided into three stages: recognition of a stressor, biological defence against the stressor and consequence of stress response (Moberg, 2000).

Environmental stressors are known to influence the neural and neuroendocrine mechanisms involved in appetite control, consequently decreasing the voluntary feed intake and promoting muscle degradation and fat mobilisation (Baker and Johnson, 1999; Elsasser *et al.*, 2000; Matteri *et al.*, 2000). In addition the stress-induced reductions in voluntary feed intake result in a reduction in protein retention with a consequent reduction in the daily requirement for a specific amino acid (Baker and Johnson, 1999).

Chapple (1993) hypothesised that the stress experienced with maintaining social order in groups and with limited floor-space allowance, is mediated through biochemical factors that down-regulate tissue growth, lower nutrient requirements and reduce voluntary feed intake. In support of this, Ferguson *et al.* (2001) demonstrated that, when floor-space allowance per pig was reduced by increasing the number of pigs per pen, protein retention was constrained below the animal's potential irrespective of nutrient intake.

Therefore, environmental stress has been identified as one of the many factors responsible for the inability of the animal to achieve its potential growth. The main objective of the research reported in this thesis was to determine whether the amino acid content of the feed should be reduced when the potential growth rate of an animal is constrained in some way. Because environmental stress has been shown to reduce the performance of pigs, and because these are non-evasive stressors, social stresses (group size, feeder space allowance and floor-space allowance) will be used in this investigation to reduce the potential growth rate of the animal. The information gathered from this investigation would be of value when formulating feeds for growing pigs that are known to have a higher potential than they can achieve because of factors constraining their growth potential.

2.4.1 Effect of group size on pig performance during the growing-finishing period

The competitive and intensive nature of any production system requires the producer to maximise output and minimise input to achieve both economic and biological efficiency. In a comprehensive review of research undertaken at the University of Illinois, Wolter and Ellis (2002) alluded to the widely accepted approach of large integrated production systems and modifications in the design and management for growing-finishing pigs, creating opportunities for similar age and/or size groups. Consequently, pigs in larger groups have more total space and a greater degree of choice over their microenvironment than pigs in smaller groups (Spoolder *et al.*, 1999).

The feasibility of rearing growing-finishing pigs in large groups is a contentious issue and objections based on performance variables, carcass characteristics and social behaviour have been raised. For the remainder of this review the growing-finishing period is the focus, as it encompasses the range of maximum protein deposition and is not sufficiently large in reducing the accuracy of determining the protein retention in spite of the changes that take place over time, especially maintenance.

2.4.1.1 Individual compared with group penning on performance variables and carcass characteristics during the growing-finishing period

It is widely accepted and clearly illustrated that group penning has an unfavourable effect on the performance variables and carcass characteristics of growing-finishing pigs, which are considerably lower than individually penned pigs treated similarly (Black *et al.*, 2001).

The performance variables collected over eight experiments, and reviewed in this section, are summarised in Table 2.1, indicating the variable yet consistent degree to which group penning reduces feed intake and growth. However, two experiments are questionable, namely, Chapple (1993) who reported no statistical analysis to support his argument and Nielsen *et al.* (1996) who allowed group penning to occur prior to individual penning so this cannot be considered a simultaneous comparison of penning arrangements.

The results of all experiments except Chapple (1993), indicate that individually penned pigs have significantly higher growth rates than group penned pigs, which have significantly lower feed intakes (Spicer and Aherne 1987; Gonyou *et al.*, 1992; Nielsen *et al.*, 1996; Gomez *et al.*, 2000; Ferguson *et al.*, 2001). However, feed conversion ratio was no different in individually or group penned pigs in any of the studies other than that by Chapple (1993).

Although the carcass characteristics (where applicable) are not summarised in Table 2.1, there appears to be some controversy regarding the P_2 backfat thickness measurement at increasing group size. Several researchers (Patterson, 1985; de Haer and de Vries, 1993; Gomez *et al.*, 2000) have observed a reduction in P_2 backfat thickness measurement with increasing group size, unlike the increase reported by Chapple (1993).

The results of Ferguson *et al.* (2001) demonstrated that group size (7 vs. 13) had no effect on body protein content at 60 kg, but did significantly ($P < 0.05$) increase body lipid content. However, the individually penned pigs had significantly ($P < 0.001$) higher protein retention rates than the group penned pigs, unlike the lipid retention rates which remained unaffected by penning arrangement.

Morgan *et al.* (1999) suggested that the 'stress' of grouping may have a detrimental effect on the feeding behaviour, feed intake and growth following the initial introduction to a group. In an attempt to counteract the 'stress' associated with grouping, Gonyou *et al.* (1992) and Gomez *et al.* (2000) grouped all pigs prior to individual and group penning to ensure similar treatment and observed a reduction in daily gain and feed intake in spite of this.

The reduction in feed intake associated with group penning may be the result of changes in the overall feeding behaviour, as suggested by computerised feed intake recording generated data (Morgan *et al.*, 1999). Using data from de Haer and Merks (1992) and de Haer and de Vries (1993), Morgan *et al.* (1999) illustrated that group penned pigs ate fewer meals (9.2 *vs*. 20.1 and 10.3 *vs*. 22.9 per day) of a larger size (225.0 *vs*. 110.0 and 223.8 *vs*. 103.6 g) consumed at a faster rate (32.0 *vs*. 27.2 and 32.4 *vs*. 26.9 g/min.) and spent less time eating (63.5 *vs*. 84.1 and 62.5 *vs*. 83.2 min./d), relative to individually penned pigs. Only de Haer and de Vries (1993) reported these effects as being significantly ($P < 0.01$) different. In support of this Nielsen *et al.* (1996) noted that pigs previously penned in groups, and later as individuals, increased their feeding frequency (14.2 to 17.0 visits/d) and feeder occupation (52.7 to 65 min./d), both of which were significant ($P < 0.05$), although housing had no effect on feed intake per visit or feeding rate.

Thus group penning has a detrimental effect on the performance variables and carcass characteristics of growing-finishing pigs, such that a reduction in growth, voluntary feed intake and protein content in the empty body are noted in comparison to individually penned pigs. However, in spite of this, the penning arrangement had no significant effect on feed conversion ratio. Although researchers have attempted to alleviate the 'stress' of grouping through regrouping pigs prior to penning, their attempts have been unsuccessful, suggesting a change in feeding behaviour may be responsible and this possibility will be discussed later. Whilst the application of individual penning appears attractive, commercially it is uneconomical from a labour, building and management standpoint, with the extra input outweighing the marginal output.

Table 2.1 *The effect of individual compared with group penning on daily feed intake (DFI, kg), average daily gain (ADG, kg) and feed conversion ratio (FCR, kg feed per kg gain) measured in eight separate locations/experiments (adapted from Morgan et al., 1999).*

	Group Size								
	1	2	3	4	5	7	8	10	13
Papers									
Patterson[a]									
DFI	1.68				1.66				
ADG	0.67				0.65				
FCR	2.50				2.55				
Spicer[b]									
DFI	0.79	0.78		0.80					
ADG	0.58	0.57		0.52					
FCR	0.77	0.77		0.80					
Gonyou[c]									
DFI	2.70				2.57				
ADG	0.84				0.81				
FCR	3.21				3.17				
de Haer[d]									
DFI	2.07						1.93		
ADG	0.74						0.64		
FCR	2.98						3.17		
Chapple[e]									
DFI	2.41		2.30		2.19				
ADG	0.89		0.87		0.84				
FCR	2.71		2.66		2.64				
Nielsen[f]									
DFI	1.60							1.36	
ADG	0.81							0.69	
FCR	1.99							2.00	
Gomez[g]									
(a)									
DFI	1.85			1.80					
ADG	0.80			0.76					
FCR	2.31			2.37					
(b)									
DFI	2.76			2.61					
ADG	0.98			0.92					
FCR	2.82			2.84					
Ferguson[h]									
DFI	2.17					1.82			1.71
ADG	0.94					0.83			0.78
FCR	2.31					2.18			2.17

[a]**Patterson (1985):** Weight range 37-81 kg live weight, entire males and females, floor-space allowance: 2.70 and 1.62 m^2/pig for group sizes 1 and 5 respectively, daily feed intake allowances adjusted after each weighing to scale based on metabolic live weight, water provided on top of meal at 2 ℓ/kg, ambient temperature maintained at 21° C.

[b]**Spicer and Aherne (1987):** Yorkshire × Landrace pigs weaned at 28 days, floor-space allowance: 1.44, 0.72 and 0.35 m^2/pig for group sizes 1, 2 and 4 respectively, one nipple drinker and six-hole nursery feeder provided in each pen, *ad libitum* access to pelleted semi complex feed for starter pigs, ambient temperature maintained at 28 ° C throughout four week study.

[c]**Gonyou *et al.* (1992):** Weight range 31-90 kg live weight, castrated males and gilts, all pigs subjected to regrouping prior to experiment, partially slatted pens, floor-space allowance: 1.2 and 0.88 m^2/pig (grower) and 1.8 and 1.16 m^2/pig (finisher) for group sizes 1 and 5 respectively, one nipple drinker and two-hole feeder, *ad libitum* access to meal feed containing 16% protein, pens illuminated continuously.

[d]**de Haer and de Vries (1993):** Weight range 25-100 kg live weight, Dutch Landrace boars and gilts, floor-space allowance: 3.3 and 0.76 m^2/pig for group sizes 1 and 8 respectively, single IVOG® feeding station per pen, *ad libitum* access to commercial feed containing 18% and 17% protein for the starter and grower feed respectively.

[e]**Chapple (1993):** Weight range 20-100 kg live weight, floor-space allowances: 1.39, 0.90 and 0.80 m^2/pig for group sizes 1, 3 and 5 respectively.

[f]**Nielsen *et al.* (1996):** Weight range 39-50 kg live weight, Large White × Landrace boars, previously group penned (two weeks) before individually penned (two weeks), naturally ventilated room, insulated kennels, straw bedding, floor-space allowance: 1.3 m^2/pig for group sizes 1 and 10, two water bowls and one computerized single space feeder.

[g]**Gomez *et al.* (2000):** Weight range 18-51 (a) and 46-119 (b) kg live weight for grower and finisher phase respectively, Large White × Landrace × Duroc × Hampshire gilts, all pigs subjected to regrouping prior to experiment, fully slatted floors, floor-space allowance: 1.3 m^2/pig for group sizes 1 and 4, one and four nipple drinkers and single hole feeder per group size respectively, *ad libitum* access to meal feed containing 19% and 16% protein for starter and finisher phase respectively, ambient temperature maintained at 22 ° C.

[h]**Ferguson *et al.* (2001):** Weight range 20-60 kg live weight respectively, Large White × Landrace gilts, floor-space allowance: 1.98, 0.99 and 0.53 m^2/pig for group sizes 1, 7 and 13 respectively, one nipple drinker and self feeder per individual pen and two nipple drinkers and self feeder per group pen, *ad libitum* access to one of four dietary lysine treatments ranging from 13.3 and 7.6 g lysine/kg feed and 23 and 13% protein produced using a summit dilution technique.

2.4.1.2 *Group penning on performance variables and carcass characteristics during the growing-finishing period*

It is well established that group penning results in a reduction in performance variables and unfavourable carcass characteristics, the degree of reduction being dependent on the group size. The current movement towards large group penning has been encouraged as a means of lowering production costs and facilitating ease of management. However, literature on the effect of group penning on common production parameters is variable and inconsistent and the suitability and use of this as a stressor will be evaluated in this section.

According to the results of Randolph *et al.* (1981) (5 or 20 pigs/pen), McGlone and Newby (1994) (10, 20 or 40 pigs/pen) and Nielsen *et al.* (1995) (5, 10, 15 or 20 pigs/pen) varying group size has a marginal effect on the performance variables. However, Heitman *et al.* (1961) (3, 6 or 12 pigs/pen), Gehlbach *et al.* (1966) (4, 6 or 8 pigs/pen), Petherick *et al.* (1989) (6, 18 or 36 pigs/pen), Hyun and Ellis (2001) (2, 4, 8 or 12 pigs/pen) and Wolter *et al.* (2001) (25, 50 or 100 pigs/pen) noted that the degree of reduction in the performance variables was dependent on the group size. In addition, Gehlbach *et al.* (1966) suggested that whilst the size of the group affected the performance variables, the optimum number of pigs/pen is also influenced by environmental factors (i.e. season). The results of Spoolder *et al.* (1999) (20, 40 or 80 pigs/pen), Turner *et al.* (2000) (20 or 80 pigs/pen), Wolter *et al.* (2001) (25, 50 or 100 pigs/pen), Turner *et al.* (2002) (20 or 80 pigs/pen) and Schmolke *et al.* (2003) (10, 20, 40 or 80 pigs/pen) are inconclusive and inconsistent over the growing-finishing period.

Kornegay and Notter (1984) developed a series of equations predicting the relationships between group size (2 – 33 pigs/pen) and performance. The popularity of large group sizes has warranted the review of these equations to accommodate sizes typically found in industry. Consequently, Turner *et al.* (2003) used a similar approach but larger group sizes (3 – 120 pigs/pen) and excluded studies confounding group size with floor-space allowance (Table 2.2). Their analysis suggested that during the grower stage, average daily gain decreases with increasing group size but not as a result of lower average daily feed intake; consequently efficiency of growth is reduced (increased feed conversion ratio). Therefore, the poor growth rate may be a reflection that dietary energy was partitioned to satisfy demands of greater locomotory activity. However, above 69 kg no statistically significant relationship between group size and performance was found.

Table 2.2 *Equations from Kornegay and Notter (1984)† and Turner et al. (2003)‡ predicting the effects of floor-space allowance¹ and group size² on performance.*

	Floor-space allowance¹	Group Size²
Grower period (27-54 kg)†		
ADG (kg/d)	$= 0.489 + 0.520\ S - 0.281\ S^2$ (R^2=0.93)	$= 0.6407 - 0.0019\ N$ (R^2=0.43)
ADFI (kg//d)	$= 1.542 + 0.856\ S - 0.404\ S^2$ (R^2=0.93)	$= 1.5950 - 0.0025\ N$ (R^2=0.87)
FCR (kg gain/kg feed)	$= 3.037 - 0.734\ S + 0.406\ S^2$ (R^2=0.94)	$= 2.4974 + 0.0037\ N$ (R^2=0.94)
Grower period (31-68 kg)‡		
ADG (kg/d)		$= 0.654 - 0.00048\ N$ (R^2=0.90)
ADFI (kg//d)		$= 1.790 - 0.00005\ N$ (R^2=0.98)
FCR (kg gain/kg feed)		$= 2.750 + 0.00179\ N$ (R^2=0.97)
Finisher period (44-92 kg)†		
ADG (kg/d)	$= 0.398 + 0.704\ S - 0.340\ S^2$ (R^2=0.69)	$= 0.7497 - 0.0012\ N$ (R^2=0.82)
ADFI (kg//d)	$= 1.619 + 1.833\ S - 0.8375\ S^2$ (R^2=0.74)	$= 2.3748 + 0.0032\ N$ (R^2=0.92)
FCR (kg gain/kg feed)	$= 3.840 - 0.927\ S + 0.520\ S^2$ (R^2=0.40)	$= 3.2182 + 0.0060\ N$ (R^2=0.72)
Finisher period (≥ 69 kg)‡		
ADG (kg/d)		$= 0.715 - 0.00009\ N$ (R^2=0.99)
ADFI (kg//d)		$= 2.340 + 0.00033\ N$ (R^2=0.84)
FCR (kg gain/kg feed)		$= 3.329 + 0.00104\ N$ (R^2=0.97)

where ¹S is the space allowance per pig (m^2) and ²N is the number of pigs per pen.

In spite of limited data being available on the effect of group size on carcass characteristics, this consequence cannot be ignored as it has financial implications attached to it. The results of Wolter *et al.* (2001) (25, 50 or 100 pigs/pen) demonstrated that varying group size has no significant influence on carcass yield, backfat or loin eye measurements, ante-mortem or post-mortem. Whilst the impact of large group size on carcass characteristics appears small, the absence of significant group size effects on growth traits during the growing-finishing period is reflected (Turner *et al.*, 2003).

Therefore, the literature suggested that group size appears to be less effective than floor-space allowance in reducing the potential growth rate of animal due to inconsistencies such as: acceptable group size, severity, duration and confounding of group size and floor-space allowance throughout the growing-finishing period.

2.4.2 Social effects of grouping

Much of the focus thus far has examined the physical effects of grouping on performance variables and carcass characteristics of growing-finishing pigs. However, pigs by nature are social animals and large group housing presents a different kind of constraint, namely the social effect of grouping.

The social environment influences almost every action performed by a pig penned in a group, with no explanation for differences in the performance variables observed between individually- and group-penned pigs (Morgan *et al.*, 1999). In trying to understand the social effects of grouping, the quantification and identification of the social constraint is important i.e. feeding behaviour and behavioural synchrony, especially as the social organisation structure influences this (Morgan *et al.*, 1999).

Social facilitation in group penned pigs may result from pigs wanting or needing to eat quickly thus increasing the competition for feeding space at the same time, whilst the feeding behaviour of individuals is influenced more by sounds than by other pigs (Wood-Gush and Csermely, 1981; de Haer and Merks, 1992; Wolter *et al.*, 2000a). Irrespective of competition, the availability and accessibility of feeding space should remain sufficiently adequate to allow all group-penned pigs access to feed.

The final interface between a pig and the feed(s) formulated to meet its nutrient requirements is a feeder (Gonyou and Lou, 2000). However, a limitation (quantity, spatial distribution or preference availability) results in the competition for feeder access placing pressure on preferred feeders, despite the pig: trough ratio remaining the same (Spoolder *et al.*, 1999). Consequently, the relationship between the number of pigs/pen and the number of feeding troughs is altered by changes to one, the other or both (Morgan *et al.*, 1999).

Attempts to reduce social facilitation in large groups through the provision of more than one feeding space and feed location have yielded variable results. In determining the effects of number and siting of single-space feeders on the performance of growing-finishing pigs, Morrow and Walker (1994) (20 pigs/pen) observed the following. Two *vs.* one single-space feeder/pen placed side by side significantly increased feed intake, but the lack of corresponding effect on growth rate or feed conversion efficiency suggested feed spillage was implicated. In addition, siting two single-space feeders/pen at varying distances (0, 2.0 and 2.6 m) instead of side by side, resulted in feed conversion efficiency improving when feeders were placed 2.0 m or more apart although feed intake and growth rate were not significantly affected. However, Spoolder *et al.* (1999) (20, 40 or 80 pigs/pen and either one or two single-space feeders/20 pigs) noted that only growth rate was significantly affected by both the size of the group and number of feeders per 20 pigs initially, disappearing later and overall by the number of single space feeders available per 20 pigs. Consequently, the presence of an extra feeder alleviated the lower weight gains in larger groups, compared to smaller groups. Overall both Wolter *et al.* (2000a) (20 or 100 pigs/pen and one or five two-sided feeders arranged in a single, central or multiple locations respectively) and Ferguson *et al.* (2001) (7 or 13 pigs/pen and one, two, three or four single-space feeders) demonstrated that in spite of increasing the accessibility and availability of feeders, performance variables in large groups were not significantly improved.

The confounding of group size, floor-space allowance and single-space feeder(s) results in inexplicable differences in the social constraint of the animal as to which stressor(s) is/are responsible (Morgan *et al.*, 1999). According to Nielsen and Lawrence (1993) (5, 10, 15 or 20 pigs/pen and one single-space feeder/pen), the treatments imposed had no significant effect on performance variables over the period of study, despite group size and feeder space allowance being confounded. Likewise, O'Doherty and McKeon (2000) (13 or 16 pigs/pen) confounded the number of pigs per single-space feeder with pen space allocation and group size. They established that a reduction in the pig: single space feeder ratio resulted in significant increases in feed intake and growth rate, compared with providing pigs less feeder space, but increasing the ratio improved the feed conversion ratio compared with decreasing it.

Although recommendations on the number of feeding spaces/pig appear useful, they make no reference to dimensions of space, location of space within the pig's environment, or factors that influence the pig's interaction with the feed delivery service (Brumm and Gonyou, 2001). In order for an individual to feed comfortably, space needs to be allocated according to the size of the animal and posture during feeding (Baxter, 1991). Petherick (1983) estimated that feeder trough space (mm/pig) could be predicted from the shoulder width (mm) of a pig ($61 \times BW^{0.33}$). In agreement, Turner *et al.* (2002) observed a depression in feed intake and growth rate during the late phase in the low feeder space allowance, suggesting little merit in specifying differential feeder space allowances according to group size and recommended allometric equations instead. This approach ensures the accurate estimation and provision of feeder trough space throughout the growing-finishing period as the animal ages.

The feeding behaviour is constrained not only by social facilitation, but also by the reluctance to feed at night due to the circadian rhythm of the animal (inherent photoperiodicity) (Nielsen *et al.*, 1995). On the other hand, Walker (1991) demonstrated when 30 pigs were housed per pen, they occupied the single-space feeder 0.92 of the time (24 hours/d), unlike the two peaks of activity during the day and a low level at night by the 10 pigs housed per pen. According to Nielsen *et al.* (1995) in spite of pigs being successful in adapting to the lack of feeding space, they displayed behaviour not normally seen in diurnal animals, suggesting the pig: trough ratio had reached a maximum without adversely affecting performance.

Thus, performance variables appear acceptable at 20 pigs per single-space feeder, suggesting a factor other than feeder access limits performance in large groups. In contrast, the feeder trough space acts as a potential stressor capable of reducing the performance of an animal especially as it gets older, hence further research is necessary to establish optimal allowances maximising performance. Despite feeder trough space being available as a potential non-evasive stressor in reducing the performance variables of growing-finishing pigs, the purpose of this investigation was to reduce the potential performance of growing pigs so that the effect of this reduction in growth rate on the efficiency of utilisation of dietary protein may be measured.

Nielsen (1999) explained behavioural synchrony as a period of resting and feeding occurring simultaneously for all group-penned animals, such that feeding rate is affected if the preference to behave like a group overrides the preference to eat at a given rate. The social constraint increases, resulting in the feeding rate of individual animals eventually reaching a maximum and daily feed intake decreases when all troughs are constantly occupied. However, it is possible that when kept in a social environment some animals lower their level of intake long before the point of physical constraint is reached. Therefore the reduction in feed intake in group-penned pigs may be the result of synchronised behavioural patterns in terms of feeding and social behaviours (Morgan *et al.*, 1999).

In view of the experimental evidence presented thus far, it appears group size is an appropriate non-evasive stressor to use, as it is guaranteed to reduce the voluntary feed intake and potential growth rate of the genotype concerned in this investigation. The physical and social effects of large group housing cannot be seen as two separate entities, as both are responsible for impinging on the performance variables and carcass characteristics through the feeding behaviour and behavioural synchrony. Thus, the challenge herein lies in formulating a balanced feed to meet the requirement of the genotype concerned and feeding for maximum protein growth rate, especially when animals are socially constrained.

2.4.3 Effect of floor-space allowance on pig performance during the growing-finishing period

The objective of any intensive pig production system is to maximise the building efficiency in an attempt to reduce the cost per unit of pork produced, usually achieved at the expense of a slight reduction in performance variables and carcass characteristics (Kornegay *et al.*, 1993a).

Floor-space allowance is at a premium: a surplus is costly and wasteful and a scarcity leads to operational inconveniences, hazardous practices and unacceptable performance (Baxter, 1984). In maximising building efficiency, the producer must know the number of pigs that may be used per unit of area, without adversely affecting performance variables and carcass characteristics (Randolph *et al.*, 1981). However, this reduction only occurs once the floor-space allowance decreases below a certain level (Petherick, 1983).

The effect of floor-space allowance remains a controversial issue, especially as the reduction in growth interferes not only with physiological changes, but behavioural changes as well. This knowledge is important in ensuring a solid foundation for designing new buildings and maintaining acceptable floor-space allowance in existing infrastructures for growing-finishing pigs.

2.4.3.1 Floor-space allowance on performance variables and carcass characteristics during the growing-finishing period

It is well established that the intensive and competitive nature of pig production requires the producer to efficiently and appropriately utilise housing. In an attempt to separate the effects of group size and floor-space allowance, researchers have invariably confounded them through the addition of more pigs to a pen of a given size (Randolph *et al.*, 1981). Thus an increase in group size may have a separate effect from a decrease in floor-space allowance per pig (Randolph *et al.*, 1981). In spite of the inconclusive and inconsistent results from the literature, the suitability and use of floor-space allowance as a non-evasive stressor guaranteed to reduce voluntary feed intake and potential growth rate in this investigation will be evaluated.

The results of Heitman *et al.* (1961) (0.46, 0.93 and 1.86 m^2/pig), Jensen *et al.* (1973) (0.36, 0.54, 0.72 and 0.45, 0.72, 0.90 m^2/pig between 50 to 68 and 68 to 100 kg live weight respectively), Randolph *et al.* (1981) (0.82, 1.64 and 0.33, 0.66 m^2/pig in experiment one and two respectively) and Meunier-Salaun *et al.* (1987) (0.34, 0.68 and 1.10 m^2/pig) demonstrated that the degree of reduction on the performance variables differed between experiments and thus was dependent on the extent of decreasing floor-space allowance. However, Gehlbach *et al.* (1966) (0.36, 0.54, 0.72 and 0.54, 0.72, 0.90 m^2/pig between 50 to 70 and 70 to 90 kg live weight respectively) suggested that in addition to examining floor-space allowances constraining average daily gain, environmental factors (i.e. season) need to be considered when recommending acceptable allowances.

In an attempt to predict the effects of floor-space allowance and group size on performance variables, Kornegay and Notter (1984) determined the relationship between them from various experiments using a model adjusting for average differences among studies and weighted each mean by the number of pens (replications). Although these equations have served the industry favourably over the years, Chapple (1993) described various inadequacies, making them difficult to interpret and implement largely resulting from the empirical approach used. He alluded to the fact that the statistical nature of the equations cannot be interpreted biologically (quadratic estimates are not different from zero suggesting a linear representation is adequate and all equations have highly significant positive intercepts predicting growth when no space is available or pigs present) and many of the data sets used to generate floor-space allowance equations were confounded with group size. Regardless of the shortcomings associated with this approach, it was the most comprehensive attempt to quantify the effects of floor-space allowance and group size on performance variables and has subsequently encouraged further research (Morgan *et al.*, 1999).

In support of the argument presented by Chapple (1993), Wellock *et al.* (2005) highlighted that the equations of Kornegay and Notter (1984), and more recently Turner *et al.* (2003), have provided insight on the effect of group size and floor-space allowance on pig performance, but are difficult to interpret or implement as they fail to predict interactions between the type of pig and the environment in which it is reared. Furthermore, Wellock *et al.* (2005) demonstrated that the equations of Kornegay and Notter (1984) and Turner *et al.* (2003) predicted an average daily gain of zero in growing pigs when group size approached 223 and 1363 respectively. This emphasises the danger of extrapolating empirical equations to environmental conditions other than those in which they were developed, especially since pigs housed in large groups (>2000) are reared profitably in some pig production enterprises (Wellock *et al.*, 2005).

An alternative approach is to express floor-space allowance as a function of the live weight of an animal through a mathematically defined biological relationship, considering the size, shape and behaviour relative to the amount of space used (Edwards *et al.*, 1988, Hurnik and Lewis, 1991). Since body weight is proportional to volume and floor-space allowance proportional to surface area of a pig, they are regarded as three and two-dimensional measures respectively (Brumm and Gonyou, 2001).

Petherick (1983) suggested that the relationship between floor-space allowance and body weight could be expressed as $A = k\ BW^{0.67}$, where A is the area occupied by the pig (m^2), k an empirical coefficient and BW the body weight (kg). In generating equations for body dimensions of height, breadth and length, the space occupied by a sternal recumbent (pig lying with all four legs tucked under body) and fully recumbent (pig lying on its side) pig was estimated to be $A = 0.047\ BW^{0.67}$ and $A = 0.019\ BW^{0.67}$ respectively. Although pigs attempt to maintain a position to achieve thermal comfort within this range, the social space requirements are less simply defined and may vary according to the structure of the group (Morgan *et al.*, 1999).

Edwards *et al.* (1988) observed a reduction in performance and profitability at a floor-space allowance of less than that defined by $A = 0.027\ BW^{0.67}$, thus $A = 0.030\ BW^{0.67}$ was recommended as an appropriate commercial guide to the minimum space requirements of growing-finishing pigs kept on fully slatted floors. Similarly, Gonyou and Stricklin (1998) noted a reduction in the floor-space allowance coefficient from 0.048 to 0.039 had no effect on the performance variables. However, an additional decrease to 0.030 caused a reduction and they concluded that crowding at floor-space allowances between coefficients of 0.030 and 0.039 compromised productivity.

Although the approach of expressing floor-space allowance relative to the live weight of an animal assists in planning, designing and managing pig production systems efficiently and accurately, the consistency would also be assured. The dilemma facing pig producers is the choice between maximum profit at the expense of animal performance or maximum performance at the expense of profit. Thus the challenge herein lies in trying to achieve a balance somewhere between these two extremes ensuring building efficiency, animal performance and ultimately profitability.

The effect of reduced floor-space allowance is well documented in the literature with a wealth of experiments. However, a consistent flaw in many is the use of the same dietary nutrient densities for all treatments, making it difficult to determine whether the reduction in growth rate was a result of restricted floor-space allowance, or a decrease in total nutrient intake associated with a reduction in feed intake (Brumm and Miller, 1996).

Several researchers have employed various nutritional approaches in an attempt to overcome the reduction in pig performance such as: the addition of antibiotics to the feed (Moser *et al.*, 1985); increasing trace mineral elements (Kornegay *et al.*, 1993a); increasing dietary lysine (Kornegay *et al.*, 1993b) and amino acids and protein levels (Hahn *et al.*, 1995); Brumm and Miller (1996) (increasing dietary lysine and energy); Edmonds *et al.* (1998) (amino acids and protein levels) and Ferguson *et al.* (2001) (increasing dietary lysine) attempted to overcome the reduction in pig performance with nutritional approaches, but confounded floor-space allowance with the number of pigs/pen.

Although largely unsuccessful in attempting to produce an improvement in the performance variables and carcass characteristics (where applicable) of pigs housed at restricted floor-space allowances, Ferguson *et al.* (2001) observed significant interactions between dietary lysine and stocking density for body composition and lipid retention rate. This supports the hypothesis that responses in body composition to the first limiting nutrient in the feed are dependent on the size of the group or to the stocking density applied. They suggested that there was merit in increasing the concentration (g/kg feed) of the most limiting nutrient in the feed or matching the requirement of the animal to counteract the drop in nutrient intake irrespective of floor-space allowance per pig. This was contrary to the view of other authors, that increasing the nutrient density has little or no effect in overcoming reduced performance associated with high stocking density.

McGlone and Newby (1994) hypothesised that if a fixed total space is provided per pig, a direct relationship between group size and the amount of free space exists. Consequently, a pen containing a large group size may have more free or unused space, suggesting that if group size is increased (e.g. commercially), then total space may be decreased, without changing free space or reducing performance. It was demonstrated by examining the posture of finishing pigs penned in groups (10, 20 and 40 pigs/pen) at constant floor-space allowance, that an increase in free or unused space occurred at increasing group size. The hypothesis was tested on groups of 20 pigs/pen through removing all, half and none of the available free space. The removal of half of the free space did not negatively affect pig performance but the removal of all reduced it. Similarly Wolter *et al.* (2000b) investigated this concept in weanling pigs penned in groups (20 and 100 pigs/pen) with the floor-space allowance at the calculated requirement or calculated requirement less 50% of estimated free space. Despite both group sizes having similar levels of performance at the reduced floor-space allowance, the actual floor-space allowance was 13% lower for 100 *vs.* 20 pigs/pig on the calculated requirement less 50% of estimated free space treatment. In support of McGlone and Newby (1994), they suggested a reduction of less than 50% of free space is required to maintain feed intake and growth rate in weanling pigs. Because the relationship between group size and floor-space allowance was not directly tested, further research is required (Wolter *et al.*, 2000b).

From this section it can be summarised that the unfavourable effect of floor-space allowance on performance variables and carcass characteristics in growing-finishing pigs, depends on the extent of the decrease usually dictated by the current situation. Petherick (1983) suggested that group size has a small effect on the production parameters and this only becomes apparent once floor-space allowance is below a certain level. In attempting to quantify and identify the effect of floor-space allowance on production many inconsistencies have been reported such as: confounding group size and floor-space allowance by not keeping the group size constant and varying the floor-space allowance or *vice versa* or employing the same nutrient densities for all treatments. Although the use of allometric equations promote the efficient utilisation of floor-space allowance from a biological perspective, the economic feasibility of such a practice needs to be assessed. In spite of the reduced performance and undesirable carcass characteristics associated with reduced floor-space allowances, feeding according to the maximum protein growth rate is encouraged to counteract the reduction in nutrient intake. Thus, floor-space allowance appears to be an appropriate non-evasive stressor to use in this investigation as a means of reducing performance, with the outcome having significant implications for the commercial management of pigs.

2.4.4 Stress and growth on pig performance during the growing-finishing period

Stress has an undesirable effect on the performance variables and carcass characteristics of growing-finishing pigs in confinement housing in view of the evidence presented thus far. In addition, it is highly unlikely that the commercial environment remains non-limiting throughout the growing-finishing period and it is equally difficult to quantify and identify the stressor(s) responsible for compromised results. The suitability and use of social stress as a non-evasive means to reduce feed intake and potential protein growth rate have been presented thus far. However the biological processes involving the mechanism of stress warrants further explanation.

Stressors are complex in that they influence the neural and neuroendocrine mechanisms involving appetite control, consequently decreasing the voluntary feed intake and potential protein accretion of the animal, as illustrated in Figure 2.4 (Baker and Johnson, 1999; Matteri *et al.*, 2000).

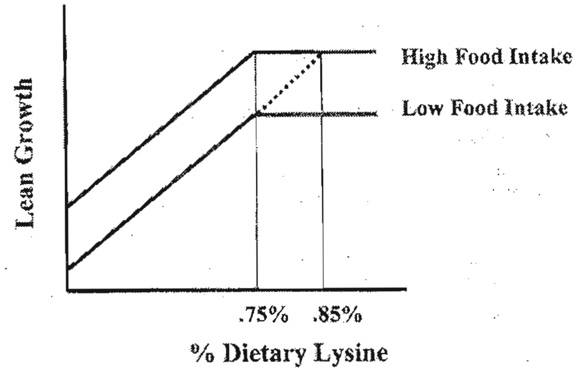

Figure 2.4 *The effect of stress-induced reductions in voluntary feed intake on dietary lysine requirements (after Baker and Johnson, 1999).*

The cognitive and non-cognitive response of the animal to stress is determined by patterns of chemical messengers redirecting the use of nutrients by various tissues (Elsasser *et al.*, 2000). The constantly changing environment of biochemical signals (neurally excitant and depressant amino acids, prostaglandins, neuropeptides, hormones and cytokines) is required to initiate responses, rebalance and stabilise the internal environment and facilitate recovery of physiological processes, but the degree of response ranges from mild decreases in growth rate (young animal) to cachectic catabolism resulting in muscle degradation and fat mobilization (severe stress) (Elsasser *et al.*, 2000).

Leptin, a protein hormone produced by adipose tissue is considered the link between adipose tissue and its role in the regulation of feed intake and control of body stores (Wray-Cahen, 2001). Furthermore it is implicated in the endocrine regulation of leptin-neuropeptide Y and release in the brain, administered either centrally or peripherally, decreasing feed intake (and subsequently body weight) presumably through its actions on leptin-neuropeptide Y release (Matteri *et al.*, 2000). Consequently, cytokines initiate a sequence of catabolic events increasing in plasma cortisol and urea nitrogen, indicating body protein catabolism (Baker and Johnson, 1999).

Experimental evidence on the impact of social stress on the potential protein growth rate is limited. However, Chapple (1993) hypothesised that the reduction in feed intake associated with increasing group size was not responsible for the decrease in protein growth. He suggested the opposite was likely to occur as a reduced protein growth created a decrease in protein demand and feed intake. Thus, the stress associated with maintaining social order in groups is mediated through biochemical factors (cortisol, growth hormone, insulin-like growth factors and cytokines) down-regulating tissue growth. The diversion results in the appetite of the animal being directly affected by high stocking density and indirectly by decreasing the amount of protein deposited (Ferguson *et al.*, 2001). Consequently, the reduction in the daily nutrient requirement for protein occurs and the animal is unable to attain its inherent potential protein deposition rate in spite of the opportunity to consume enough of the first limiting nutrient when offered a higher nutrient density feed (Ferguson *et al.*, 2001).

Growing-finishing pigs reared in commercial units are likely to be affected by many environmental stressors (high temperature, immunological stress, feeder space allowance, stocking density and social stress), at any one time or combination resulting in undesirable characteristics. McFarlane *et al.* (1989) and Hyun *et al.* (1998) investigated the effect of six (aerial ammonia, beak trimming, coccidiosis, intermittent electric shock, heat stress and continuous noise) and three multiple concurrent stressors (temperature, space allocation and regrouping) on chick and pig performance respectively. Both research groups observed a linear reduction in all performance variables as the number of simultaneous stressors ('order') increased. This indicates that chicks and pigs respond to each stressor similarly, irrespective of whether the stressor occurs singly or concurrently with up to five and two others, with very few stressor interactions being reported. However, each stressor does not contribute equally to the reduction in performance, whilst the presence or absence of a stressor is informative, the level induced is equally important (Hyun *et al.*, 1998). Therefore, pigs reared commercially are likely to experience more than one stressor at the same time and the effects of multiple, concurrent, unrelated stressors on performance may be estimated to first approximation by the addition of the effects of the respective stressors when acting alone (McFarlane *et al.* 1989).

The objective of this investigation was to determine whether a pig should be fed according to its genetic potential in spite of this not being achievable due to a constraint on the farm. Although a wealth of literature on the negative effect of social stress (group size and floor-space allowance) on performance variables and carcass characteristics exists, there has been little research on the nutritional management to counteract this effect. Those researchers attempting to do so have inadvertently confounded the two, making it difficult to assess which stressor is responsible for the reduction. Thus, the knowledge gathered from this investigation is crucial in understanding the cause and effect of social stress and ultimately has significant implications for the nutritional management of commercial pigs whose performance is known to be compromised.

CHAPTER 3

EFFECT OF GROUP SIZE AND FLOOR-SPACE ALLOWANCE ON THE EFFICIENCY OF LYSINE UTILISATION BY GROWING PIGS

3.1 INTRODUCTION

The biological process of growth is fuelled by the provision of adequate nutrients utilised by the pig in converting energy, protein and amino acids into carcass gain (Close, 1994). Despite genetic improvements and stricter control over all aspects of pig production, the feed and environment are sources of constraint preventing the animal from achieving its inherent growth potential due to a reduction in feed intake and potential protein growth rate (Emmans and Oldham, 1988).

Ideally the amino acid requirements of growing-finishing pigs should be based on the potential protein growth rate and maintenance requirements of the genotype concerned (Ferguson *et al.*, 2001). However, under commercial conditions it is highly unlikely that the environment remains non-limiting throughout the growing-finishing period, with stressors such as disease challenges, environmental temperature, feeder space, social stress and stocking density impinging on feed intake and ultimately diverting nutrients from maintenance and growth. Consequently, the question has been raised as to the advisability of recommending that the nutrient requirements should be based on the potential growth rate of the pig when this is clearly not achievable.

The intensive and competitive nature of pork production demands that the producer maximise body weight gain in a specific facility and period, minimising the facility cost per unit of pork produced through large group housing and restricted floor-space allowance at the expense of individual pig performance (Kornegay and Notter, 1984). However, in maximising building efficiency the producer must identify the number of pigs that may be used per unit of area, without adversely affecting performance variables and carcass characteristics (Randolph *et al.*, 1981).

In attempting to overcome the negative effects associated with large group housing and restricted floor-space allowance on performance variables and carcass characteristics, several researchers have employed various nutritional approaches e.g. increasing the dietary lysine, trace mineral elements, amino acids and protein levels and dietary lysine and energy in growing-finishing pig feeds (Moser *et al.*, 1985; Kornegay *et al.*, 1993a, b; Hahn *et al.*, 1995; Brumm and Miller 1996; Edmonds *et al.* 1998). In spite of increasing the nutrient density of the feed, these researchers found that pigs were largely unsuccessful in overcoming the reduction in performance variables and carcass characteristics associated with social stress, suggesting the impracticality of this application.

On the contrary, Ferguson *et al.* (2001) explained that feeding socially stressed pigs low nutrient dense feeds may not impinge on an already reduced protein growth rate, rather the severity of constraint on maximum protein retention and sufficient feed intake to meet the reduced protein requirement are of more concern. They suggested that increasing the concentration (g/kg feed) of the most limiting nutrient in the feed or feeding to requirement in compensating for a reduced nutrient intake, may not counteract the unfavourable effect(s) of social stress on reducing the maximum protein retention. However, maintaining the nutrient density for maximum protein growth may counteract the drop in nutrient intake associated with social stress.

In attempting to quantify and identify the effect of social stress on pig production, inconsistencies such as the confounding of group size and restricted floor-space allowance and employing the same nutrient densities for all treatments are evident. According to Brumm and Miller (1996) this makes it difficult to determine whether the reduction in growth rate is a result of group size or restricted floor-space allowance, or a decrease in total nutrient intake associated with a reduction in feed intake.

The question addressed in this paper is whether a pig should be fed according to its genetic potential in spite of this not being achievable due to a constraint on the farm. Group size and space allocation were used to reduce potential growth rate as it is well established that social stress is one of the most potent factors responsible for the inability of an animal to achieve its inherent growth potential.

3.2 MATERIALS AND METHODS

3.2.1 Experimental Design

The experiment was divided into two growth periods (Period 1: 40 to 60 kg and Period 2: 60 to 85 kg). The experimental design consisted of four dietary lysine concentrations (in Period 1: 10.6, 8.8, 7.0 and 5.3, and in Period 2: 7.8, 6.7, 5.5 and 4.4 g lysine/kg feed respectively) and three group sizes (one, four and eight) in a completely randomised design. Because of the facilities available, the amount of space allocated to the pigs (0.86, 1.72 and 1.94 m^2/pig) differed within group sizes, resulting in some confounding of group size and space allocation (Table 3.1). The individually-penned pigs were fed either *ad libitum* (AL) or pair-fed according to the mean feed intake of pigs in groups of four (R4) or eight (R8).

3.2.2 Animals

Each of the 294 entire male Large White × Landrace pigs used in this trial was randomly allocated to a treatment and reared from 40.3 ± 0.21 to 85.4 ± 0.52 kg live weight. The pigs arrived at the facility at eight weeks of age, weighing approximately 15 kg. They were fed a commercial grower feed (14.2 MJ Digestible Energy (DE)/kg and 11.0 g lysine/kg) until an individual or average pen weight of 40 kg was attained. There were four replicates of each lysine × feeding level treatment for pigs housed singly and three replicates per lysine treatment for the pigs housed in groups. All animals remained on their respective treatments until an individual or average pen weight of 85 kg was achieved.

Six additional pigs were grown together with those in the group pens and these pigs were slaughtered when they reached 40 kg to determine the initial chemical composition of the empty body. Two animals per group-housed treatment and four animals per individually-housed treatment (120 pigs in total) were randomly selected to be slaughtered to determine the chemical composition of the empty body at the end of the trial.

Table 3.1 *Experimental design showing treatment structure (group size and floor-space allowance) and replications across all buildings.*

Treatment	Lysine Treatment	Pigs/pen	Floor-space allowance (m^2/pig)	Feeding Level
1	L1	1	1.72	*Ad libitum*
2	L2	1	1.72	*Ad libitum*
3	L3	1	1.72	*Ad libitum*
4	L4	1	1.72	*Ad libitum*
5	L1	1	1.72	Restricted: Paired with 4 pigs/pen
6	L2	1	1.72	Restricted: Paired with 4 pigs/pen
7	L3	1	1.72	Restricted: Paired with 4 pigs/pen
8	L4	1	1.72	Restricted: Paired with 4 pigs/pen
9	L1	1	1.72	Restricted: Paired with 8 pigs/pen
10	L2	1	1.72	Restricted: Paired with 8 pigs/pen
11	L3	1	1.72	Restricted: Paired with 8 pigs/pen
12	L4	1	1.72	Restricted: Paired with 8 pigs/pen
13	L1	4	1.72	*Ad libitum*
14	L2	4	1.72	*Ad libitum*
15	L3	4	1.72	*Ad libitum*
16	L4	4	1.72	*Ad libitum*
17	L1	8	1.94	*Ad libitum*
18	L2	8	1.94	*Ad libitum*
19	L3	8	1.94	*Ad libitum*
20	L4	8	1.94	*Ad libitum*
21	L1	8	0.86	*Ad libitum*
22	L2	8	0.86	*Ad libitum*
23	L3	8	0.86	*Ad libitum*
24	L4	8	0.86	*Ad libitum*

3.2.3 Housing and Management

Pigs were housed in one of three buildings each containing light timers set at 16 L: 8 D (sixteen hours of light and eight hours of darkness). One building contained 12 open-sided group pens with cemented floors sloping down towards a drainage area covered with plastic slats; the other buildings were open-sided, with cemented floors and a drainage area covered with plastic slats, roll up curtains and insulated ceilings. One of these two buildings contained 48 individual pens and the other 24 group pens. The open-sided group pens housed 8 pigs per pen and measured 15.53 m^2 (pen size minus feeder bin space) and had a large hardened plastic self-feeder bin (Lean Machine®) in the centre of the pen with two nipple drinkers and two feed dispensing levers activated by touch. An additional nipple drinker was provided on the side of each pen. The individual pens measured 1.72 m^2 (pen size minus feeder bin space) each pen having its own nipple drinker and two hardened plastic self-feeder bins. The group pens, measuring 6.86 m^2 (pen size minus feeder bin space), housed either four or eight pigs per pen, each pen having two nipple drinkers and two hardened plastic self-feeder bins. The allocation of pigs per pen was intended to produce the following stocking density (or space allocation) treatments: 1.72 (one pig/pen), 1.72 (four pigs/pen), 0.86 (eight pigs/pen) and 1.94 (eight pigs/pen) m^2/pig. The recommendations for adequate floor-space allowance over the weight range 27 to 100 kg according to Kornegay and Notter (1984) is between 0.44 and 1.05 m^2 with an average of 0.74 m^2. In this experiment the group and individually-housed treatments were provided with a floor-space allowance greater than the adequate recommendations.

These facilities allowed for free and continuous access to feed (except in the case of the pair-fed pigs) and water. The pigs were weighed weekly on Wednesdays at 06h00 until they were within three kg of the changeover (60kg) and slaughter weight (85kg) whereupon they were weighed every second day. The feeder bins were checked twice daily and when feed was required, this was weighed out and recorded. On Thursdays, at 08h00, the feed remaining at the end of the week was measured, whereafter feed intakes for the pigs fed *ad libitum* were calculated by determining the difference in the weight of the feed plus feeder at the beginning and end of each week, in addition to any feed that was weighed out in between.

3.2.4 Diets and Feeding

A summit-dilution technique described by Ferguson *et al.* (2000a) was used to produce the four dietary treatments in each growth period. The summit diet for period one was formulated to contain 13.8 MJ DE, 11.2 g lysine/kg and 185 g protein/kg and for period two 12.9 MJ DE, 8.1 g lysine/kg and 152 g protein/kg. In both cases a minimum of 1.3 of the requirements of all the essential amino acids other than lysine, ensured that lysine (at 1.2 of requirement) was the limiting amino acid in the feed. The dilution diets for periods one and two were formulated to contain 13.6 MJ DE, 6.7 g lysine/kg and 125 g protein/kg, and 13.0 MJ DE, 4.7 g lysine/kg and 89 g protein/kg respectively. In this feed a minimum of 0.65 of the requirements of all the essential amino acids other than lysine (at 0.60 of the requirement) were specified. The composition of these four basal feeds is given (Table 3.2). Amino acid requirements were determined by the model described by Ferguson *et al.* (1994). The model allows for the prediction of amino acid requirements for a given dietary energy level based on the assumption that potential growth can be estimated from the Gompertz growth function. Values for the parameters defined by the Gompertz function were determined from data acquired from previous experiments where a similar genotype was used (Ferguson and Gous, 1997). The summit diet was blended with the dilution diet in the required proportions (1.0:0.00, 0.67:0.33, 0.33:0.67, 0.00:1.00) to obtain the four dietary treatments (L1, L2, L3 and L4) in both growing periods (Table 3.3). Vitamins and minerals were included at 1.5 times the prescribed rate to ensure that these were not limiting. The composition of the dietary treatments used in both growth periods, determined by chemical analysis is given (Table 3.4). In order to improve the accuracy with which the protein and lysine contents of the experimental feeds was estimated, a linear regression of the measured dietary protein and lysine contents on the proportion of summit feed in each treatment was performed on the data for both growth periods, and the fitted values are given (Table 3.5). Amino acid contents were determined using single-column ion-exchange chromatography in a Beckman 6300 (Applications Data, 1983) after hydrolysis in 6N HCl (Moore and Stein, 1948; Association of Official Analytical Chemists, 2003). The regression equations for dietary lysine and protein concentration in both growth periods are given (Table 3.5).

3.2.5 Application of the pair-feeding technique

The body weights of the individually-housed pigs at the start of the week were used throughout the week when calculating the daily amount of feed to be allocated to each pig. The feed allocation for each pig each day was weighed out at 07h00 in a 3ℓ plastic bucket. Half of this allocation was fed at 07h30 and the other half at 15h00. This procedure was performed to ensure that the individually-penned restricted pigs were fed at the same rate as the group-penned (four and eight pigs/pen) *ad libitum* pigs determined in the following manner. The feeder bins were checked twice daily and when feed was required, this was weighed out and recorded. Every alternate day the feed remaining at the end of the two day period was measured, whereafter feed intakes for the group-penned pigs fed *ad libitum* were calculated by determining the difference in the weight of the feed plus feeder at the beginning and end of each two-day period. Thereafter, the feed intake was divisible by the weekly average body weight raised to the power of 0.75 (metabolic rate) of the respective group for the week in question to determine a coefficient. A mean coefficient for each lysine and group size treatment was obtained through an average and multiplied by the weekly body weight raised to the power of 0.75 (metabolic rate) of the individual in question to ascertain the daily feed allocation over the two day period. This procedure was repeated over both growth periods. All individually-penned restricted pigs were treated similarly and assigned the same coefficients over both growth periods as the trial progressed.

The daily feed allocation for pair-fed pigs was determined in the following manner:

The coefficient for the group-penned *ad libitum* pigs:
[(Feed In – Feed Out) / Pigs per pen / Days / Weekly average body weight, $kg^{0.75}$)]

The daily feed allocation for individually-penned restricted pigs:
Coefficient × Weekly body weight, $kg^{0.75}$

3.2.6 Slaughter Procedure and Carcass Analysis

Pigs were killed by exsanguination, after being stunned. Blood was collected in a 2ℓ plastic bucket. The pigs were eviscerated and the gastrointestinal tract, bladder, heart, liver, lungs, kidneys and reproductive organs were removed. The empty carcass was halved along the midline, with the right half of the carcass being chosen for further analyses. The half carcass, organs and blood were stored overnight at 0°C in a sealed plastic bag. The contents of the stomach and intestines were emptied and weighed. The half carcass was portioned and, together with the empty gastrointestinal tract, remaining organs and blood, stored in a sealed plastic bag and frozen at -20°C. The frozen carcass portions and half the combined blood and organs were later homogenized in a mincer. Samples were then collected in duplicate from each pig in 500g glass containers and used in the laboratory for proximate analysis according to Association of Official Analytical Chemists (2003) methods, except for lipid which was calculated from the gross energy and protein contents according to the following equation described by Ferguson *et al.* (2000a):

lipid (g/kg DM) = (2.410 × GE) – (0.5898 × protein)

where: GE = gross energy, MJ/kg DM; protein = protein content, g/kg DM.

The duplicated results were averaged to provide a single result for each pig. The dry matter content of each sample was determined by freeze-drying the samples for 72 hours. The ash content was determined by burning in a muffle furnace at 550°C overnight, while the crude protein content was calculated as nitrogen x 6.25, where nitrogen content of the dry matter was determined on a LECO FP 2000 Nitrogen Analyser (LECO Corporation, 3000 Lakeview Avenue, St Joseph, Michigan, U.S.A) using the Dumas combustion method, approved by Association of Official Analytical Chemists (2003).

Table 3.2 *The ingredient and calculated chemical composition (g/kg fresh weight) of the summit (L1) and dilution (L4) feeds offered in the two periods.*

Ingredient	Period 1 (40 to 60 kg)		Period 2 (60 to 85 kg)	
	Summit	Dilution	Summit	Dilution
Yellow maize	669.20	840.40	658.20	828.70
Soybean oilcake meal	257.40	38.00	151.90	
Wheat bran	25.00	41.00	147.40	126.00
Monocalcium phosphate	30.00	33.00	23.60	27.00
Limestone	10.00	9.50	9.50	9.00
Salt	3.33	3.40	3.30	3.33
Vitamin and mineral premix	3.10	3.10	3.10	3.10
Extruded full fat soya		3.00		
Lysine HCl	1.60	1.60	1.90	1.90
Natuphos Pig 500			1.00	1.00
Methionine DL	0.30		0.00	
Calculated Composition (g/kg):				
Crude Protein (N x 6.25)	185.00	124.80	151.90	88.80
Digestible Energy (MJ/kg) †	13.76	13.62	12.91	13.05
Lysine, Total Calculated	10.60	5.30	7.80	4.40
Lysine, Total Analysed	11.26	6.78	8.11	4.70
Lysine, True Digestible‡	10.00	4.80	7.70	3.70

† DE = 3.77 - (0.19 × NDF) + (0.75 × GE) (Whittemore, 1993)

‡ Winfeed 2 Feed Formulator, EFG Software (Natal) (2003)

Table 3.3 *Dilution of summit diet with dilution diet, and the expected lysine concentration and proportion of requirements of the dietary treatments for both growing periods.*

			Lysine concentration (g/kg)	
Treatment	Dilution (%)	Proportion of requirement	Period 1 (40 to 60 kg)	Period 2 (60 to 85 kg)
L1	0	1.20	10.60	7.80
L2	33	1.00	8.85	6.68
L3	67	0.80	7.05	5.52
L4	100	0.60	5.30	4.40

Table 3.4 *Chemical composition (g/kg) of the summit, dilution and blended diets determined by analysis for Periods 1 and 2.*

Nutrient (g/kg)	Summit (L1)		L2		L3		Dilution (L4)	
Growth Period (kg)	40–60	60–85	40–60	60–85	40– 60	60–85	40–60	60–85
Digestible Energy (MJ/kg)†	13.76	12.91	13.65	12.90	13.61	12.89	13.62	13.05
'Fitted'	13.60	12.75	13.56	12.79	13.51	12.83	13.47	12.87
Metabolizable Energy (MJ/kg)‡	13.71	12.87	13.20	12.86	13.57	12.85	13.58	13.00
'Fitted'	13.55	12.71	13.51	12.75	13.47	12.79	13.42	12.83
Crude protein (g/kg)	185	152	157	128	139	109	125	89
'Fitted'	181	151	162	130	141	109	122	88
Lysine, Total Analysed (g/kg)	11.26	8.11	9.34	6.40	7.69	5.31	6.78	4.70
'Fitted'	11.03	7.82	9.54	6.71	8.00	5.55	6.51	4.44
'Digestible'	10.00	7.70	8.28	6.38	6.52	5.02	4.80	3.70
Total methionine	2.24	1.60	2.02	1.57	1.76	1.31	1.50	1.23
Total threonine	5.19	4.79	4.88	4.32	4.25	3.49	3.65	2.74

†DE = 3.77 - (0.19 × NDF) + (0.75 × GE) (Whittemore, 1993)

NDF = neutral-detergent fibre; GE = gross energy

‡ME = DE × (0.997 – 0.000189 × crude protein) (Agricultural Research Council, 1981)

Table 3.5 *A summary of the regression equations for dietary lysine and protein concentration for Periods 1 and 2.*

Dietary component	Constant term	Regression coefficient	s.e.	R^2
Lysine	4	8		
40 – 60 kg	6.51 ± 0.303	4.52 ± 0.485	0.362	0.960
60 – 85 kg	4.44 ± 0.326	3.39 ± 0.523	0.390	0.930
Protein				
40 – 60 kg	12.2 ± 0.424	5.93 ± 0.680	0.508	0.960
60 – 85 kg	8.84 ± 0.152	6.23 ± 0.244	0.182	0.990

3.2.7 Statistical Analysis

The data were divided into three live weight periods: 40 to 60; 60 to 85 and 40 to 85 kg to establish whether responses to growth at an increasing lysine level were dependent on live weight. A pen of pig(s) was the experimental unit for all statistical analyses. The average daily gain (ADG) for each treatment was determined from a linear regression analysis of live weight over time for each week and growth period. The average pen weight was used for the group-housed treatment whilst individual weights were used for the single-penned pigs. The mean ADG between the various live weight ranges was provided by the regression coefficient.

The existing infrastructure did not permit the exact number of replications across all buildings, thus buildings were used to impose the different stressors resulting in some confounding of group size and space allocation. Multiple linear regression analyses were performed to determine whether the responses were a consequence of group size, floor-space allowance or a combination of the two. The results of the multiple regression analyses showed that there were no significant quadratic effects in any instance; therefore, simple linear regressions were used. One individually penned animal died of natural causes and his data from 60 to 85 kg was disregarded and treated as a missing plot.

This investigation was designed to characterize the effects of group size and space allocation as stressors on the efficiency of utilisation of lysine by growing pigs. The efficiency of utilisation of lysine is measured by regressing body lysine gain on digestible lysine intake and comparing the amount of digestible lysine required per gram lysine gain with the amount of lysine in the tissue being formed. The appropriate statistical analysis is therefore a simple linear regression analysis with groups (Genstat Release 6.1 (2002)); the groups being the various stressors imposed on the pigs. The three stressors used in this trial as possible modifiers of the efficiency of utilisation of lysine, were group size, feeding regime and space allocation. Each of these was used as a 'group' when regressing average daily gain and protein retention on lysine intake and lysine retention on digestible lysine intake. Prior to conducting the linear regression with groups it was necessary to determine whether the responses were linear or quadratic, so curvilinear regressions were initially performed on the data, using lysine intake and it's squared term as independent variates.

Due to the complexity of the experiment the results could not be presented in a comprehensive table. Instead, tables containing specific contrasts are presented, and graphs have been included to illustrate the overall effects of group size, feeding level, floor-space allowance and constant group size at varying floor-space allowance on growth performance and carcass characteristics.

Residual maximum likelihood Meta Analysis (REML) was not used as it brings together comparisons that may utilise different measures of the same variables, different statistical techniques and different settings resulting in a loss of information. Also, the random effect (building) was bound; indicating that the variation attributed to this factor could not be quantified.

3.3 RESULTS

The proportions for the summit (L1), blends (L2 and L3) and dilution (L4) are presented in Table 3.6.

Table 3.6 *Feed intake on the restricted feeding treatments as a proportion of the ad libitum intake over three periods of growth.*

	Proportion of *ad libitum* intake	
Level	Restricted: Paired with 4 pigs/pen	Restricted: Paired with 8 pigs/pen
40 – 60 kg		
L1	0.82	0.80
L2	0.85	0.82
L3	0.93	0.85
L4	0.98	0.87
60 – 85 kg		
L1	0.88	0.85
L2	0.85	0.79
L3	0.86	0.87
L4	0.88	0.82
40 – 85 kg		
L1	0.72	0.69
L2	0.73	0.69
L3	0.81	0.79
L4	0.84	0.77

The Restricted four pigs/pen and Restricted eight pigs/pen fed higher lysine contents experienced the pair feeding technique to a greater extent than pigs fed lower lysine contents and this trend was particularly evident over the 40 to 60 and 40 to 85 kg growth period.

A summary of days on trial for the three group sizes (1, 4 and 8 pigs/pen), housed at three floor-space allowances (0.86, 1.72 and 1.94 m^2/pig) on the feeding regimes imposed (*Ad libitum*, Restricted four pigs/pen and Restricted eight pigs/pen) and offered feeds varying in lysine content during the two periods of growth is shown in Table 3.7.

Among the *ad libitum* treatments the number of days on trial over all periods of growth was unaffected by group size and floor-space allowance but increased significantly as the dietary lysine content decreased. Within the pigs housed individually the number of days on trial increased significantly as dietary lysine content decreased and feed restriction increased.

The pair feeding technique may have been flawed experimentally as the coefficient for the group-penned *ad libitum* pigs was determined every alternate day and based on the weekly average body weight. Consequently, the product of the coefficient and average weekly body weight determined the daily feed allocation for the individually-penned restricted pigs. However, given the nature of this experiment, the manner in which the daily feed allocation for pair-fed pigs was calculated was practical both from an animal and management point of view. The daily weighing of all the group-penned and individually-penned pigs would have required additional labour and more importantly created unnecessary stress.

The effect of floor-space allowance – varying group size with the same pen size (6.86 m^2)

The effects of dietary lysine and group size (4 or 8 pigs/pen) on the average daily gain, feed intake and feed conversion efficiency (FCE) of growing pigs over three live weight periods, given a fixed floor-space (6.86 m^2), are shown in Table 3.8.

The linear increase in average daily gain with increasing dietary lysine content was similar for both group sizes over the early (40 to 60 kg), late (60 to 85 kg) and overall (40 to 85 kg) growth periods (42, 128 and 86 g/day per g/kg of dietary lysine, respectively). However, at any dietary lysine concentration pigs housed in groups of 8 had significantly lower average daily gains than pigs housed in groups of 4 ($P < 0.05$, $P < 0.01$ and $P < 0.001$ for the early, late and overall growth periods, respectively). Over the early growth period, feed intake decreased for the groups of 4 ($P > 0.05$) and increased for the groups of 8 ($P < 0.05$) with dietary lysine content. Nonetheless, the groups of 8 still consumed significantly less ($P < 0.01$) when compared to the groups of 4. However, for the late and overall growth periods the linear increase in feed intake with dietary lysine content (105 and 65 g/day per g/kg of dietary lysine, respectively) was similar for both group sizes. Thus, at any dietary lysine concentration pigs housed in groups of 8 had significantly ($P < 0.01$ and $P < 0.001$ for late and overall growth periods, respectively) lower feed intakes than pigs housed in groups of 4. FCE was unaffected by group size during the early and overall growth periods but increased linearly as the dietary lysine content increased. Over the late growth period, the linear increase in FCE with dietary lysine content (41 g gain/kg feed per g/kg of dietary lysine) was similar for both group sizes. However, the pigs housed in groups of 8 had significantly ($P < 0.05$) lower efficiencies than pigs housed in groups of 4 at all dietary lysine concentrations.

The effects of dietary lysine and group size (4 or 8 pigs/pen) on the chemical composition of the empty body weight of pigs at 85 kg live weight and the daily rate of change in empty body ash, lipid, protein and water between 40 and 85 kg of pigs given a fixed floor-space (6.86 m^2) are shown in Tables 3.9 and 3.10.

Ash decreased while protein content increased at increasing dietary lysine contents, with group size having no effect on this response. Lipid content decreased and water content increased as the lysine content increased for the groups of 4 ($P < 0.001$) and 8 pigs ($P < 0.01$). Pigs housed in groups of 8 contained significantly less lipid ($P < 0.01$) and more water ($P < 0.01$) than pigs housed in groups of 4.

Ash retention was unaffected by group size, but increased linearly with dietary lysine content. Lipid retention decreased linearly for the groups of 4 ($P < 0.01$) but increased linearly for the groups of 8 ($P < 0.05$) as the lysine content increased, although the groups of 8 had significantly ($P < 0.01$) lower lipid retentions compared with pigs housed in groups of 4. The linear increase in protein and water retention with dietary lysine content was similar for both group sizes (22 and 69 g/day per g/kg of dietary lysine, respectively). However, at all dietary lysine concentrations, pigs housed in groups of eight had significantly lower protein retentions ($P < 0.05$) and higher water retentions ($P = 0.01$) than pigs housed in groups of four.

The effect of group size – similar floor-space allowance

The effects of dietary lysine and group size (4 or 8 pigs/pen) on the average daily gain, feed intake and feed conversion efficiency (FCE) of growing pigs over three different live weight periods at a similar floor-space allowance (1.72 or 1.94 m^2/pig) are shown in Table 3.11.

Group size had no effect on average daily gain over all growth periods, but increased linearly with dietary lysine content. Feed intake was not influenced by group size, but decreased linearly ($P > 0.05$) during the early growth period and increasing linearly ($P < 0.05$) during the late growth period as dietary lysine content increased. The linear increase in feed intake with dietary lysine content ($P > 0.05$) over the overall growth period was similar for both group sizes. However, at all dietary lysine concentrations pigs housed in groups of 8 had significantly ($P < 0.01$) lower feed intakes than pigs housed in groups of 4. Over the early growth period the linear increase in FCE (17 g gain/kg feed per g/kg of dietary lysine) with dietary lysine content was similar for both group sizes. Pigs housed in groups of 8 had significantly ($P < 0.05$) lower efficiencies than pigs housed in groups of 4. Group size had no effect on FCE over the late and overall growth period, although FCE increased linearly with dietary lysine content during these periods.

The effects of dietary lysine and group size (4 or 8 pigs/pen) on the chemical composition of the empty body weight of pigs at 85 kg live weight given a similar floor-space allowance (1.72 and 1.94 m^2/pig), and the daily rate of change in empty body ash, lipid, protein and water between 40 and 85 kg, are shown in Tables 3.12 and 3.13.

Although the components were unaffected by group size, ash and lipid decreased and protein and water increased linearly as the dietary lysine content increased.

Ash, protein and water retention were unaffected by group size and increased as the dietary lysine content increased whilst lipid retention decreased.

Table 3.7 *The number of days on trial for three group sizes (1, 4 and 8 pigs/pen), housed at three floor-space allowances (0.86, 1.72 and 1.94 m²/pig) on the feeding regimes imposed (Ad libitum, Restricted 4 pigs/pen and Restricted 8 pigs/pen).*

Pigs/pen		1		4	8	
Space (m^2/pig)		1.72		1.72	0.86	1.94
Level	AL	R4	R8	AL	AL	AL
40 – 60 kg						
L1	18	21	24	21	23	24
L2	18	25	24	23	24	23
L3	24	25	28	26	29	25
L4	26	26	29	25	28	27
60 – 85 kg						
L1	23	29	32	28	28	27
L2	24	30	35	26	33	31
L3	31	36	36	35	37	34
L4	39	41	42	46	50	43
40 – 85 kg*						
L1	41	50	56	49	51	51
L2	42	55	59	49	57	54
L3	55	61	64	61	66	59
L4	65	67	71	71	78	70

* The days on trial for the 40 to 85 kg live weight period was calculated by the addition of the 40 to 60 and 60 to 85 kg live weight period respectively.

Table 3.8 *Mean weight gain, feed intake and feed conversion efficiency of pigs given a fixed floor-space (6.86 m²), housed in groups of four or eight pigs/pen, and offered one of four feeds varying in lysine content, over three periods of growth.*

Factor	Gain in weight (g/d)			Feed intake (kg/d)			Feed conversion efficiency (g gain/kg feed)		
Pigs/pen	4	8	Mean	4	8	Mean	4	8	Mean
40 – 60 kg									
L1	963	879	921	2.02	2.00	2.01	477	439	458
L2	852	842	847	2.03	1.98	2.01	419	427	423
L3	773	721	747	1.99	1.86	1.93	389	387	388
L4	823	666	745	2.12	1.76	1.94	387	379	383
Mean	853	777		2.04	1.90		418	408	
R.M.S.		5181			0.0160			398	
s.e.d. (L)		41.6			0.0729			11.5	
s.e.d. (P)		29.4			0.0516			8.14	
s.e.d. (L x P)		58.8			0.103			16.3	
60 – 85 kg									
L1	944	889	916	2.58	2.48	2.53	368	358	363
L2	954	733	844	2.71	2.35	2.53	352	312	332
L3	698	641	670	2.43	2.35	2.39	286	272	279
L4	542	435	488	2.33	2.03	2.18	234	215	224
Mean	784	675		2.51	2.30		310	289	
R.M.S.		4406			0.0309			363	
s.e.d. (L)		38.3			0.102			11.0	
s.e.d. (P)		27.1			0.0717			7.78	
s.e.d. (L x P)		54.2			0.144			15.6	
40 – 85 kg									
L1	929	875	902	2.52	2.28	2.40	370	385	377
L2	904	783	844	2.56	2.23	2.39	354	351	353
L3	741	683	712	2.38	2.18	2.28	311	314	313
L4	631	514	573	2.36	1.95	2.16	269	264	266
Mean	801	714		2.45	2.16		326	328	
R.M.S.		2010			0.0224			233	
s.e.d. (L)		25.9			0.0864			8.80	
s.e.d. (P)		18.3			0.0611			6.23	
s.e.d. (L x P)		36.6			0.122			12.5	

Table 3.9 *Mean ash, lipid, protein and water content in the empty body at 85 kg of pigs housed at constant floor-space (6.86 m²) and kept at two group sizes (4 and 8 pigs/pen) on four dietary lysine contents.*

Component	Ash (g/kg)			Lipid (g/kg)			Protein (g/kg)			Water (g/kg)		
Pigs/pen	4	8	Mean	4	8	Mean	4	8	Mean	4	8	Mean
40 – 85 kg												
L1	27.7	28.2	27.9	126	145	136	175	172	174	655	637	646
L2	28.7	28.5	28.6	161	165	163	167	169	168	628	625	626
L3	31.1	29.2	30.1	186	177	181	162	162	162	609	618	614
L4	29.2	31.5	30.4	233	203	218	150	154	152	574	600	587
Mean	29.2	29.3		176	172		164	165		616	620	
R.M.S.		17.4			262			16.3			147	
s.e.d. (L)		2.41			9.34			2.33			7.00	
s.e.d. (P)		1.70			6.60			1.65			4.95	
s.e.d. (L x P)		3.41			13.2			3.30			9.90	

Table 3.10 *Mean ash, lipid, protein and water retention from 40 to 85 kg of pigs housed at constant floor-space (6.86 m²) and kept at two group sizes (4 and 8 pigs/pen) on four dietary lysine contents.*

Retention	Ash (g/d)			Lipid (g/d)			Protein (g/d)			Water (g/d)		
Pigs/pen	4	8	Mean	4	8	Mean	4	8	Mean	4	8	Mean
40 – 85 kg												
L1	27	27	27	136	160	148	170	156	163	570	506	538
L2	27	24	26	186	168	177	146	133	139	479	425	452
L3	25	21	23	181	161	171	111	107	109	369	362	366
L4	20	19	19	214	152	183	84	74	79	281	255	268
Mean	25	23		179	160		128	117		425	387	
R.M.S.		27.1			743.8			150.3			1189	
s.e.d. (L)		3.01			15.75			7.08			19.91	
s.e.d. (P)		2.13			11.13			5.00			14.08	
s.e.d. (L x P)		4.25			22.27			10.01			28.16	

Table 3.11 *Mean weight gain, feed intake and feed conversion efficiency of pigs given similar floor-space allowances (1.72 and 1.94 m²/pig), housed in groups of four or eight pigs/pen, and offered one of four feeds varying in lysine content, over three periods of growth.*

Factor	Gain in weight (g/d)			Feed intake (kg/d)			Feed conversion efficiency (g gain/kg feed)		
Pigs/pen	4	8	Mean	4	8	Mean	4	8	Mean
40 – 60 kg									
L1	963	826	894	2.02	1.96	1.99	477	418	447
L2	852	851	852	2.03	2.06	2.05	419	415	417
L3	773	787	780	1.99	2.09	2.04	389	376	383
L4	823	716	770	2.12	2.00	2.06	387	359	373
Mean	853	795		2.04	2.03		418	392	
R.M.S.		9058			0.0282			528	
s.e.d. (L)		54.9			0.0969			13.3	
s.e.d. (P)		38.9			0.0685			9.38	
s.e.d. (L x P)		77.7			0.137			18.8	
60 – 85 kg									
L1	944	960	952	2.58	2.47	2.52	368	389	378
L2	954	814	884	2.71	2.48	2.60	352	328	340
L3	698	712	705	2.43	2.40	2.42	286	297	292
L4	542	564	553	2.33	2.36	2.35	234	237	235
Mean	784	763		2.51	2.43		310	313	
R.M.S.		7445			0.0392			631	
s.e.d. (L)		49.8			0.114			14.5	
s.e.d. (P)		35.2			0.0808			10.3	
s.e.d. (L x P)		70.5			0.162			20.5	
40 – 85 kg									
L1	929	895	912	2.52	2.23	2.38	370	401	385
L2	904	822	863	2.56	2.35	2.46	354	350	352
L3	741	743	742	2.38	2.28	2.33	311	325	318
L4	631	614	623	2.36	2.22	2.29	269	278	273
Mean	801	769		2.45	2.27		326	338	
R.M.S.		3940			0.0266			467	
s.e.d. (L)		36.2			0.0942			12.5	
s.e.d. (P)		25.6			0.0666			8.82	
s.e.d. (L x P)		51.2			0.133			17.6	

Table 3.12 *Mean ash, lipid, protein and water content in the empty body at 85 kg of pigs housed at similar floor-space allowances (1.72 and 1.94 m²/pig) and kept at two group sizes (4 and 8 pigs/pen) on four dietary lysine contents.*

Component	Ash (g/kg)			Lipid (g/kg)			Protein (g/kg)			Water (g/kg)		
Pigs/pen	4	8	Mean	4	8	Mean	4	8	Mean	4	8	Mean
40 – 85 kg												
L1	27.7	30.4	29.1	126	127	127	175	175	175	655	652	654
L2	28.7	28.4	28.6	161	156	159	167	169	168	628	631	630
L3	31.1	30.4	30.8	186	184	185	162	162	162	609	606	607
L4	29.2	28.4	28.8	233	213	223	150	155	152	574	591	583
Mean	29.2	29.4		176	170		164	165		616	620	
R.M.S.		16.7			196			15.7			101	
s.e.d. (L)		2.36			8.09			2.29			5.81	
s.e.d. (P)		1.67			5.72			1.62			4.11	
s.e.d. (L x P)		3.34			11.44			3.24			8.22	

Table 3.13 *Mean ash, lipid, protein and water retention from 40 to 85 kg of pigs housed at similar floor-space allowances (1.72 and 1.94 m²/pig) and kept at two group sizes (4 and 8 pigs/pen) on four dietary lysine contents.*

Retention	Ash (g/d)			Lipid (g/d)			Protein (g/d)			Water (g/d)		
Pigs/pen	4	8	Mean	4	8	Mean	4	8	Mean	4	8	Mean
40 – 85 kg												
L1	27	30	29	136	133	134	170	163	167	570	538	554
L2	27	25	26	186	166	176	146	140	143	479	455	467
L3	25	25	25	181	188	184	111	116	113	369	379	374
L4	20	19	19	214	191	203	84	91	87	281	301	291
Mean	25	25		179	170		128	127		425	418	
R.M.S.		27.8			717			232.2			2141	
s.e.d. (L)		3.05			15.46			8.80			26.71	
s.e.d. (P)		2.15			10.93			6.22			18.89	
s.e.d. (L x P)		4.31			21.86			12.44			37.78	

Effect of floor-space allowance – same group size

The effects of dietary lysine and floor-space allowance (0.86 or 1.94 m^2/pig) on the average daily gain, feed intake and feed conversion efficiency (FCE) of growing pigs over three live weight periods at a constant group size (8 pigs/pen) are shown in Table 3.14.

Floor-space allowance had no effect on average daily gain over the early growth period and FCE over the overall growth period although both increased with dietary lysine content. Over the late and overall growth periods, the rate of increase in average daily gain with dietary lysine content (120 and 81 g/day per g/kg of dietary lysine, respectively) were similar for both floor-space allowances. However, at any dietary lysine content pigs provided a space of 1.94 m^2/pig had significantly ($P < 0.01$ and $P < 0.05$ for the late and overall growth periods, respectively) higher average daily gains than pigs provided with 0.86 m^2/pig. The linear increase in feed with dietary lysine content over the early ($P > 0.05$) and late growth ($P < 0.01$) periods, resulted in pigs provided with 1.94 m^2/pig having significantly ($P < 0.05$) higher feed intakes than pigs provided with 0.86 m^2/pig at any dietary lysine concentration. Over the overall growth period, feed intake increased linearly as the dietary lysine content increased at both floor-space allowances, but this increase was significantly ($P < 0.05$) higher for pigs allocated the larger space. FCE increased linearly (15 and 42 g gain/kg feed per g/kg of dietary lysine) with dietary lysine content for both floor-space allowances over the early and late growth periods, respectively. Over the early growth period, at any dietary lysine concentration, pigs provided with 1.94 m^2/pig had significantly ($P < 0.05$) lower FCE's than pigs provided with 0.86 m^2/pig. The opposite occurred over the late growth period such that pigs provided with 1.94 m^2/pig had significantly ($P < 0.05$) higher FCE's than pigs provided with 0.86 m^2/pig.

The effects of dietary lysine and floor-space allowance (0.86 and 1.94 m^2/pig) on the chemical composition of the empty body weight of pigs at 85 kg live weight and the daily rate of change in empty body ash, lipid, protein and water between 40 and 85 kg of pigs at constant group size (8 pigs/pen) are shown in Tables 3.15 and 3.16.

Ash and protein content were unaffected by floor-space allowance and ash decreased while protein increased as the dietary lysine content increased. As the dietary lysine content increased, the lipid content decreased while the water content increased. Pigs provided with floor-space allowances of 1.94 m^2/pig had significantly lower lipid ($P < 0.05$) and higher water ($P < 0.05$) contents compared to pigs provided with 0.86 m^2/pig.

Floor-space allowance had no effect on ash, protein and water retention, which tended to increase as the dietary lysine content increased. The increase in dietary lysine content resulted in lipid retention increasing ($P > 0.05$) for pigs provided with 0.86 m^2/pig and decreasing ($P < 0.01$) for pigs provided with 1.94 m^2/pig. However, at the highest dietary lysine content, pigs provided with 1.94 m^2/pig had a significantly ($P < 0.01$) higher lipid retention compared to pigs provided with 0.86 m^2/pig.

Table 3.14 *Mean weight gain, feed intake and feed conversion efficiency of pigs allocated different floor-space allowances (0.86 and 1.94 m²/pig), housed in groups of 8 pigs/pen, and offered one of four feeds varying in lysine content, over three periods of growth.*

Factor	Gain in weight (g/d)			Feed intake (kg/d)			Feed conversion efficiency (g gain/kg feed)		
Space (m^2)	0.86	1.94	Mean	0.86	1.94	Mean	0.86	1.94	Mean
40 – 60 kg									
L1	879	826	852	2.00	1.96	1.98	439	418	428
L2	842	851	847	1.98	2.06	2.02	427	415	421
L3	721	787	754	1.86	2.09	1.98	387	377	382
L4	666	716	691	1.76	2.00	1.88	379	359	369
Mean	777	795		1.90	2.03		408	392	
R.M.S.		5734			0.0210			383	
s.e.d. (L)		43.7			0.0837			11.3	
s.e.d. (P)		30.9			0.0592			7.99	
s.e.d. (L x P)		61.8			0.118			16.0	
60 – 85 kg									
L1	889	960	925	2.48	2.47	2.48	358	389	374
L2	733	814	774	2.35	2.48	2.42	312	328	320
L3	641	712	677	2.35	2.40	2.38	272	297	285
L4	435	564	500	2.03	2.36	2.20	215	237	226
Mean	675	763		2.30	2.43		289	313	
R.M.S.		6704			0.0171			713	
s.e.d. (L)		47.3			0.0755			15.4	
s.e.d. (P)		33.4			0.0534			10.9	
s.e.d. (L x P)		66.9			0.107			21.8	
40 – 85 kg									
L1	875	895	885	2.28	2.23	2.26	385	401	393
L2	783	822	803	2.23	2.35	2.29	351	350	351
L3	683	743	713	2.18	2.28	2.23	314	325	320
L4	514	614	564	1.95	2.20	2.09	264	277	270
Mean	714	769		2.16	2.27		328	338	
R.M.S.		3026			0.0112			368	
s.e.d. (L)		31.8			0.0610			11.1	
s.e.d. (P)		22.5			0.0432			7.83	
s.e.d. (L x P)		44.9			0.0863			15.7	

Table 3.15 *Mean ash, lipid, protein and water content in the empty body at 85 kg of pigs housed at varying floor-space allowances (1.72 and 1.94 m^2/pig) and kept at constant group size (8 pigs/pen) on four dietary lysine contents.*

Component	Ash (g/kg)			Lipid (g/kg)			Protein (g/kg)			Water (g/kg)		
Space (m^2)	0.86	1.94	Mean	0.86	1.94	Mean	0.86	1.94	Mean	0.86	1.94	Mean
40 – 85 kg												
L1	28.2	30.4	29.3	145	128	136	172	175	174	637	652	645
L2	28.5	28.4	28.5	165	156	160	169	169	169	625	631	628
L3	29.2	30.4	29.8	177	184	181	162	162	162	618	606	612
L4	31.5	28.4	29.9	203	213	208	154	155	155	600	591	595
Mean	29.3	29.4		172	170		165	165		620	620	
R.M.S.		10.9			203			23.0			124	
s.e.d. (L)		1.90			8.22			2.77			6.43	
s.e.d. (P)		1.35			5.82			1.96			4.55	
s.e.d. (L x P)		2.69			11.6			3.92			9.10	

Table 3.16 *Mean ash, lipid, protein and water retention from 40 to 85 kg of pigs housed at varying floor-space allowances (1.72 and 1.94 m^2/pig) and kept at constant group size (8 pigs/pen) on four dietary lysine contents.*

Retention	Ash (g/day)			Lipid (g/day)			Protein (g/day)			Water (g/day)		
Space (m^2)	0.86	1.94	Mean	0.86	1.94	Mean	0.86	1.94	Mean	0.86	1.94	Mean
40 – 85 kg												
L1	27	31	28	160	133	146	156	163	160	506	538	522
L2	24	25	24	168	166	163	133	140	136	425	455	440
L3	21	25	23	161	188	175	107	116	112	362	379	370
L4	19	19	19	152	191	172	74	91	82	255	301	278
Mean	23	25		160	170		117	127		387	418	
R.M.S.		10.73			499			220.1			1901	
s.e.d. (L)		1.89			12.90			8.57			25.17	
s.e.d. (P)		1.34			9.12			6.06			17.80	
s.e.d. (L x P)		2.68			18.25			12.11			35.60	

Effect of feeding level – Individuals; fed *Ad libitum (AL) vs.* Restricted to 4 (R4) or 8 (R8) pigs/pen

The effects of dietary lysine and feeding level on the average daily gain, feed intake and feed conversion efficiency (FCE) of individually-housed growing pigs over three live weight periods at a fixed floor- space (1.72 m^2/pig) are shown in Table 3.17.

Average daily gain increased linearly as the dietary lysine content increased for all feeding levels over all growth periods. Over the early growth period this increase was noted as being significantly ($P < 0.05$) lower for the R4 (33 g/day per g/kg of dietary lysine) compared to AL and R8 pigs (76 g/day per g/kg of dietary lysine). However, over the late growth period it was significantly ($P < 0.001$) lower for the R8 (16 g/day per g/kg of dietary lysine) compared to AL and R4 pigs (41 g/day per g/kg of dietary lysine) whilst over the entire growth period it was significantly ($P < 0.01$ and $P < 0.001$) lower for the R4 (67 g/day per g/kg of dietary lysine) and R8 (50 g/day per g/kg of dietary lysine) compared to AL (108 g/day per g/kg of dietary lysine) pigs. Feed intake over the early growth period increased for the pigs on AL and R8 ($P < 0.001$) and decreased for R4 ($P < 0.01$) as the dietary lysine content increased resulting in the R4 pigs consuming significantly ($P < 0.05$) less feed than the AL and R8 pigs. Over the late growth period the linear increase in feed intake with dietary lysine content was similar for all feeding levels but at any dietary lysine concentration the R4 and R8 consumed significantly ($P < 0.001$) less feed than the AL pigs. Feed intake over the overall growth period increased linearly as the dietary lysine content increased but this rate of increase was significantly ($P < 0.001$ and $P < 0.01$) lower for the R4 and R8 pigs respectively. The linear increase in FCE (20 g gain/kg feed per g/kg of dietary lysine) with dietary lysine content was similar for all feeding levels over the early growth period, and at all dietary lysine concentrations the R4 and R8 pigs had significantly ($P < 0.05$ and $P < 0.01$ respectively) lower FCE's than the AL pigs. The converse was noted over the entire growth period where the R4 and R8 pigs had significantly ($P < 0.001$) higher FCE's than the AL pigs. However over the late growth period the FCE increased linearly (23 g gain/kg feed per g/kg of dietary lysine) as the dietary lysine content increased for all feeding levels but the R8 pigs had significantly ($P < 0.001$) lower FCE's (16 g gain/kg feed per g/kg of dietary lysine) compared with the AL and R4 pigs (41 g gain/kg feed per g/kg of dietary lysine).

The effects of dietary lysine and feeding level on the chemical composition of the empty body weight of pigs at 85 kg live weight and the daily rate of change in empty body ash, lipid, protein and water between 40 and 85 kg of pigs at a fixed floor-space allowance (1.72 m^2) and housed individually are shown in Tables 3.18 and 3.19.

Feeding level had no effect on ash or protein contents, both increasing as the dietary lysine content increased. The linear decrease in lipid content and increase in water content with dietary lysine content was similar for all feeding levels. However, at any dietary lysine concentration the R8 pigs contained significantly less lipid ($P < 0.05$) and more water ($P < 0.01$) than the AL and R4 pigs.

The linear increase in ash retention and decrease in lipid retention with dietary lysine content was similar for all feeding levels. However, at any dietary lysine concentration the R8 pigs had significantly ($P < 0.05$) lower ash retentions compared to AL and R4 pigs and the R4 and R8 had significantly lower lipid retentions ($P < 0.01$ and $P < 0.001$) than the AL pigs. Protein retention increased linearly with dietary lysine content for all feeding levels but the rate of increase was significantly ($P < 0.05$) lower for the R8 compared to AL and R4 pigs. The water retention increased linearly as the dietary lysine content increased for all feeding levels but this rate of increase was significantly lower ($P < 0.001$) for the R4 and R8 pigs, which had significantly ($P < 0.05$) higher water retentions compared to AL pigs.

Table 3.17 *Mean weight gain, feed intake and feed conversion efficiency of pigs given a fixed floor-space allowance (1.72 m²/pig), housed individually, and offered one of four feeds varying in lysine content and three feeding levels, (Ad libitum (AL), Restricted four pigs/pen (R4) and Restricted eight pigs/pen (R8) were pair-fed the amounts consumed by groups of four and eight pigs respectively), over three periods of growth.*

Factor	Gain in weight (g/d)				Feed intake (kg/d)				Feed conversion efficiency (g gain/kg feed)			
Level	AL	R4	R8	Mean	AL	R4	R8	Mean	AL	R4	R8	Mean
40 – 60 kg												
L1	1132	917	838	962	2.35	1.93	1.89	2.06	481	474	444	467
L2	1108	822	822	917	2.34	1.99	1.91	2.08	479	413	430	441
L3	875	787	698	787	2.13	1.98	1.80	1.97	411	398	387	399
L4	831	763	640	745	2.06	2.01	1.80	1.95	405	380	357	381
Mean	986	822	749		2.22	1.98	1.85		444	416	405	
R.M.S.		6491				0.0168				1533		
s.e.d. (L)		32.9				0.0529				16.0		
s.e.d. (P)		28.5				0.0458				13.8		
s.e.d. (L x P)		57.0				0.0917				27.7		
60 – 85 kg												
L1	1043	929	831	934	2.73	2.41	2.33	2.49	382	385	358	375
L2	1015	837	734	862	2.90	2.47	2.29	2.55	355	339	321	338
L3	803	710	714	743	2.72	2.33	2.37	2.47	295	305	302	300
L4	617	606	636	620	2.54	2.23	2.10	2.29	246	272	304	274
Mean	869	771	729		2.72	2.36	2.27		319	325	321	
R.M.S.		3824				0.0413				600		
s.e.d. (L)		25.3				0.0829				10.0		
s.e.d. (P)		21.9				0.0718				8.66		
s.e.d. (L x P)		43.7				0.1437				17.3		
40 – 85 kg												
L1	1066	922	835	941	3.05	2.20	2.13	2.46	350	418	391	386
L2	1061	832	763	885	3.08	2.25	2.13	2.48	346	370	359	358
L3	816	737	702	751	2.68	2.18	2.12	2.33	304	338	331	324
L4	680	662	639	661	2.56	2.14	1.97	2.22	268	309	325	301
Mean	906	788	735		2.84	2.19	2.09		317	359	351	
R.M.S.		2420				0.0191				389		
s.e.d. (L)		20.1				0.0564				8.05		
s.e.d. (P)		17.4				0.0488				6.97		
s.e.d. (L x P)		34.8				0.0976				14.0		

Table 3.18 *The effect of feeding level (Ad libitum (AL), Restricted four pigs/pen (R4) and Restricted eight pigs/pen (R8) were pair-fed the amounts consumed by groups of four and eight pigs respectively) and dietary lysine content on ash, lipid, protein and water content in the empty body at 85 kg of pigs housed at 1.72 m²/pig.*

Component	Ash (g/kg)				Lipid (g/kg)				Protein (g/kg)				Water (g/kg)			
Level	AL	R4	R8	Mean	AL	R4	R8	Mean	AL	R4	R8	Mean	AL	R4	R8	Mean
40 – 85 kg																
L1	28.6	28.8	29.6	29.0	141	138	127	135	170	176	174	173	644	644	656	648
L2	25.3	28.8	28.4	27.5	179	162	144	162	166	169	171	169	612	624	641	626
L3	29.3	27.5	28.8	28.5	171	172	185	176	164	163	163	163	615	619	608	614
L4	28.2	27.6	28.0	27.9	212	199	196	202	158	156	153	156	582	599	603	595
Mean	27.8	28.2	28.7		176	168	163		164	166	165		613	621	627	
R.M.S.		9.76				345				32.5				192		
s.e.d. (L)		1.28				7.58				2.33				5.66		
s.e.d. (P)		1.10				6.56				2.02				4.90		
s.e.d. (L x P)		2.21				13.1				4.03				9.80		

Table 3.19 *The effect of feeding level (Ad libitum (AL), Restricted four pigs/pen (R4) and Restricted eight pigs/pen (R8) were pair-fed the amounts consumed by groups of four and eight pigs respectively) and dietary lysine content on the rates of ash, lipid, protein and water retention from 40 to 85 kg at 1.72 m²/pig.*

Retention	Ash (g/day)				Lipid (g/day)				Protein (g/day)				Water (g/day)			
Level	AL	R4	R8	Mean	AL	R4	R8	Mean	AL	R4	R8	Mean	AL	R4	R8	Mean
40 – 85 kg																
L1	32.5	28.5	26.6	29.2	186	153	120	153	180	167	148	165	612	529	499	547
L2	26.3	24.5	23.5	24.8	261	167	137	188	175	135	134	148	561	430	445	479
L3	25.3	20.4	20.9	22.2	181	166	174	174	129	115	107	117	422	382	345	383
L4	19.5	18.7	18.3	18.8	202	183	171	185	98	95	86	93	303	321	311	312
Mean	25.9	23.0	22.3		207	167	150		145	128	119		475	416	400	
R.M.S.		19.1				1063				134				1008		
s.e.d. (L)		1.78				13.3				4.73				13.0		
s.e.d. (P)		1.54				11.5				4.10				11.2		
s.e.d. (L x P)		3.09				23.1				8.19				22.5		

Pair feeding – Group; *Ad libitum*; 4 pigs/pen *vs.* Individual; Restricted; 4 pigs/pen

The effects of dietary lysine and group size (a comparison of a group of 4 pigs with individually-penned pigs pair-fed the mean daily feed intake of the four pigs/pen) on the average daily gain, feed intake and feed conversion efficiency (FCE) of growing pigs over three live weight periods at a fixed floor-space allowance (1.72 m^2/pig) and housed individually are shown in Table 3.20.

Average daily gain was unaffected by group size in the early, late and overall growth periods, and increased with dietary lysine content. Over the early growth period feed intake decreased and FCE increased as the dietary lysine content increased, these responses being unaffected by group size. The linear increase in feed intake with dietary lysine content was similar for both group sizes over the late (32.9 g/day per g/kg of dietary lysine) and overall (73.6 g/day per g/kg of dietary lysine) growth periods. In spite of this, at any dietary lysine concentration, pigs housed in groups of 4 consumed significantly ($P < 0.05$ and $P < 0.001$) more than pigs housed individually over the late and overall growth periods respectively. Over the late and overall growth periods, the linear increases in FCE (27 and 36 g gain/kg feed per g/kg of dietary lysine, respectively) were similar for both group sizes. However at any dietary lysine concentration the pigs housed in groups of 4 had significantly ($P < 0.05$ and $P < 0.001$ over the late and overall growth period, respectively) lower FCE's than individually-housed pigs.

The effects of the above treatments on the chemical composition of the empty body weight of pigs at 85 kg live weight and the daily rate of change in empty body ash, lipid, protein and water between 40 and 85 kg of pigs at fixed floor-space allowance (1.72 m^2/pig) and housed individually are shown in Tables 3.21 and 3.22.

Ash and protein content were unaffected by group size while ash decreased but protein increased as the dietary lysine content increased. Lipid content decreased as the dietary lysine content increased for both group sizes, but the groups of 4 contained significantly less lipid ($P < 0.01$) compared with the individual pigs. As the dietary lysine content increased the water content increased for both group sizes but the groups of 4 contained significantly ($P < 0.01$) more water when compared with the individually-penned pigs.

Ash, protein and lipid retention were unaffected by group size with ash and protein increasing and lipid decreasing as the dietary lysine content increased. The water retention increased linearly as the dietary lysine content increased for both group sizes, but the groups of 4 had significantly ($P < 0.05$) higher water retentions compared with pigs penned individually.

Table 3.20 *Mean weight gain, feed intake and feed conversion efficiency of pigs given the same floor-space allowance (1.72 m^2/pig), housed individually (Restricted four pigs/pen (R4) were pair-fed the amounts consumed by groups of four), or in groups of four pigs per pen, and offered one of four feeds varying in lysine content, over three periods of growth.*

Factor	Gain in weight (g/d)			Feed intake (kg/d)			Feed conversion efficiency (g gain/kg feed)		
Pigs/pen	R4	AL4	Mean	R4	AL4	Mean	R4	AL4	Mean
40 – 60 kg									
L1	917	963	937	1.93	2.02	1.97	474	477	476
L2	822	852	835	1.99	2.03	2.01	413	419	416
L3	787	773	781	1.98	1.99	1.98	398	389	394
L4	763	823	789	2.01	2.12	2.06	380	387	383
Mean	822	853		1.98	2.04		416	418	
R.M.S.		4522			0.00971			552	
s.e.d. (L)		35.9			0.0527			12.6	
s.e.d. (P)		25.7			0.0376			8.97	
s.e.d. (L x P)		51.4			0.0753			17.9	
60 – 85 kg									
L1	929	944	935	2.41	2.58	2.48	385	368	378
L2	837	954	887	2.47	2.71	2.57	339	352	345
L3	710	699	705	2.33	2.43	2.37	305	286	297
L4	606	542	579	2.23	2.33	2.27	272	234	256
Mean	771	784		2.36	2.51		325	310	
R.M.S.		2653			0.02204			229	
s.e.d. (L)		27.5			0.0794			8.09	
s.e.d. (P)		19.7			0.0567			5.78	
s.e.d. (L x P)		39.3			0.113			11.6	
40 – 85 kg									
L1	922	929	925	2.20	2.52	2.34	418	370	397
L2	832	904	863	2.25	2.56	2.38	370	354	363
L3	737	741	739	2.18	2.38	2.27	338	311	327
L4	662	631	649	2.14	2.36	2.23	309	269	292
Mean	788	801		2.19	2.45		359	326	
R.M.S.		1642			0.0157			237	
s.e.d. (L)		21.7			0.0670			8.22	
s.e.d. (P)		15.5			0.0479			5.87	
s.e.d. (L x P)		31.0			0.0958			11.8	

Table 3.21 *The effect of equalised feeding (Restricted four pigs/pen (R4) were pair-fed the amounts consumed by groups of four) and dietary lysine content on ash, lipid, protein and water content in the empty body at 85 kg of pigs allocated the same floor-space allowance (1.72 m^2/pig).*

Component	Ash (g/kg)			Lipid (g/kg)			Protein (g/kg)			Water (g/kg)		
Pigs/pen	R4	AL4	Mean	R4	AL4	Mean	R4	AL4	Mean	R4	AL4	Mean
40 – 85 kg												
L1	28.8	27.7	28.3	138	126	133	176	175	176	644	655	649
L2	28.8	28.7	28.8	162	161	162	169	167	168	624	628	626
L3	27.5	31.1	29.0	172	186	178	163	162	163	619	609	615
L4	27.6	29.2	28.3	199	233	214	156	150	154	599	574	588
Mean	28.2	29.2		168	176		166	164		621	616	
R.M.S.		14.3			314			25.2			167	
s.e.d. (L)		2.02			9.48			2.68			6.91	
s.e.d. (P)		1.45			6.77			1.92			4.94	
s.e.d. (L x P)		2.89			13.5			3.83			9.88	

Table 3.22 *The effect of equalised feeding (Restricted four pigs/pen (R4) were pair-fed the amounts consumed by groups of four) and dietary lysine content on the rates of ash, lipid, protein and water retention from 40 to 85 kg of pigs allocated the same floor-space allowance (1.72 m^2/pig).*

Retention	Ash (g/)			Lipid (g/d)			Protein (g/d)			Water (g/d)		
Pigs/pen	R4	AL4	Mean	R4	AL4	Mean	R4	AL4	Mean	R4	AL4	Mean
40 – 85 kg												
L1	29	27	27	153	136	145	168	170	168	529	570	547
L2	25	27	27	167	186	175	135	146	139	430	479	451
L3	20	25	25	166	181	173	115	111	113	382	369	378
L4	19	20	20	183	214	196	95	84	90	321	281	304
Mean	23	25		167	179		128	128		416	425	
R.M.S.		28.82			768			155.6			1323	
s.e.d. (L)		2.87			14.81			6.67			19.44	
s.e.d. (P)		2.05			10.58			4.76			13.89	
s.e.d. (L x P)		4.10			21.17			9.53			27.78	

Pair feeding – Group; *Ad libitum*; 8 pigs/pen *vs.* Individual; Restricted; 8 pigs/pen

The effects of dietary lysine and group size (a comparison of a group of 8 pigs with individually-penned pigs pair-fed the mean daily feed intake of the 8 pigs/pen) on the average daily gain, feed intake and feed conversion efficiency (FCE) of growing pigs over three different live weight periods at varying floor-space allowance (1.72 and 0.86 m^2/pig respectively) and housed individually are shown in Table 3.23.

Over the early growth period average daily gain, feed intake and FCE were unaffected by group size and increased as the dietary lysine content increased. Average daily gain over the late and overall growth periods increased linearly as the dietary lysine content increased for both group sizes but this increase was significantly ($P < 0.001$) lower for the individuals compared with the groups of 8 pigs. Over the late and overall growth periods feed intake increased linearly as the dietary lysine content increased but this rate of increase was significantly ($P < 0.05$) higher for the groups of 8 when compared with the individuals. FCE over the late and overall growth period increased linearly as the dietary lysine content increased, with the individuals having significantly ($P < 0.001$ and $P < 0.01$, respectively) higher FCE's compared with the groups of 8 pigs.

The effects of these treatments on the chemical composition of the empty body weight of pigs at 85 kg live weight and the daily rate of change in empty body ash, lipid, protein and water between 40 and 85 kg of pigs at varying floor-space allowance (1.72 and 0.86 m^2/pig respectively) and housed individually are shown in Tables 3.24 and 3.25.

Group size had no effect on any of the component weights, with ash and lipid contents decreasing and protein and water contents increasing as the dietary lysine content increased.

Ash, protein and water retention were unaffected by group size and increased as the dietary lysine content increased. The lipid retention decreased for the individuals and increased for the groups of 8 pigs and consequently the individuals had significantly ($P < 0.05$) lower lipid retentions in comparison to the groups of 8 pigs.

Table 3.23 *Mean weight gain, feed intake and feed conversion efficiency of pigs given a different floor-space allowances (1.72 and 0.86 m²/pig), housed individually (Restricted eight pigs/pen (R8) were pair-fed the amounts consumed by groups of eight), or in groups of eight pigs per pen, and offered one of four feeds varying in lysine content, over three periods of growth.*

Factor	Gain in weight (g/d)			Feed intake (kg/d)			Feed conversion efficiency (g gain/kg feed)		
Pigs/pen	R8	AL8	Mean	R8	AL8	Mean	R8	AL8	Mean
40 – 60 kg									
L1	838	879	855	1.89	2.00	1.94	444	439	442
L2	822	842	830	1.91	1.98	1.94	430	427	429
L3	698	721	708	1.80	1.86	1.83	387	387	387
L4	640	666	651	1.80	1.76	1.78	357	379	366
Mean	749	777		1.85	1.90		405	408	
R.M.S.		3525			0.00417			865	
s.e.d. (L)		31.7			0.0345			15.7	
s.e.d. (P)		22.7			0.0247			11.2	
s.e.d. (L x P)		45.3			0.0493			22.5	
60 – 85 kg									
L1	831	889	856	2.33	2.48	2.39	358	358	358
L2	734	733	734	2.29	2.35	2.32	321	312	317
L3	714	641	683	2.37	2.35	2.36	302	272	289
L4	636	435	550	2.10	2.03	2.07	304	215	266
Mean	729	675		2.27	2.30		321	289	
R.M.S.		3341			0.00399			564	
s.e.d. (L)		30.9			0.0338			12.7	
s.e.d. (P)		22.1			0.0241			9.07	
s.e.d. (L x P)		44.1			0.0483			18.2	
40 – 85 kg									
L1	835	875	852	2.13	2.28	2.19	391	385	389
L2	763	783	772	2.13	2.23	2.17	359	351	356
L3	702	683	694	2.12	2.18	2.15	331	314	323
L4	639	514	586	1.97	1.95	1.96	325	264	299
Mean	735	714		2.09	2.16		351	328	
R.M.S.		1714			0.00318			313	
s.e.d. (L)		22.1			0.0301			9.46	
s.e.d. (P)		15.8			0.0215			6.76	
s.e.d. (L x P)		31.6			0.0430			13.5	

Table 3.24 *The effect of equalised feeding (Restricted eight pigs/pen (R8) were pair-fed the amounts consumed by groups of eight) and dietary lysine content on ash, lipid, protein and water content in the empty body at 85 kg of pigs allocated different floor-space allowances (1.72 and 0.86 m^2/pig).*

Component	Ash (g/kg)			Lipid (g/kg)			Protein (g/kg)			Water (g/kg)		
Pigs/pen	R8	AL8	Mean	R8	AL8	Mean	R8	AL8	Mean	R8	AL8	Mean
40 – 85 kg												
L1	29.6	28.2	29.0	127	145	135	174	172	173	656	637	648
L2	28.4	28.5	28.5	144	165	153	171	169	170	641	625	634
L3	28.8	29.2	29.0	185	177	181	163	162	163	608	618	613
L4	28.0	31.5	29.5	196	203	199	153	154	154	603	600	602
Mean	28.7	29.3		163	172		165	165		627	620	
R.M.S.		12.6			304			28.7			195	
s.e.d. (L)		1.89			9.33			2.87			7.45	
s.e.d. (P)		1.35			6.66			2.05			5.33	
s.e.d. (L x P)		2.71			13.3			4.09			10.7	

Table 3.25 *The effect of equalised feeding (Restricted eight pigs/pen (R8) were pair-fed the amounts consumed by groups of eight) and dietary lysine content on the rates of ash, lipid, protein and water retention from 40 to 85 kg of pigs allocated different floor-space allowances (1.72 and 0.86 m^2/pig).*

Retention	Ash (g/day)			Lipid (g/day)			Protein (g/day)			Water (g/day)		
Pigs/pen	R8	AL8	Mean	R8	AL8	Mean	R8	AL8	Mean	R8	AL8	Mean
40 – 85 kg												
L1	27	27	27	120	160	137	148	156	151	499	506	502
L2	24	24	24	137	168	150	134	133	133	445	425	437
L3	21	21	21	174	161	168	107	107	107	345	362	352
L4	18	19	19	171	152	163	86	74	81	311	255	287
Mean	22	23		150	160		119	117		400	387	
R.M.S.		16.88			617.4			119.7			891.4	
s.e.d. (L)		2.20			13.28			5.85			15.96	
s.e.d. (P)		1.57			9.49			4.18			11.40	
s.e.d. (L x P)		3.14			18.98			8.35			22.80	

Overall effect of grouping

The effects of dietary lysine and group size (1, 4 and 8 pigs/pen) on feed intake and feed conversion efficiency (FCE) between 40 and 85 kg, and body lipid and water content at 85kg, are shown in Figure 3.1.

Feed intake increased linearly as the dietary lysine content increased for all group sizes but this rate of increase was significantly ($P < 0.05$) lower for the groups of 8 compared with the individuals and groups of 4. The linear increase in FCE with dietary lysine content (27 g gain/kg feed per g/kg of dietary lysine) was similar for all group sizes, and at all dietary lysine concentration the pigs housed in groups of 8 had significantly ($P < 0.05$) higher efficiencies than pigs housed individually or in groups of 4. As the dietary lysine content increased the lipid content decreased linearly and this decrease was significantly ($P < 0.05$) higher for pigs housed in groups of 4. As a result pigs housed in groups of 4 contained significantly ($P < 0.05$) less lipid compared with pigs housed individually and in groups of 8. However the water content was unaffected by group size and increased linearly as the dietary lysine content increased.

The effects of dietary lysine intake and group size (1, 4 and 8 pigs/pen) on the average daily gain and protein retention, and digestible lysine intake on lysine retention between 40 and 85 kg are shown in Figures 3.2 and 3.3.

Although the average daily gain increased linearly (34 g/day per extra 1 g/kg of dietary lysine) as the dietary lysine content increased for all group sizes, at any dietary lysine concentration the groups of 4 and 8 had significantly ($P < 0.01$ and $P < 0.001$) lower average daily gains than the individual pigs. Protein and lysine retention were unaffected by group size and increased linearly as the dietary lysine intake and digestible lysine intake increased respectively. As a result the efficiency of dietary lysine utilisation for lysine retention was 0.45 (2.2 mg digestible lysine per gram of lysine retention) in growing pigs over all group sizes from 40 to 85 kg live weight.

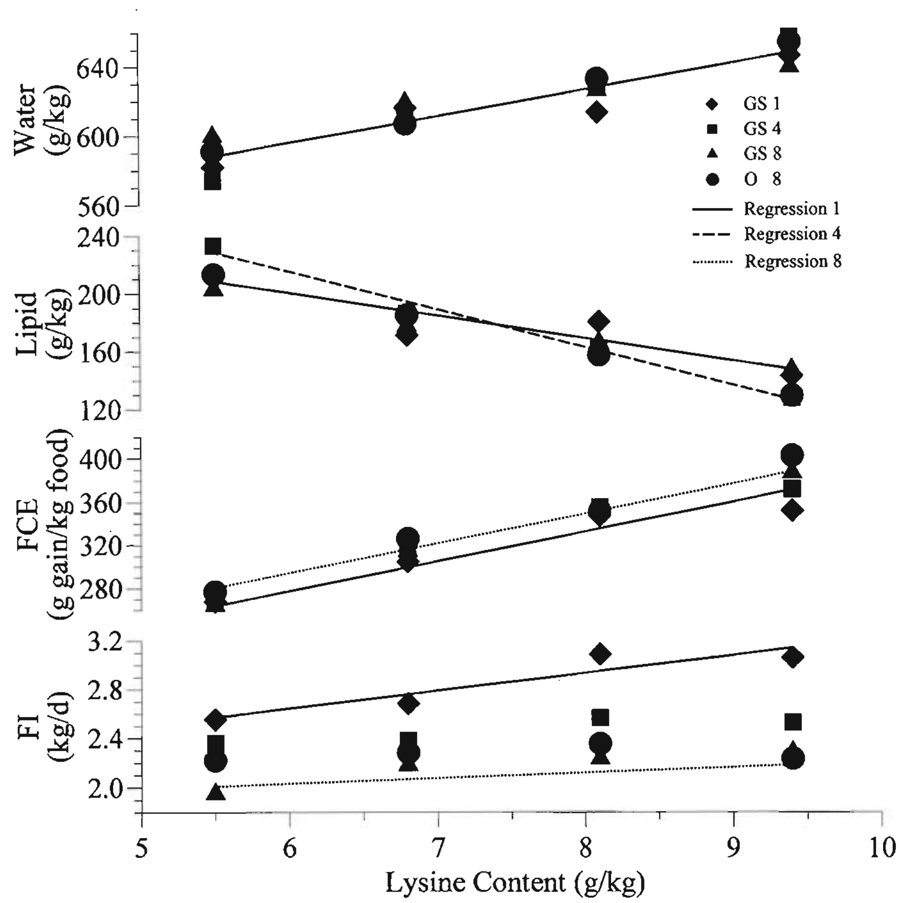

Figure 3.1 *The responses in feed intake (FI), feed conversion efficiency (FCE), lipid and water content of pigs housed individually (GS 1) or in groups of four (GS 4) or eight (GS 8 and O 8) pigs/pen, and offered one of four feeds varying in lysine content over the period 40 to 85 kg live weight.*

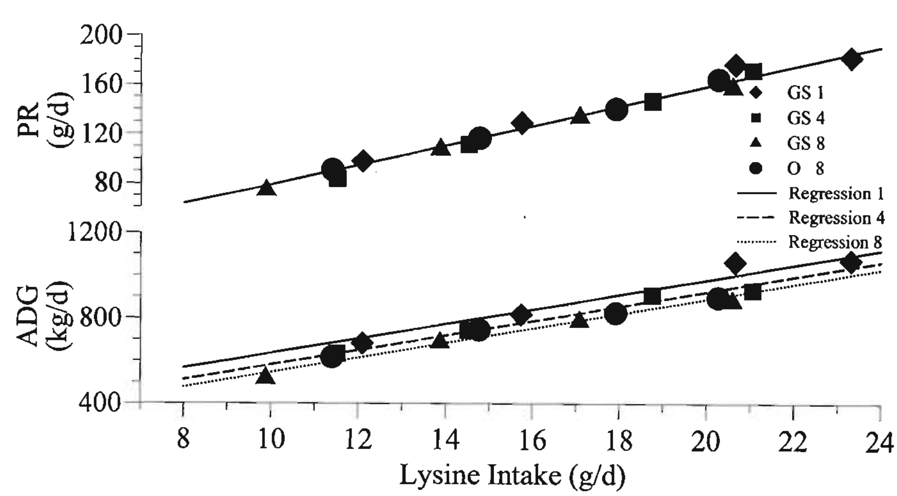

Figure 3.2 *The response in average daily gain (ADG) and protein retention (PR) of pigs housed individually (GS 1) or in groups of four (GS 4) or eight (GS 8 and O 8) pigs/pen to lysine intake over the period 40 to 85 kg live weight.*

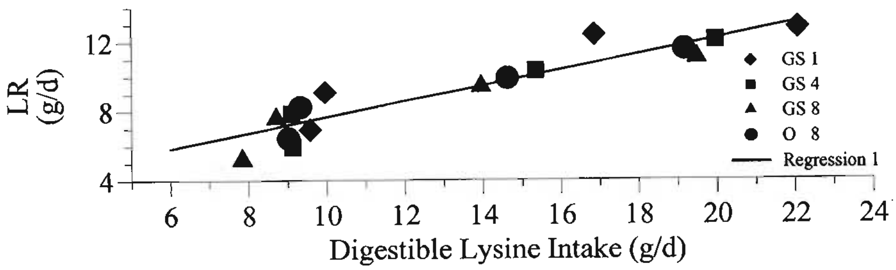

Figure 3.3 *The relationship between lysine retention (LR) and digestible lysine intake of pigs housed individually (GS 1) or in groups of four (GS 4) or eight (GS 8 and O 8) pigs/pen over the period 40 to 85 kg live weight.*

Overall effect of feeding level

The effects of dietary lysine and feeding level (AL, R4 and R8) on feed intake and feed conversion efficiency (FCE) between 40 and 85 kg, and lipid and water contents at 85kg, of pigs at fixed floor-space allowance (1.72 m^2/pig) and housed individually are shown in Figure 3.4.

Feed intake increased linearly as the dietary lysine content increased for all feeding levels, however this rate of increase was significantly ($P < 0.001$ and $P < 0.01$) lower for the R4 and R8 respectively when compared with the AL pigs. Although the linear increases in FCE with dietary lysine content were similar for all feeding levels at all dietary lysine concentrations the R4 and R8 pigs had significantly ($P < 0.001$) higher FCE's than the AL pigs. As the dietary lysine content increased, lipid and water contents decreased and increased respectively. However at any dietary lysine concentration the R8 pigs had significantly ($P < 0.05$ and $P < 0.01$) lower lipid and higher water contents respectively than the AL and R4 pigs.

The effects of these dietary treatments on average daily gain and protein retention, and digestible lysine intake on the lysine retention, between 40 and 85 kg are shown in Figures 3.5 and 3.6.

Average daily gain increased linearly as the dietary lysine content increased, but this rate of increase was significantly ($P < 0.05$) lower for the R8 resulting in the R8 having significantly ($P < 0.01$) lower average daily gains when compared with AL and R4 pigs.

Feeding level had no effect on the protein retention, which increased linearly as the dietary lysine content increased. The linear increase in lysine retention with digestible lysine intake was similar for all feeding levels but at any digestible lysine intake the R8 pigs had significantly ($P < 0.05$) lower lysine retentions than the AL and R4 pigs. The efficiency of dietary lysine utilisation for lysine retention over all feeding levels in growing pigs from 40 to 85 kg live weight was 0.40 (2.5 mg digestible lysine per gram of lysine retention).

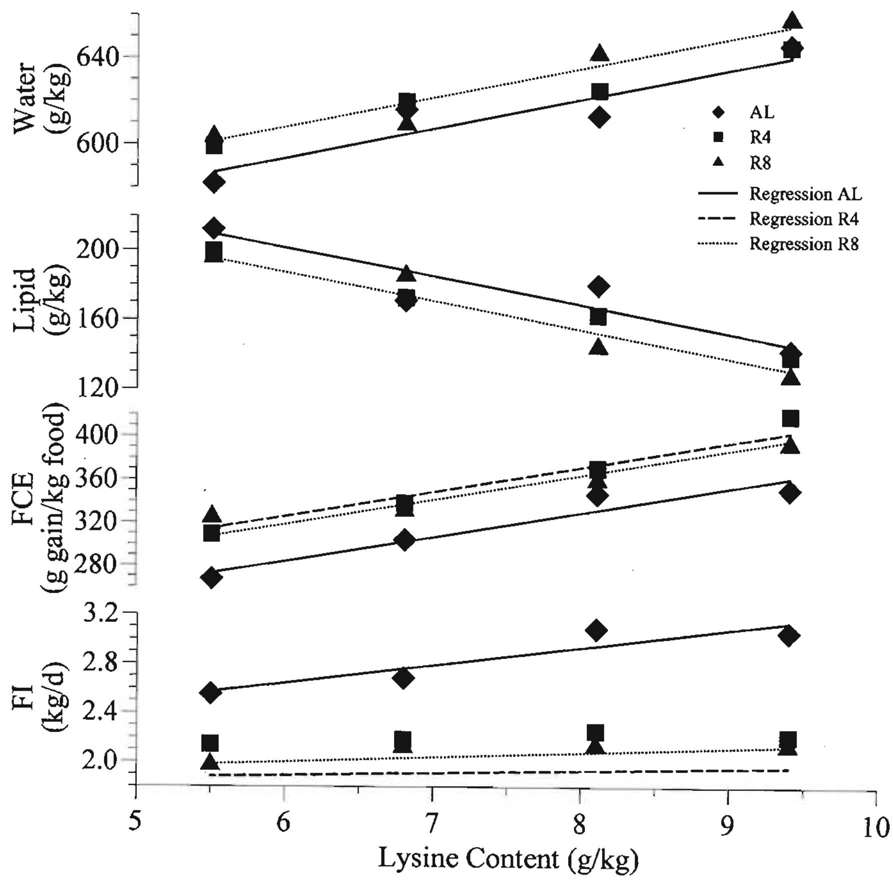

Figure 3.4 *The responses in feed intake (FI), feed conversion efficiency (FCE) and lipid and water content of pigs housed individually, offered one of four feeds varying in lysine content at three feeding levels (Ad libitum (AL), Restricted four pigs/pen (R4) and Restricted eight pigs/pen (R8)) over the period 40 to 85 kg live weight.*

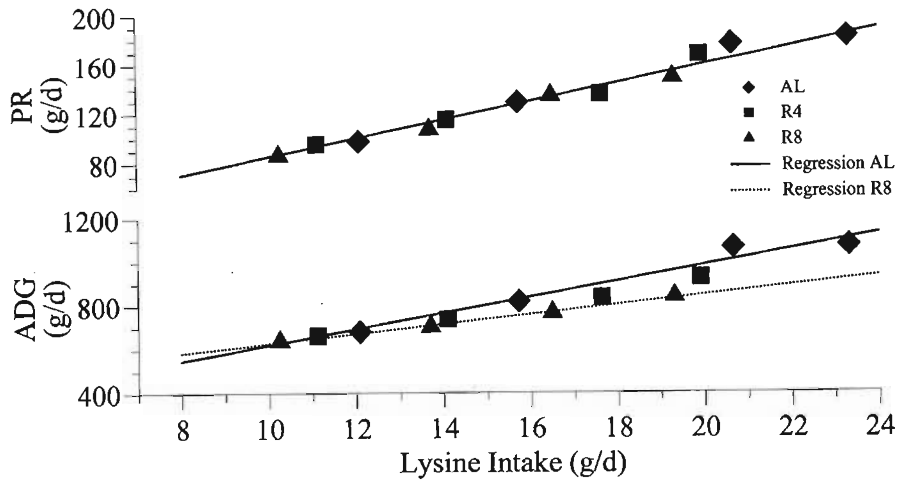

Figure 3.5 *The response in average daily gain (ADG) and protein retention (PR) of pigs housed individually, offered one of four feeds varying in lysine content at three feeding levels, (Ad libitum (AL), Restricted four pigs/pen (R4) and Restricted eight pigs/pen (R8) over the period 40 to 85 kg live weight.*

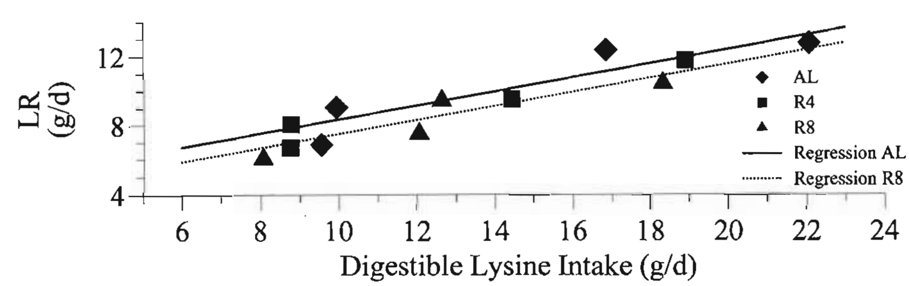

Figure 3.6 *The relationship between lysine retention (LR) and digestible lysine intake of pigs housed individually, and offered one of four feeds varying in lysine content at three feeding levels, (Ad libitum (AL), Restricted four pigs/pen (R4) and Restricted eight pigs/pen (R8) over the period 40 to 85 kg live weight.*

Effect of floor-space allowance at constant group size

The effects of dietary lysine and floor-space allowance (0.86 and 1.94 m^2/pig) on feed intake and feed conversion efficiency (FCE) between 40 and 85 kg, and on body lipid and water content, of pigs at constant group size (8 pigs/pen) are shown in Figure 3.7.

Feed intake increased linearly with dietary lysine content, but this rate of increase was significantly ($P < 0.05$) lower for pigs housed at 1.94 m^2/pig, and they tended to consume significantly ($P < 0.05$) more feed than those housed at 0.86 m^2/pig. FCE was unaffected by floor-space allowance and increased as the dietary lysine content increased. Lipid content decreased linearly as the dietary lysine content increased, the rate of decrease being significantly ($P < 0.05$) higher for pigs housed at 1.94 m^2/pig. Body water content increased linearly with dietary lysine content but this rate of increase was significantly ($P < 0.05$) higher for the 1.94 m^2/pig and contained significantly ($P < 0.05$) more water compared to 0.86 m^2/pig.

The effects of dietary lysine intake and floor-space allowance (0.86 and 1.94 m^2/pig) on average daily gain and protein retention, and digestible lysine intake on the lysine retention, between 40 and 85 kg are shown in Figures 3.8 and 3.9.

Average daily gain and protein retention were unaffected by floor-space allowance, and increased linearly with dietary lysine intake. Floor-space allowance had no effect on lysine retention and increased as the digestible lysine intake increased resulting in the efficiency of dietary lysine utilisation for lysine retention in growing pigs kept at constant group size and varying floor-space allowance from 40 to 85 kg live weight being 0.46 (2.2 mg digestible lysine per gram of lysine retention).

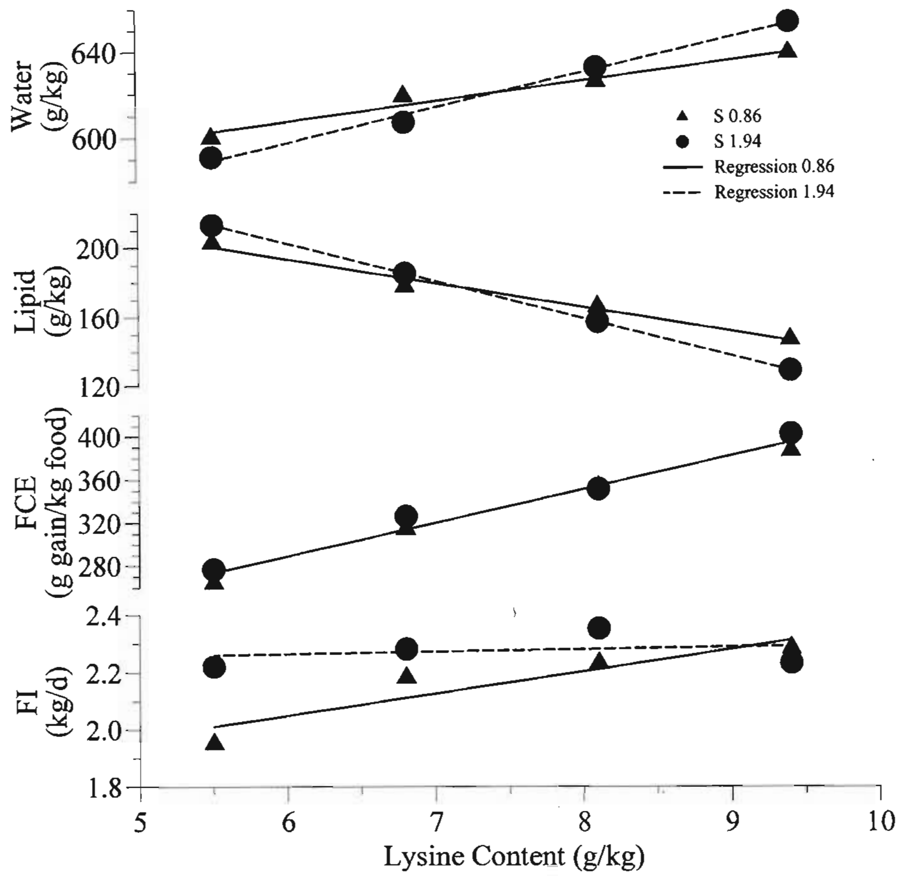

Figure 3.7 *The responses in feed intake (FI), feed conversion efficiency (FCE), lipid and water content of pigs allocated different floor-space allowances (0.86 and 1.94 m*^{2}*/pig), housed in groups of eight pigs/pen, and offered one of four feeds varying in lysine content, over the period 40 to 85 kg live weight.*

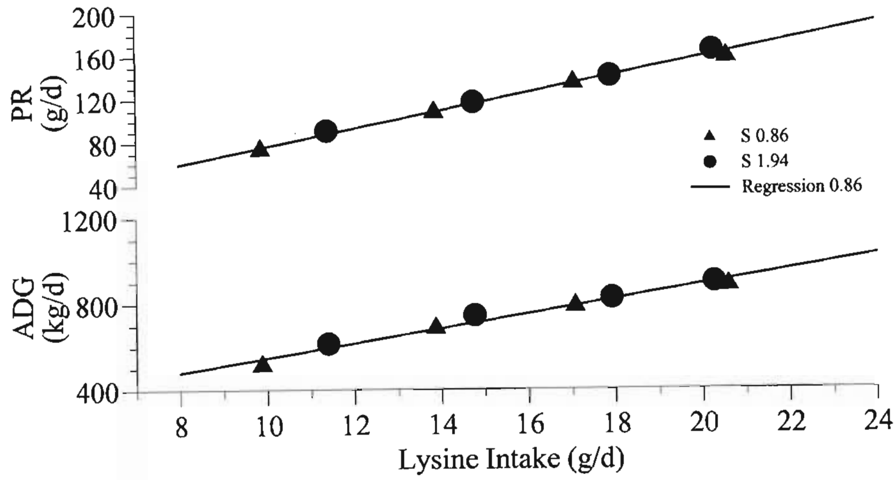

Figure 3.8 *The response in average daily gain (ADG) and protein retention (PR) of pigs allocated different floor-space allowances (0.86 and 1.94 m²/pig), housed in groups of eight pigs/pen, to lysine intake over the period 40 to 85 kg live weight.*

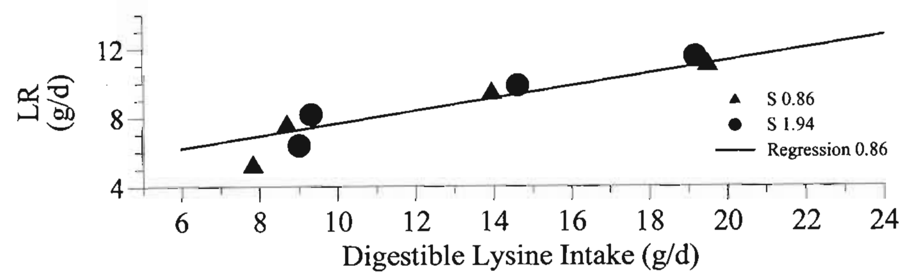

Figure 3.9 *The relationship between lysine retention (LR) and digestible lysine intake of pigs allocated different floor-space allowances (0.86 and 1.94 m²/pig), housed in groups of eight pigs/pen, over the period 40 to 85 kg live weight.*

Overall effect of floor-space allowance

The effects of dietary lysine and floor-space allowance (0.86, 1.72 and 1.94 m^2/pig) on feed intake and feed conversion efficiency (FCE) between 40 and 85 kg, and in body lipid and water content at 85kg, are shown in Figure 3.10.

The linear increase in feed intake with dietary lysine content was similar for both group sizes, and at all dietary lysine concentration pigs provided with 1.72 m^2/pig had significantly ($P < 0.001$) higher feed intakes than pigs provided with 0.86 and 1.94 m^2/pig of floor-space allowance. FCE and lipid contents were unaffected by floor-space allowance, and increased and decreased linearly respectively as the dietary lysine content increased. Water content increased linearly as the dietary lysine content increased for all floor-space allowances but this increase was significantly ($P = 0.01$ and $P < 0.05$) higher for pigs provided with floor-space allowances of 1.72 and 1.94 m^2/pig. Pigs provided with a floor-space allowance of 0.86 m^2/pig had significantly ($P < 0.01$) lower water contents compared with those housed at the other two floor-space allowances.

The effects of dietary lysine intake and floor-space allowance (0.86, 1.72 and 1.94 m^2/pig) on average daily gain and protein retention, and digestible lysine intake on the lysine retention, between 40 and 85 kg are shown in Figures 3.11 and 3.12.

The linear increase in average daily gain with dietary lysine intake was similar for all floor-space allowances, but at any dietary lysine intake pigs provided with a space of 1.72 m^2/pig had significantly ($P < 0.001$) higher average daily gains than pigs housed at 0.86 or 1.94 m^2/pig. Protein and lysine retentions were unaffected by floor-space allowance, and increased linearly as the dietary lysine and digestible lysine intakes increased, respectively. Hence the efficiency of dietary lysine utilisation for lysine retention over all space allocations in growing pigs from 40 to 85 kg live weight was 0.45 (2.2 mg digestible lysine per gram of lysine retention).

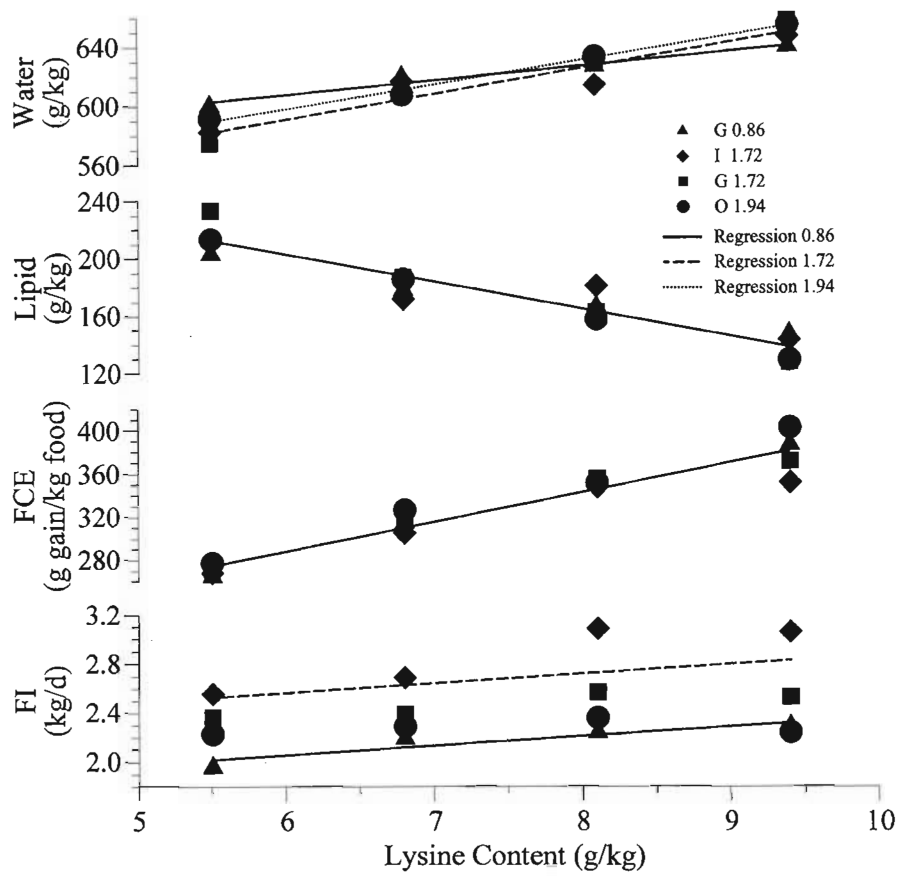

Figure 3.10 *The responses in feed intake (FI), feed conversion efficiency (FCE), lipid and water content of pigs allocated different floor-space allowances (0.86, 1.72 and 1.94 m²/pig) and offered one of four feeds varying in lysine content, over the period 40 to 85 kg live weight.*

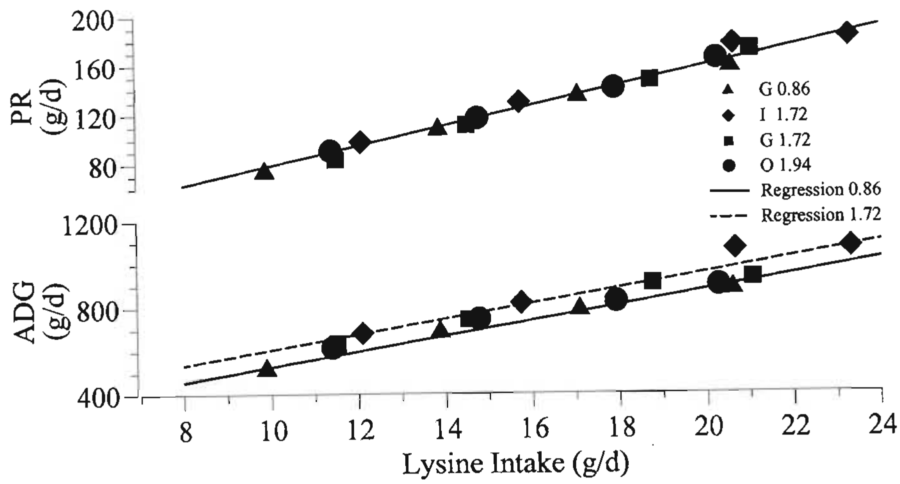

Figure 3.11 *The response in average daily gain (ADG) and protein retention (PR) of pigs allocated different floor-space allowances (0.86, 1.72 and 1.94 m^2/pig) to lysine intake, over the period 40 to 85 kg live weight.*

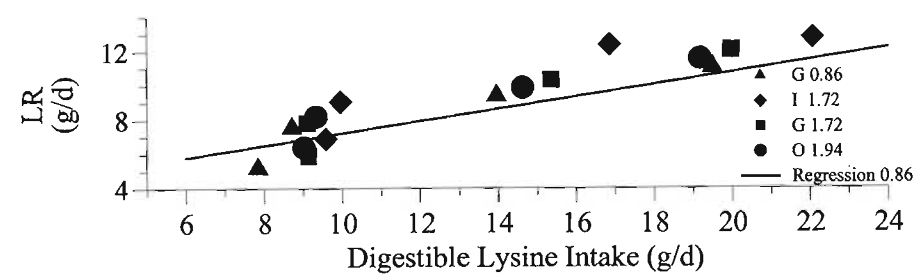

Figure 3.12 *The relationship between lysine retention (LR) and digestible lysine intake of pigs allocated different floor-space allowances (0.86, 1.72 and 1.94 m^2/pig), over the period 40 to 85 kg live weight.*

3.4 DISCUSSION

In this experiment, the number of pigs per pen and floor-space allowance may have confounded the response to dietary lysine concentration and the difference in performance variables and carcass characteristics due to the number of pigs per pen or floor-space allowance *per se* is unknown. However, the focus of this study was to determine to what extent a stressor, in this case a high number of pigs per pen or a floor-space allowance, would alter the efficiency of utilisation of lysine by the stressed pigs, and whether it would be economical to feed such stressed pigs a feed lower in nutrient content than for pigs growing at their potential, on the assumption that the higher nutrient content would be wasted on pigs growing below their potential.

Experimental evidence (Gonyou *et al.*, 1992; Nielsen *et al.*, 1995 and Morgan *et al.*, 1999) suggests that there are many social and behavioural differences between animals housed singly and in groups, and it is therefore not appropriate to consider stocking density as a continuous variable from 1 to 8 pigs per pen. The group-housed treatments were therefore analysed separately, whilst specific comparisons between group and single penned treatments were performed.

Feed Intake

Over all live weight growth periods, the feed intake increased linearly as the dietary lysine concentration increased, irrespective of the number of pigs per pen or floor-space allowance. Ferguson *et al.* (2001) noted that growing-finishing pigs attempted to compensate for the dietary lysine deficiency by increasing their voluntary feed intakes irrespective of the number of pigs per pen or floor-space allowance. This difference in observation may be explained by the fact that pig experiments are conducted between body weights and not between two dates, thus pigs fed higher dietary lysine concentrations, which grow faster than pigs fed lower dietary lysine concentrations, are on trial for less time than the slower-growing pigs and therefore consume more feed per day on trial. However, if pigs remained on trial for the same number of days, the pigs fed lower dietary lysine concentrations would consume considerably more feed than those pigs fed higher dietary lysine concentrations.

The voluntary feed intake remained unaffected by the number of pigs per pen over the early growth period across all the comparisons. However, an increase in the number of pigs per pen for the pair feeding comparisons (individual restricted, 4 pigs per pen and group *ad libitum,* 4 pigs per pen and individual restricted, 8 pigs per pen and group *ad libitum*, 8 pigs per pen) over the late and overall growth period and the number of pigs per pen housed at similar floor-space allowances over the overall growth period resulted in a significant decrease in voluntary feed intake. The overall effect of grouping demonstrated that the groups of 8 consumed significantly less than the individuals and groups of 4.

Although the pair feeding technique used may have been flawed experimentally, with the inaccurate determination of the coefficient and daily feed allocation, practically this served an important purpose. Whittemore *et al.* (2001) described daily feed intake as being separately and together a function of: feed allocated by an equation based on weight or indicator of weight; animal description (e.g. gut capacity, nutrient requirements, type of pig); feed characteristics (e.g. bulk, density) and environmental constraints (e.g. temperature, stocking density, disease challenges, feeder space and social stress). Determining the daily feed intake of growing-finishing pigs at different body weights or times does not quantitatively differentiate between the animal, environment and feed constraints (with the exception of weight) and although mathematical functions may be accurate in their description, they do not necessarily demonstrate the quantification of fundamental principles required for simulation and prediction (Whittemore *et al.*, 2001).

A number of studies have reported a reduction in the voluntary feed intake as the number of pigs per pen is increased (Heitman *et al.*, 1961; Gehlbach *et al.*, 1966; Kornegay and Notter, 1984; Spicer and Aherne, 1987; Gonyou *et al.*, 1992; Gonyou and Stricklin, 1998; Gomez *et al.*, 2000; Hyun and Ellis, 2001) and others little effect (Randolph *et al.*, 1981; Petherick *et al.*, 1989; McGlone and Newby, 1994; Nielsen *et al.*, 1995; Spoolder *et al.*, 1999; Wolter *et al.*, 2001; Turner *et al.*, 2002; Schmolke *et al.*, 2003). However, the differing number of pigs per pen and variable responses in voluntary feed intake are not unexpected.

In contrast, decreasing the floor-space allowance significantly influenced the voluntary feed intake over all growth periods and across all comparisons such that pigs provided with less space consumed less feed than those provided with more space. However, the overall effect of floor-space allowance demonstrated that pigs provided with an intermediate floor-space allowance (1.72 m^2/pig) consumed significantly more feed than those provided with the lowest and highest floor-space allowance (0.86 and 1.94 m^2/pig respectively). This is due partly to the individual *ad libitum* pigs housed at this floor-space allowance in addition to the group of 4 pigs per pen. It is well established that individually-penned pigs consume more feed than group-penned pigs (Spicer and Aherne, 1987; de Haer and Merks, 1992; Gonyou and Stricklin, 1998; Gomez *et al.*, 2000).

Likewise, the effect of floor-space allowance on the voluntary feed intake of growing-finishing pigs has differed, with some studies showing a decrease in voluntary feed intake (Heitman *et al.*, 1961; Gehlbach *et al.*, 1966; Jensen *et al.*, 1973; Kornegay and Notter, 1984) and others showing little effect (Randolph *et al.*, 1981; Moser *et al.*, 1985; Meunier-Salaun *et al.*, 1987; Edwards *et al.*, 1988; McGlone and Newby, 1994).

Previous research has indicated that increasing the nutrient density of the feed under decreasing floor-space allowance did not improve the reduced voluntary feed intake compared to those with adequate space (Kornegay *et al.*, 1993b; Hahn *et al.*, 1995; Brumm and Miller, 1996; Edmonds *et al.*, 1998). On the contrary, the results of this experiment and that of Ferguson *et al.* (2001) demonstrate that increasing the concentration of the most limiting nutrient in the feed or feeding the animal to the requirement for maximum protein growth, irrespective of the number of pigs per pen or floor-space allowance, may be beneficial. However, an increase in the concentration of the most limiting nutrient in the feed may not fully compensate for a reduction in voluntary feed intake associated with social stress; it may negate it.

Live weight changes and feed conversion

The increase in dietary lysine concentration resulted in a concomitant increase in average daily gain and improvement in feed conversion efficiency over all growth periods, irrespective of the number of pigs per pen and floor-space allowance. Increasing the dietary lysine concentration results in less feed being required per unit of growth and consequently the feed conversion efficiency is improved (Ferguson, 2001).

The number of pigs per pen had no effect on the average daily gain over all growth periods for the comparisons involving pigs housed at varying group size but similar floor-space allowance and pair feeding individual restricted, 4 pigs per pen and group *ad libitum*, 4 pigs per pen. The average daily gain of pair feeding individual restricted, 8 pigs per pen and group *ad libitum*, 8 pigs per pen remained unaffected by the number of pigs per pen over the early growth period. On the contrary, over the late and whole growth period the increase in average daily gain was significantly lower for the individual restricted, 8 pigs per pen than group *ad libitum*, 8 pigs per pen, illustrating the shortcomings of the pair feeding technique. However, the overall effect of grouping demonstrated that the individuals grew significantly faster than the groups of 4 and 8.

Published research investigating the effect of the number of pigs per pen on average daily gain has yielded variable results with a number of studies reporting a marginal effect (Heitman *et al.*, 1961; Gehlbach *et al.* 1966; Randolph *et al.*, 1981; Petherick *et al.*, 1989; McGlone and Newby, 1994; Nielsen *et al.*, 1995; Turner *et al.*, 2002; Schmolke *et al.*, 2003) and others a reduction (Patterson, 1985; Spicer and Aherne, 1987; Gonyou *et al.*, 1992; Gonyou and Stricklin, 1998; Gomez *et al.*, 2000; Hyun and Ellis, 2001; Wolter *et al.*, 2001). Furthermore, experiments have indicated that the effect of the number of pigs per pen may be greater during the weanling and growing period and disappearing during the finishing period (Kornegay and Notter, 1984; Spoolder *et al.*, 1999).

Over the early growth period, the average daily gain of pigs housed at a varying floor-space allowance but constant group size was not affected by decreasing the floor-space allowance. This response was absent for the remaining growth periods and the comparison involving pigs housed in a pen of the same area with varying group size, observed that pigs receiving greater floor-space allowances had significantly higher average daily gains than those receiving less. On the contrary, the overall effect of spacing demonstrated that pigs provided with an intermediate floor-space allowance (1.72 m^2/pig) had significantly higher average daily gains than those provided with the lowest and highest floor-space allowance (0.86 and 1.94 m^2/pig respectively). Thus increased daily gain was primarily due to increase daily feed intake of the intermediate floor-space allowance group in comparison with the other two.

The trend for decreasing floor-space allowances reducing the average daily gain is well documented in the literature (Heitman *et al.*, 1961; Gehlbach *et al.*, 1966; Jensen *et al.*, 1973; Randolph *et al.*, 1981; Moser *et al.*, 1985; Meunier-Salaun *et al.*, 1987; Edwards *et al.*, 1988; Hyun *et al.*, 1998). However, other studies have demonstrated little effect of floor-space allowance on average daily gain (McGlone and Newby, 1994; Hahn, *et al.*, 1995; Turner *et al.*, 2000).

A number of studies have reported the lack of response in average daily gain under decreasing floor-space allowances to feeds of increased nutrient density (Kornegay *et al.*, 1993b; Hahn *et al.*, 1995; Brumm and Miller, 1996; Edmonds *et al.*, 1998). The results of this experiment illustrate that the negative effect on average daily gain associated with social stress was not eradicated completely through increased nutrient density, however pigs housed in larger groups, smaller floor-space allowances and fed better quality feeds grew faster than their counterparts on poor quality feeds housed under similar conditions.

The number of pigs per pen had no effect on FCE over the early growth period for both pair feeding comparisons. On the contrary, the FCE for pigs housed at varying group size but similar floor-space allowance over the early growth was significantly lower for the groups of 8 than 4 and disappeared over the remaining live weight growth periods. The FCE's for the pair feeding comparisons over the late and whole growth period were significantly lower for the group fed *ad libitum* than individual restricted pigs. The results of the overall effect of grouping demonstrated that pigs penned in large groups have significantly higher FCE's than those penned in smaller groups.

Published studies on the effect of increasing the number of pigs per pen on feed conversion efficiency have reported increases (Heitman *et al.*, 1961; Gonyou and Stricklin, 1998); Wolter *et al.*, 2001), decreases (Petherick *et al.*, 1989) and little change (Gehlbach *et al.*, 1966; Randolph *et al.*, 1981; Spicer and Aherne, 1987; Gonyou *et al.*, 1992; McGlone and Newby, 1994; Nielsen *et al.*, 1995; Spoolder *et al.*, 1999; Gomez e*t al.*, 2000; Hyun and Ellis, 2001; Turner *et al.*, 2002; Schmolke *et al.*, 2003).

The FCE of pigs housed in a pen of the same area with varying group size was unaffected by floor-space allowance over the early and overall growth period. However, over the late growth period a significant decrease in FCE for the larger group was observed. In addition, pigs housed at varying floor-space allowances with constant group size demonstrated that pigs provided with more space had significantly lower efficiencies over the early growth period than pigs with less space and the reverse occurring over the late growth period. Contrary to the individual comparisons, the overall effect of floor-space allowance resulted in FCE being unaffected by restricted floor-space allowances.

The variability in FCE associated with floor-space allowances reported in this experiment is similar to that reported in the literature with increases (Heitman *et al.*, 1961; Randolph *et al.*, 1981; Meunier-Salaun *et al.*, 1987; Turner *et al.*, 2002) and decreases (Moser *et al.*, 1985; Edwards *et al.*, 1988; Hyun *et al.*, 1998) and little change (Gehlbach *et al.*, 1966; Jensen *et al.*, 1973; McGlone and Newby, 1994).

Body protein and protein retention

The body protein content increased linearly as the dietary lysine concentration increased and remained unaffected by increasing the number of pigs per pen, or decreasing the floor-space allowance, contrary to the results of Ferguson *et al.* (2001). These results suggest that increasing the concentration of the most limiting nutrient in the feed, irrespective of the number of pigs per pen or floor-space allowance, is beneficial in counteracting adverse effects of social stress.

Several researchers have employed various nutritional approaches in an effort to overcome the reduction in pig performance such as: increasing dietary lysine (Kornegay *et al.*, 1993b); Brumm and Miller (1996) (increasing dietary lysine and energy) and Edmonds *et al.* (1998) (amino acids and protein levels), but confounded floor-space allowance with the number of pigs/pen. Irrespective of the average daily gain and feed conversion efficiency being improved as the nutrient density of the feed increased, it had little effect on improving the reduced performance of growing-finishing pigs associated with social stress. Furthermore, Edmonds *et al.* (1998) suggested that pigs housed under restricted floor-space allowances (reduced average daily gains and feed intakes) have lower amino acid requirements (g/d) compared to those pigs housed under adequate floor-space allowances performing optimally. However, the decrease in the nutrient requirement (g/d) translated into a reduction in the dietary concentration (g/kg) is dependent on the extent of the decrease in protein retention due to a reduction in nutrient intake or physiological or endocrinological constraint (Ferguson *et al.*, 2001). Hence, it is not unexpected that the results of the abovementioned experiments and that of Ferguson *et al.* (2001) (increasing dietary lysine) and the current study are likely to differ in the responses to performance variables and carcass characteristics, due to the nature and variation of the factors being investigated.

The body protein retention for pigs housed at varying group size but similar floor-space allowance and varying space but constant group size, increased linearly as the dietary lysine concentration increased and remained unaffected by increasing number of pigs per pen and decreasing floor-space allowance. On the contrary, the body protein retention for the pair-fed comparisons and pigs housed in a pen of the same area with varying group size were significantly higher for the group *ad libitum* pigs and lower for larger group sizes respectively. The overall effect of grouping and floor-space allowance demonstrated that irrespective of stressor the body protein retention increased linearly as the dietary lysine content increased. Hence, maintaining the nutrient density of the feed may not negate an already reduced body protein retention rate, however it is imperative that socially stressed animals remain on high quality feeds if they are to perform optimally under constrained conditions.

The efficiency of protein utilisation provides no understanding about the efficiency with which individual amino acids are utilised or whether the efficiency of utilisation is equal to or better than that of individual amino acids (Chung and Baker, 1992). The efficiency of lysine utilisation required to support maximum protein growth may be determined when lysine is the first limiting nutrient in the feed. This information is used in the development of simulation models predicting animal performance and response under a variety of nutritional conditions (Ferguson *et al.*, 2000a).

In this study, the number of pigs per pen or floor-space allowance or feeding level had no effect on the efficiency of lysine utilisation (0.45 for grouping and spacing and 0.40 for feeding level) observed by the lack of significant differences for the overall effect of grouping and floor-space allowance comparisons. The efficiency of lysine utilisation is less than 100% because lysine is lost during normal physiological processes of growth, conversion of lysine to methylated and hydroxylated derivatives, absorption of lysine in forms unsuitable for protein synthesis and lysine oxidation (Adeola, 1995). The low efficiency of lysine utilisation may be explained by an extended growing period 40 to 85 kg live weight and the change in dietary lysine concentration at 60 kg live weight. In addition, the estimate of carcass lysine retention was determined using an estimated value for lysine content of the protein of the whole body of the pig. Therefore, the accuracy of this measure could be improved by using values determined by chemical analyses for carcass amino concentration.

3.5 CONCLUSION

The number of pigs per pen and floor-space allowance in this experiment may have confounded the response to dietary lysine concentration, and differences in performance variables and carcass characteristics resulting from the number of pigs per pen or floor-space allowance *per se* are unknown. The number of pigs per pen becomes an important consideration once the floor-space allowance is below a certain level. This experiment indicates that feeding high quality feeds to socially stressed growing-finishing pigs does not compensate for the reduction in performance variables and carcass characteristics, but overall they perform better than those on low quality feeds. Hence, a growing-finishing pig should be fed according to its genetic potential, even if this may not be realised due to social stress. Feeding a low quality feed may have a detrimental effect on performance variables and carcass characteristics as it may reduce an already reduced protein growth rate.

CHAPTER 4

EFFECT OF GROUP SIZE AND FLOOR-SPACE ALLOWANCE ON THE DIETARY CHOICES MADE BY GROWING PIGS

4.1 INTRODUCTION

The logical approach following the stocking density and dietary lysine response trial is to more accurately determine the nutrient requirements of growing-finishing pigs, by allowing the animals to choose a combination of two diets enabling them to express their desire for growth.

The immature animal has a set of requirements for a number of resources satisfied through its feed intake in order to achieve its inherent growth potential (Kyriazakis, 1994). The feed and environment provide resources enabling the animal to successfully achieve its growth potential and constraints preventing this (Emmans and Oldham, 1988). The pig seeks to eat because it seeks to grow, but if unsuccessful it will grow according to what it eats (Kyriazakis and Emmans, 1999). The implication of the abovementioned suggestion is that if a pig is provided *ad libitum* access to more than one feed as a choice, which together in combination is potentially non-limiting for growth, this will result in the animal selecting a diet allowing its inherent growth potential to be expressed (Kyriazakis, 1994).

Formulating a feed to satisfy the daily requirements of a growing pig would be ideal in attempting to meet the systematic changes associated with maintenance and growth (Bradford and Gous, 1991a, b). However, such a system would be impossible to implement successfully and economically, eventually leading to a compromise between the requirements of an individual and the number of feeds used (Kyriazakis *et al.*, 1990). Despite ideal conditions prevailing, any feeding system designed to meet the requirements of an average pig results in underfeeding of amino acids to some pigs causing a reduction in performance variables and carcass characteristics, and overfeeding of amino acids to other pigs, directly influencing the cost of production (Owen *et al.*, 1994).

It is proposed that pigs have nutritional wisdom to recognise their own nutritional requirements and the feed properties satisfying them (Rose and Fuller, 2001). The proposition, that pigs are able to differentiate successfully between two feeds differing in protein content but adequate in all other nutrients, has been successfully demonstrated by numerous authors (Kyriazakis *et al.*, 1990, Bradford and Gous 1991a, b; Kyriazakis *et al.*, 1991; Kyriazakis and Emmans, 1993). However, not all choice-feeding experiments have been successful. Owen *et al.* (1994) and Rose and Fuller (2001) acknowledged that while pigs can detect differences between feeds in amino acid concentrations, they fail to select different proportions of two feeds to accurately and consistently satisfy their daily requirements. The additional costs associated with feeding due to the overconsumption of an amino acid, lower gain/feed and reduced carcass leanness may not justify the additional capital required for equipment and management in choice-feeding systems (Owen *et al.*, 1994).

The choice-feeding application has significant economic and management benefits in commercial pig production operations. Production units generally offer a grower and finisher feed from weaning to slaughter with the composition remaining constant, resulting in the growing-finishing pig being unable to obtain sufficient of the limiting nutrients to satisfy its needs without over-consuming other nutrients (Bradford and Gous, 1991a). With a choice-feeding system, the individual within a group is able to select a dietary combination accurately meeting its requirement in a given state and over time by making daily changes to its nutrient intake, without depending on the change in its voluntary feed intake associated with a single conventional diet (Rose and Fuller, 1995).

The question addressed in this paper is to what extent the social stresses of grouping or floor-space allowance alters the nutrient content of the feed chosen by pigs given a choice of two feeds differing in protein: energy ratio. The previous experiment has demonstrated that feeding socially stressed growing-finishing pigs high quality feeds may not compensate for the reduction in performance variables and carcass characteristics, but overall they perform better than those on low quality feeds: a decision based on a biological, financial and nutritional perspectives. However, it is interesting and useful to determine whether pigs, when given a choice have the insight to make a similar decision or a biological one i.e. will the animal select a greater proportion of the high protein feed, eat less and grow faster; or more of the low protein feed, eat more and grow slower as a result of social stresses. This knowledge has significant implications on the nutritional management of commercial pigs where excessive group sizes and limited floor-space allowance commonly occurs.

4.2 MATERIALS AND METHODS

4.2.1 Experimental Design

Male pigs, offered a choice of two feeds differing in protein content, were allocated to one of five treatments consisting of varying group size at similar or dissimilar space allocation between two buildings in a completely randomised design with six replications of each treatment (Table 4.1). Originally this experiment was designed to have a sixth treatment comprising sixteen individually-penned pigs housed in a third building. However due to an unforeseen number of mortalities occurring in the research facility during the first three weeks, this treatment was discontinued to ensure the proposed group sizes remained comparable at similar or dissimilar space allocation between the buildings.

4.2.2 Animals

318 Entire male Large White × Landrace pigs arrived at the pig research facility at 8 weeks of age, weighing approximately 15 kg. They were fed a commercial grower feed (14.2 MJ Digestible Energy (DE)/kg and 11.0 g lysine/kg) for the first week, after which they were weighed and sorted, according to live weight, into respective treatments in such a way as to ensure an equal distribution of weight groups across all treatments. From approximately 20 kg live weight the pigs on each treatment were given simultaneous access to the high and low protein feeds. On reaching a pen average of 40 kg live weight, four pigs, with a mean live weight of 40.4 ± 0.21, were sacrificed from each treatment, from which the initial chemical composition of the empty body was determined (20 pigs in total) and P2 back-fat measurements recorded. At a pen average of 60 kg live weight, a further four pigs with a mean live weight of 60.7 ± 0.41, were sacrificed from each treatment, for chemical analysis (20 pigs in total) and P2 back-fat measurements. The pigs selected for slaughter between these live weight ranges were all from one pen per treatment ensuring minimal disturbance between pens and within replicates. Instead of adjusting pen sizes the same space allocation per pig when pigs were removed from pens for slaughter, the number of replications per treatment was reduced. All animals remained on their respective

treatments until an average pen weight of 85 kg was achieved when 8 pigs, with a mean live weight of 86.2 ± 0.53, were sacrificed per treatment from which the final chemical composition of the empty body at the end of the trial (40 pigs in total) was determined and P2 back-fat measurements recorded.

Table 4.1 *Experimental design showing treatment structure (group size and floor-space allowance) across both buildings and the number of replications at the end of each live weight growth period.*

Treatment	Building	Pigs/pen	Floor-space allowance (m^2/pig)	n		
				40 kg	60 kg	85 kg
1	House 1	9	1.72	5	4	2
2	House 1	18	0.86	5	4	2
3	House 2	4	1.72	5	4	2
4	House 2	8	0.86	5	4	2
5	House 2	14	0.49	5	4	2

4.2.3 Housing and Management

Pigs were housed in one of two buildings each containing light timers set at 16 L: 8 D (sixteen hours of light and eight hours of darkness). House 1 contained 12 open-sided group pens with cemented floors sloping down towards a drainage area covered with plastic slats, whereas House 2 was an open-sided house with cemented floors and a drainage area covered with plastic slats, roll up curtains and insulated ceilings, containing 24 group pens. Group sizes of nine or 18 pigs per pen were allocated to House 1, the pens measuring 15.53 m^2 (pen size – feeder bin space) and containing a large hardened plastic self-feeder bin (Lean Machine®) in the centre of the pen with two nipple drinkers and two feed dispensing structures activated by touch. This self-feeder remained empty for the duration of the trial serving only as nipple drinkers. Two hardened plastic self-feeder bins were attached to the right hand side of every wall. An additional nipple drinker was provided on the side of each pen. Group sizes of four, eight or 14 pigs were allocated per pen in House 2, the pens measuring 6.86 m^2 (pen size – feeder bin space) with two hardened plastic self-feeder bins and two nipple drinkers. Previous experiments in these facilities have shown no differences in growth responses between buildings thus allowing treatments to be determined by building (fixed pen sizes) and not replicated over both buildings. Each hardened plastic self-feeder bins is designed to feed 16 pigs. These facilities allowed for free and continuous access to feed and water. The recommendations for adequate floor-space allowance over the weight range 27 to 100 kg according to Kornegay and Notter (1984) is between 0.44 and 1.05 m^2 with an average of 0.74 m^2. In this experiment the treatments were provided with a floor-space allowance within and greater than these recommendations.

The pigs were weighed weekly on Wednesdays at 06h00 until they were within 3 kg of the slaughter weight (40, 60 or 85kg) whereupon they were weighed every second day. The feeder bins were checked twice daily. All feed added to the feeder bins was weighed and the amount and date were recorded. On Thursdays at 08h00, the feed remaining in each bin was measured, from which feed intakes for each pen were calculated, by determining the difference in the weight of the feed plus feeder at the beginning and end of each week, in addition to any feed that was weighed in during the week.

4.2.4 Feeds and Feeding

All pigs were offered a choice between a high and a low protein feed. The high protein feed was formulated to contain 14.0 MJ DE, 13.8 g lysine/kg feed and the low protein feed 14.0 MJ DE, 5.31 g lysine/kg feed. The composition of these two feeds is given in Table 4.2. The lysine contents of the two feeds are similar to those used previously by Bradford and Gous (1991b), enabling pigs to distinguish between the two feeds and yet provide combinations that will allow individuals to meet their requirement for potential protein growth. The required amino acid composition of the two feeds was determined by the model outlined by Ferguson *et al.* (1994), which predicts the amino acid requirements at a given dietary energy level based on the assumption that potential growth can be estimated from the Gompertz growth function. Values for the parameters defined by the Gompertz function were determined from data acquired from previous experiments where a similar genotype was used (Ferguson and Gous, 1997). Vitamins and minerals were included at 1.5 times the prescribed rate to ensure that these were not limiting. Amino acid contents were determined using single-column ion-exchange chromatography in a Beckman 6300 (Applications Data, 1983) after hydrolysis in 6N HCl (Moore and Stein, 1948; Association of Official Analytical Chemists, 2003).

Table 4.2 *The ingredient and calculated chemical composition (g/kg fresh weight) of the high (HP) and low (LP) feeds offered.*

Ingredients:	High Protein	Low Protein
Yellow maize	525.8	831.9
Soybean oilcake meal	299.9	
Extruded full fat soya	127.9	108.0
Monocalcium phosphate	23.0	28.9
Limestone	11.3	11.0
Sunflower oil	10.0	10.6
Salt	5.40	5.60
Vitamin and mineral premix	4.00	4.00
DL-Methionine	1.60	
L-Lysine HCl	1.20	
Calculated Composition (g/kg):		
Crude Protein (N x 6.25)	236.1	115.4
Digestible Energy (MJ/kg) †	14.22	13.94
Lysine, Total Calculated	13.80	5.31
Lysine, Total Analysed	13.63	4.84

† DE = 3.77 - (0.19 × NDF) + (0.75 × GE) (Whittemore, 1993)

4.2.5 Slaughter Procedure and Carcass Analysis

Pigs to be sampled for carcass analysis at 40, 60 and 85 kg were randomly selected before the trial began. On attaining their designated live weight pigs were killed by exsanguination, after being stunned. Blood was collected in a 2ℓ plastic bucket. The pigs were eviscerated and the gastrointestinal tract, bladder, heart, liver, lungs, kidneys and reproductive organs were removed. The empty carcass was halved along the midline, with the right half of the carcass being chosen for further analyses. The half carcass, organs and blood were stored overnight at 0°C in a sealed plastic bag. The contents of the stomach and intestines were emptied and weighed. The half carcass was portioned and, together with the empty gastrointestinal tract, remaining organs and blood, stored in a sealed plastic bag and frozen at -20°C. The frozen carcass portions and half the combined blood and organs were later homogenized in a mincer. Two 500g samples were then collected from each pig and these were used in the laboratory for proximate analysis for water, protein and ash according to the methods of the Association of Official Analytical Chemists (2003). The duplicated results were averaged to provide a single result for each pig. The dry matter content of each sample was determined by freeze-drying the samples for 72 hours. The ash content was determined by burning in a muffle furnace at 550°C overnight, while the crude protein content was calculated as nitrogen x 6.25, where nitrogen content of the dry matter was determined on a LECO FP 2000 Nitrogen Analyser (LECO Corporation, 3000 Lakeview Avenue, St Joseph, Michigan, U.S.A) using the Dumas combustion method, approved by Association of Official Analytical Chemists (2003). Lipid was calculated from the gross energy and protein contents according to the following equation described by Ferguson *et al.* (2000a):

$$lipid = (2.410 \times GE) - (0.5898 \times protein)\ g/kg\ DM$$

where: GE = gross energy, MJ/kg DM; protein = protein content, g/kg DM.

This method of calculating lipid was preferred to the Soxhlet extraction with petroleum ether at 40 to 60°C for 8 hours as it was cheaper and quicker with little difference in the accuracy. Simple linear regression analysis was performed to test the prediction of fat content in the pig using lipid content expressed on an empty body weight basis and P2 back-fat measurement. The regression equations, percentage variances and standard errors were compared to published values to determine whether this was a feasible method of prediction. To determine whether the relationship between lipid content on an empty body weight and P2 back-fat measurement differed at the three sampling periods, simple linear regression with groups was performed.

Pigs sampled at 40 kg provided data for the initial composition of the pigs on the trial; those at 60 kg providing data partway through the trial, and those at 85 kg, the final body composition. Carcass protein and lipid gains were calculated from 40 to 60 and from 60 to 85 kg, as well as from 40 to 85 kg.

4.2.6 Statistical Analysis

The performance data were divided into three live weight periods: 40 to 60; 60 to 85 and 40 to 85 kg to establish whether the choices made by pigs on the various treatments were dependent on live weight. A pen of pigs was the experimental unit for all statistical analyses. The average daily gain (ADG) for each treatment was determined from a linear regression analysis of live weight over time for each week and growth period. The average pen weight was used for all group-housed treatments. The mean ADG between the various live weight ranges was provided by the regression coefficient.

This investigation was designed to characterize the effects of group size and space allocation as stressors on the dietary protein content chosen by growing pigs. The appropriate statistical analysis is therefore a simple regression analysis in Genstat Release 6.1 (2002) to measure the response of the stressors on the performance and carcass composition. A general analysis of variance (ANOVA) in Genstat Release 6.1 (2002) was used to determine the treatment means of the proportion of dietary protein chosen on a weekly basis over seven weeks for each group size and space allocation treatment. Multiple and simple linear regression analyses were performed to measure the response in the proportion of dietary protein chosen for each group size and space allocation, and where the second order term was not significant this term was dropped from the regression. Simple linear regression analysis with groups was used to measure the effect of the stressors on the proportion of dietary protein chosen, the groups being week, group size and space allocation, to detect significant differences or lack thereof between group sizes and space allocations.

4.3 RESULTS

Choice-Feeding

The effect of group size (4, 8, 9, 14 and 18 pigs/pen) and floor-space allowance (0.49, 0.86 and 1.72 m^2/pig) on the proportion of high protein feed chosen by growing pigs over the first seven weeks of the experiment are shown in Tables 4.3 and 4.4, respectively.

Table 4.3 *The proportion of high protein feed chosen weekly by pigs kept in varying groups of 4, 8, 9, 14 and 18 per pen over the first seven weeks of the experiment.*

Pigs/pen	4	8	9	14	18	R.M.S.	n
Week Number							
1	85.5	85.0	75.3	58.6	61.3	190	25
2	81.1	67.9	61.9	70.9	68.6	300	25
3	77.9	73.9	71.1	72.1	57.0	152	25
4	68.3	69.1	70.9	64.8	56.1	130	23
5	67.1	61.9	68.8	72.0	56.1	284	21
6	69.8	59.5	67.7	74.8	60.3	460	20
7	65.6	62.5	67.6	76.4	58.4	283	20

Table 4.4 *The proportion of high protein feed chosen weekly by pigs allocated floor-space allowances of 0.49, 0.86 or 1.72 m²/pig over the first seven weeks of the experiment.*

Floor-space allowance (m^2/pig)	0.49	0.86	1.72	R.M.S.	N
Week Number					
1	60.0	80.2	85.5	185	25
2	69.7	64.9	81.1	278	25
3	64.5	72.5	77.9	165	25
4	60.4	70.1	68.3	127	23
5	65.0	65.3	67.1	289	21
6	67.6	63.6	69.8	439	20
7	67.4	65.1	65.6	291	20

This time frame was chosen for analysis because an acceptable number of replications (five and four) per treatment existed after pigs were removed from pens for slaughter at 40 and 60 kg body weight, respectively. The pigs housed in groups of 4, 8, 9 and 18 pigs/pen and floor-space allowances of 0.86 and 1.72 m^2/pig initially showed a preference for the high protein feed, declining and changing to a preference for the low protein feed with increasing live weight. On the contrary, the group of 14 pigs/pen and floor-space allowance of 0.49 m^2/pig displayed a preference for the high protein feed throughout the experimental period.

The effects of group size (4, 8, 9, 14 and 18 pigs/pen) and floor-space allowance (0.49, 0.86 and 1.72 m^2/pig) on the proportion of high protein feed chosen by growing pigs over the first seven weeks of the experiment are shown in Figure 4.1 and 4.2 respectively.

The results from all the analyses using multiple linear regression with groups showed that there were no significant quadratic effects in any instance, therefore, a simple linear regression with groups was used.

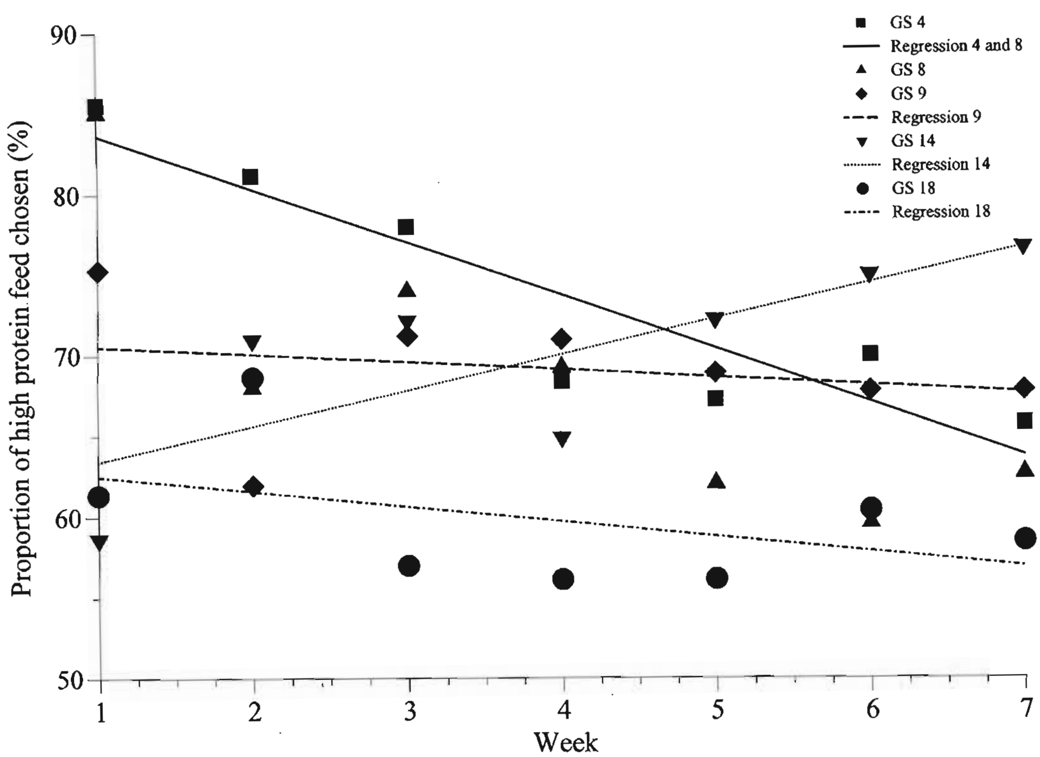

Figure 4.1 *The response in the proportion of dietary high protein chosen of pigs housed in groups of 4 (■) 8 (▲), 9 (♦), 14 (▼) and 18 (●) pigs/pen on the proportion of dietary high protein chosen by growing pigs over the first seven weeks of the experiment.*

The proportion of high protein feed chosen decreased significantly as the number of weeks progressed for the group of 4, 9 and 18 pigs/pen and increased significantly for the group of 14 pigs/pen. The response for the group of 8 pigs/pen was not significantly different from that of the group of 4 pigs/pen and a single line was fitted for both group sizes. The rate of decrease in the proportion of high protein feed chosen was significantly ($P < 0.001$) higher for the groups of 4 and 8 pigs/pen in comparison to the groups of 9 and 18 pigs/pen

(P < 0.05 and P = 0.05, respectively), this trend contrasting with the steady increase (P < 0.001) observed for the group of 14 pigs/pen.

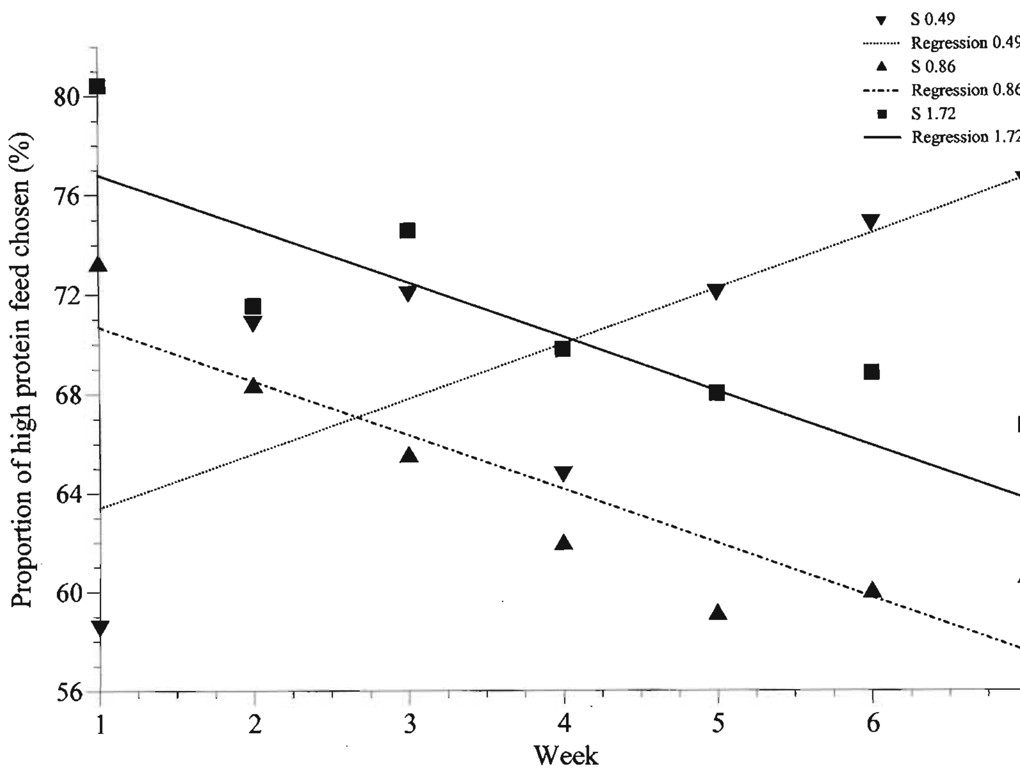

Figure 4.2 *The response in the proportion of dietary high protein chosen of pigs provided floor-space allowances of 0.49 (▼), 0.86 (▲) and 1.72 (■) m^2/pig on the proportion of dietary high protein chosen by growing pigs over the first seven weeks of the experiment.*

Similarly, the proportion of high protein feed chosen for pigs provided with floor-space allowances of 0.49 m^2/pig remained constant, contrasting with the significant (P < 0.01) decrease for pigs given floor-space allowances of 0.86 and 1.72 m^2/pig.

Growth performance and carcass characteristics

The effects of group size (4, 8, 9, 14 and 18 pigs/pen) on the average daily gain, feed intake, protein intake and feed conversion efficiency (FCE) of growing pigs over three live weight periods are shown in Table 4.5.

A significant (P < 0.001 and P < 0.05) decrease (9.7 and 8.0 g/d per pig/pen) in average daily gain over the early (40 to 60 kg) and whole (40 to 85 kg) growth period was observed with increasing group size. The corresponding decrease in average daily gain accompanying the increase in group size over the late (60 to 85 kg) growth period was evident, but not significant. Similarly, over the early and late growth period the feed intake decreased (14.6 and 30.5 g/d per pig/pen, respectively) significantly ($P < 0.05$) as the group size increased. Despite the significant reduction in performance associated with increasing group size, the feed conversion efficiency remained unimpaired over all growth periods.

Table 4.5 *Mean weight gain, feed intake and feed conversion efficiency (FCE) of pigs housed in groups of 4, 8, 9, 14 and 18 per pen and offered a choice between high and low protein feeds over three periods of growth.*

Pigs/pen	4	8	9	14	18	R.M.S.	n
40 – 60 kg							
Gain in weight (g/d)	900	844	877	768	779	3293	25
Feed intake (kg/d)	2.04	2.10	2.23	1.89	1.93	0.0212	25
FCE (g gain/kg feed)	444	403	393	406	404	609	25
60 – 85 kg							
Gain in weight (g/d)	867	873	938	794	867	9477	20
Feed intake (kg/d)	2.66	2.45	2.59	2.14	2.32	0.0699	20
FCE (g gain/kg feed)	329	359	363	370	373	1331	20
40 – 85 kg							
Gain in weight (g/d)	895	857	911	782	808	4823	20
Feed intake (kg/d)	2.17	2.19	2.29	1.97	2.06	0.0296	20
FCE (g gain/kg feed)	415	393	399	396	393	1133	20

The effects of group size (4, 8, 9, 14 and 18 pigs/pen) on the physical and chemical composition of the empty body weight of pigs at 40, 60 and 85 kg and the daily rate of change in empty body lipid and protein between 40 and 60, 60 and 85 and 40 and 85 kg are shown in Table 4.6.

Over the late growth period, a significant ($P = 0.001$ and $P < 0.001$) decrease (0.19 mm and 1.68 g/kg per pig/pen) in P2 back-fat measurement and lipid content respectively was evident at increasing group size. A significant ($P < 0.05$ and $P < 0.001$) reduction (4.72

and 3.71 g/d per pig/pen) in lipid retention occurred over the late and whole growth period respectively at increasing group size. Although the protein content remained unaffected by the increase in group size, the protein retention was significantly ($P < 0.05$) decreased (1.62 g/d per pig/pen) over the early growth period.

Table 4.6 *The effect of varying group size (4, 8, 9, 14 and 18 pigs/pen) on P2 back-fat measurement, lipid content, lipid retention, protein content and protein retention in pigs over three periods of growth offered a choice of two feeds differing in protein content.*

Pigs/pen	4	8	9	14	18	R.M.S.	n
40 – 60 kg							
P2 back-fat measurement (mm)	9.71	10.8	9.87	10.6	10.2	0.150	25
Lipid content (g/kg)	99.6	103	128	91.0	103	28.0	25
Lipid retention (g/d)	114	104	185	75.4	102	254	25
Protein content (g/kg)	158	156	165	161	158	1.71	25
Protein retention (g/d)	151	134	165	129	132	155	25
60 – 85 kg							
P2 back-fat measurement (mm)	15.8	13.5	12.0	12.9	12.5	0.248	20
Lipid content (g/kg)	153	135	132	124	128	11.4	20
Lipid retention (g/d)	243	190	129	160	162	381	20
Protein content (g/kg)	157	159	159	159	158	0.847	20
Protein retention (g/d)	133	146	136	126	137	156	20
40 – 85 kg							
Lipid retention (g/d)	186	151	158	124	136	68.6	20
Protein retention (g/d)	141	141	150	131	135	84.1	20

The effects of space allocation (0.49, 0.86 and 1.72 m^2/pig) on the average daily gain, feed intake and feed conversion efficiency (FCE) of growing pigs over three live weight periods are shown in Table 4.7.

The significant ($P < 0.001$ and $P < 0.01$) increase (94.9 and 92.2 g/d per m^2/pig) in average daily gain was observed over the early and whole growth periods respectively at increasing floor-space allowance. Over the early, late and whole growth periods, a significant ($P < 0.05$, $P = 0.005$, $P < 0.05$) increase (17.2, 35.5 and 17.7 g/d per m^2/pig, respectively) in feed intake was evident as the floor-space allowance increased. Similarly, the feed conversion efficiency remained unaffected by the increase in floor-space allowance.

Table 4.7 *Mean weight gain, feed intake and feed conversion efficiency (FCE) of pigs allocated floor-space allowances of 0.49, 0.86 and 1.72 m^2/pig offered a choice between high and low protein feeds over three periods of growth.*

Floor-space allowance (m^2/pig)	0.49	0.86	1.72	R.M.S.	N
40 – 60 kg					
Gain in weight (g/d)	768	812	889	3529	25
Feed intake (kg/d)	1.89	2.02	2.13	0.0268	25
FCE (g gain/kg feed)	406	403	419	841	25
60 – 85 kg					
Gain in weight (g/d)	794	870	903	8957	20
Feed intake (kg/d)	2.14	2.39	2.63	0.0641	20
FCE (g gain/kg feed)	370	366	346	1336	20
40 – 85 kg					
Gain in weight (g/d)	782	833	903	4568	20
Feed intake (kg/d)	1.97	2.12	2.23	0.0298	20
FCE (g gain/kg feed)	396	393	407	1032	20

The effects of space allowance (0.49, 0.86 and 1.72 m^2/pig) on the physical and chemical composition of the empty body of pigs at 40, 60 and 85 kg and the daily rate of change in empty body lipid and protein between 40 and 60, 60 and 85 and 40 and 85 kg are shown in Table 4.8.

A significant ($P < 0.001$) reduction (0.72 mm per m^2/pig) in P2 back-fat measurement was observed over the early growth period at increasing space allowance. Over the early and late growth period, a significant ($P < 0.001$) increase (16.5 and 14.3 g/kg per m^2/pig, respectively) in lipid content occurred as the floor-space allowance increased. However, the significant ($P < 0.05$) increase (2.68 g/kg per m^2/pig) in protein content at increasing space allowance was evident over the early growth period only. Increasing the floor-space allowance resulted in a significant ($P < 0.001$) increase (57.9 and 25.3 g/d per m^2/pig) in lipid and protein retention respectively over the early growth period. This trend was maintained over the whole growth period with a significant ($P < 0.001$ and $P < 0.05$) increase (36.4 and 10.8 g/d per m^2/pig) in lipid and protein retention respectively.

Table 4.8 *The effect of varying floor-space allowances (0.49, 0.86 and 1.72 m^2/pig) on P2 back-fat measurement, lipid content, lipid retention, protein content and protein retention in pigs over three periods of growth offered a choice of two feeds differing in protein content.*

Floor-space allowance (m^2/pig)	0.49	0.86	1.72	R.M.S.	N
40 – 60 kg					
P2 back-fat measurement (mm)	10.6	10.5	9.79	0.180	25
Lipid content (g/kg)	91.0	103	114	119	25
Lipid retention (g/d)	75.4	103	149	799	25
Protein content (g/kg)	161	157	162	7.27	25
Protein retention (g/d)	129	133	158	163	25
60 – 85 kg					
P2 back-fat measurement (mm)	12.9	13.0	13.9	2.09	20
Lipid content (g/kg)	124	131	142	64.8	20
Lipid retention (g/d)	160	176	186	1964	20
Protein content (g/kg)	159	159	158	1.63	20
Protein retention (g/d)	126	141	135	148	20
40 – 85 kg					
Lipid retention (g/d)	124	144	172	178	20
Protein retention (g/d)	131	138	146	88.5	20

Predicting the fat content in growing-finishing pigs

Simple and multiple linear regression with group size and space allocation as groups were performed to determine whether live weight growth period had an effect on the relationship between lipid content and P2 back-fat measurements. The second order term was not significant and the response was assumed to be linear.

The relationship between lipid content (empty body weight basis) and P2 back-fat measurement was unaffected by the phases of growth (40, 60 and 85 kg live weight). Thus the linear increase in lipid content was similar for all phases, but at any P2 back-fat measurement pigs at 40 and 60 kg had significantly ($P < 0.001$) lower lipid contents than pigs at 85 kg.

Simple linear regression analysis was performed to determine the relationship between the percentage carcass fat and P2 back-fat measurement. An equation predicting the percentage carcass fat using P2 back-fat measurement was developed and compared to a similar equation reported by Whittemore *et al.* (1988).

This study: $y = 3.938$ (s.e. 0.766) + 0.7120 (s.e. 0.0655) P2 ($R^2 = 0.597$)

Whittemore *et al.* (1988): $y = 17.6$ (s.e. 1.36) + 0.711 (s.e. 0.052) P2

While the intercepts between the two equations vary, the slopes are similar and thus the rate of response is considered constant. Data of the chemical composition of the empty body provided by Whittemore *et al.* (1988) in the form of an appendix was used in an equation developed by Ferguson *et al.* (2000a) to determine the lipid content in the empty body. This was done to evaluate the accuracy of determining lipid content by the Ferguson *et al.* (2000a) equation and found to fit the data presented by Whittemore *et al.* (1988) adequately. Hence, the equation developed by Ferguson *et al.* (2000a) is an accurate measure ($R^2 = 0.99$) in determining the lipid content of the empty body.

The efficiency of protein utilisation

The efficiency of protein utilisation was determined by calculating the amount of protein retained and digested ideal protein intake (DIPI) originally defined by Kyriazakis and Emmans (1992a) and modified for this purpose.

$$DIPI = (P_{HP}/100 \times FI \times CP_{HP} \times v_{HP} \times D_{cpHP}) + (P_{LP}/100 \times FI \times CP_{LP} \times v_{LP} \times D_{cpLP})$$

where:

HP	= high protein feed
LP	= low protein feed
P_{HP} and P_{LP}	= proportion of feed chosen (%)
FI	= feed intake (kg/d)
CP_{HP} and CP_{LP}	= crude protein (g/g)

v_{HP} and v_{LP} = digested protein in relation to crude protein

d_{cpHP} and d_{cpLP} = digestibility of crude protein

The value of v determined for the high and low protein feed was 0.82 and 0.59 and d_{cp} was 0.85 and 0.83 respectively. The relationship between protein accretion and digested ideal protein intake can be described by the following regression equation:

Protein Accretion : = 89.4 (s.e. 15.1) + 0.1895 (s.e. 0.0574) DIPI (g/d) ($R^2 = 0.292$)

The estimate of the apparent efficiency of ideal protein utilisation is provided by the slope of the fitted line (0.1895) and includes the amount for maintenance and protein accretion. A true reflection of the efficiency of protein utilisation would be to determine the net efficiency of ideal protein utilisation above maintenance (e_p) according to the equation of Kyriazakis and Emmans (1992b).

$$e_p = PR/(DIPI - MP)$$

where:

PR = protein retention (g/d)

DIPI = digested ideal protein intake (g/d)

MP = maintenance protein (kg/d) (0.0040 × protein weight of the pig)

Only increasing the group size had a significant ($P < 0.01$) effect on the efficiency of protein utilisation with larger groups using protein more efficiently than smaller groups. This may be explained by the observation that pigs housed in small groups consumed more feed, consisting largely of high protein, resulting in an over consumption of protein and ultimately a reduction in the efficiency of protein utilisation than pigs housed in small groups.

4.4 DISCUSSION

The null hypothesis in choice-feeding experiments is that pigs will consume an equal proportion of feed across all treatments (Ferguson *et al.*, 2002). However, this prediction was rejected as the proportion of high protein feed chosen, on a weekly basis, exceeded the maximum of 0.5 across all group size and floor-space allowance treatments. Initially, pigs showed a preference for the high protein feed but as the dietary composition selected varied over time, this diminished to include additional low protein feed across all treatments except the group of 14 pigs/pen housed at 0.49 m^2/pig. This decline in the proportion of high protein feed chosen over time is consistent with previous reports and illustrates the change in protein requirement relative to energy requirement during the latter period of growth (Kyriazakis *et al.*, 1990, Bradford and Gous 1991a, b; Kyriazakis *et al.*, 1991; Kyriazakis and Emmans, 1993).

The variation in the proportion of high protein feed chosen between stressors is attributed to the difference in feed intake between small and large group sizes (4 and 8 pigs/pen *vs.* 9 and 18 pigs/pen) and less and more (0.86 m^2/pig *vs.* 1.72 m^2/pig) space allowances. However, the choices made by the group of 14 pigs/pen housed at 0.49 m^2/pig were opposite to those made by pigs on all other treatments, resulting in a steady (non-significant) increase in the proportion of high protein feed chosen over the experimental period. It is assumed that pigs housed under such constraints require less energy for maintaining body temperature (energy requirement for maintenance) and spend less time at the feeder.

The possibility of a lack of feeder space contributing to the reduction in feed intake and hindering the proportion of high protein feed chosen for the group of 14 and 18 pigs/pen and floor-space allowance of 0.49 and 0.86 m^2/pig cannot be disregarded. However, the lack of significant differences in response to the number of feeder bins on performance as noted by Ferguson *et al.* (2001), suggests a single feeder bin was not a constraining factor in group-penned pigs housed at limited floor-space allowance as pigs adjusted their feeding behaviour to accommodate this change. Similarly, Nielsen *et al.* (1995) observed that in spite of pigs being successful in adapting to the lack of feeding space, they displayed behaviour not normally seen in diurnal animals, suggesting that the pig: trough ratio had reached a maximum without adversely affecting performance.

The feeds applied in this experiment were not fixed and constant throughout the experimental period as in the previous study and published work and to our knowledge no equivalent experiments or treatments exist. In order to determine whether pigs would choose differently depending on the degree of stress and the implication of this choice, it is necessary to compare the previous and current experiment as the conditions were almost identical and any difference between them is likely to be the result of the choice feeding treatment.

The results of Figure 4.3 indicate that irrespective of feed, increasing the number of pigs/pen significantly reduces the average daily gain of growing-finishing pigs in both experiments. However, this rate of reduction was steeper for pigs fed a fixed lysine content in the previous experiment than for choice-fed pigs in the current experiment. This suggests that the effect of increasing group size is not as severe with the choice-fed pigs as with pigs fed a fixed lysine content. Similarly increasing the number of pigs/pen significantly reduced the feed intake in pigs fed a fixed lysine content. Although the increase in the number of pigs/pen did not influence the decline in feed intake observed for the choice-fed pigs it is likely that the large variation can be attributed to this lack of non-significance. The efficiency of protein utilisation remained unaffected as the group size increased for the pigs fed a fixed lysine content. At any group size pigs fed lower lysine contents had higher efficiencies than pigs fed higher lysine contents. However, increasing the group size significantly increased the efficiency of protein utilisation in choice-fed pigs suggesting this effect was not as severe as for pigs fed a fixed lysine content.

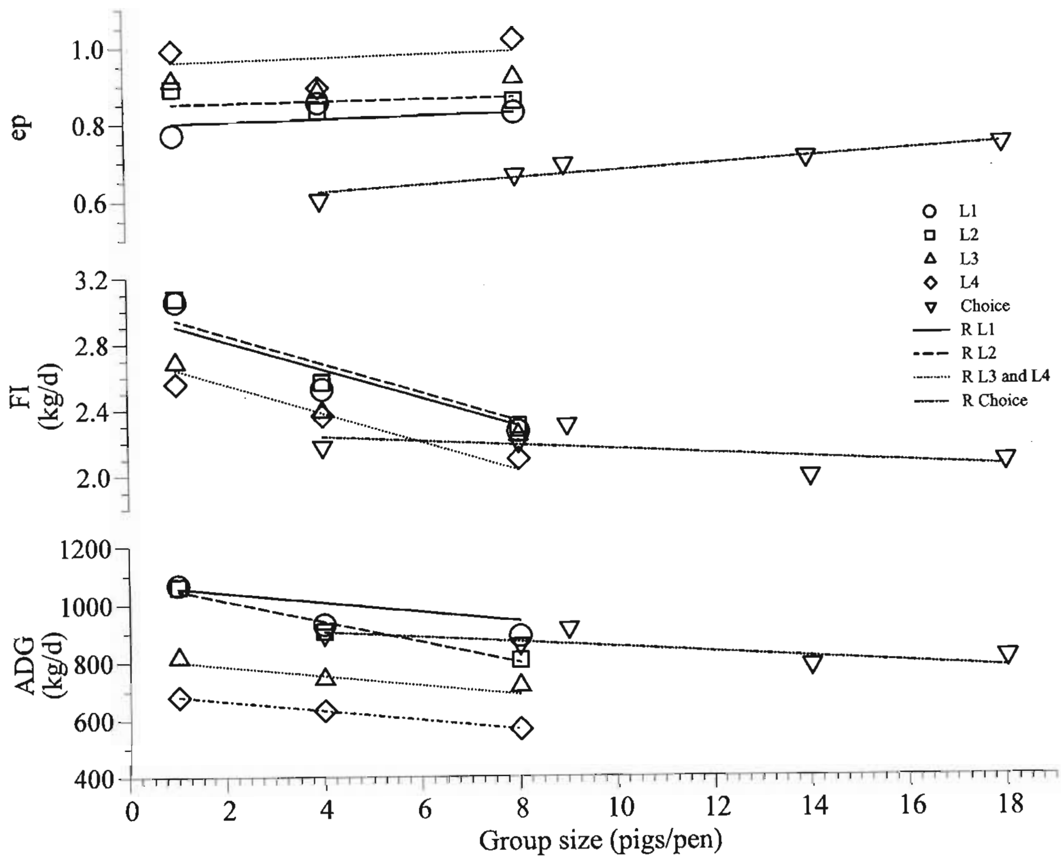

Figure 4.3 *The response in average daily gain (ADG), feed intake (FI) and efficiency of protein utilisation (e_p) of pigs housed in varying group sizes (1, 4, 8, 9, 14 and 18 pigs/pen), offered one of four feeds varying in lysine content (Experiment One) or choice-fed (Experiment Two) over the period 40 to 85 kg live weight.*

The significant improvements in average daily gain and feed intake associated with increasing the floor-space allowance for both experiments is shown in Figure 4.4. This rate of increase was similar for both experiments and suggests that irrespective of dietary treatment, average daily gain and feed intake are positively influenced with increasing floor-space allowance. Hence, the choice-fed pigs perform just as well as pigs fed a fixed lysine content at different floor-space allowances. The efficiency of protein utilisation remained unaffected by increasing the floor-space allowance for the pigs fed a fixed lysine content and pair-fed, but at any floor-space allowance pigs fed higher lysine contents had higher efficiencies than pigs fed lower lysine contents. Irrespectively, the decline in the efficiency of protein utilisation associated with increasing floor-space allowance was more pronounced for the choice-fed pigs than pigs fed a fixed lysine content.

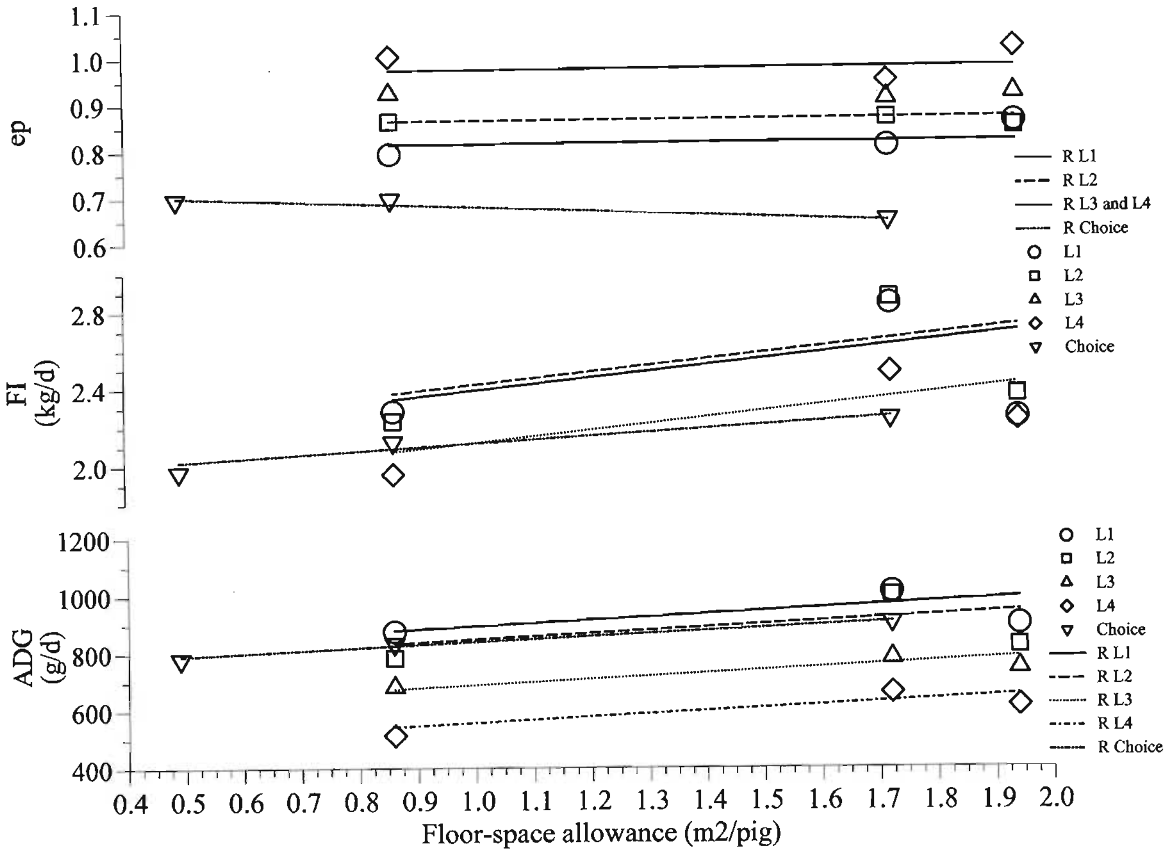

Figure 4.4 *The response in average daily gain (ADG), feed intake (FI) and efficiency of protein utilisation (e_p) of pigs housed at varying floor-space allowances (0.49, 0.86, 1.72 and 1.94 m^2/pig), offered one of four feeds varying in lysine content (Experiment One) or choice-fed (Experiment Two) over the period 40 to 85 kg live weight.*

4.5 CONCLUSION

This experiment indicates that socially stressed growing-finishing pigs, when offered a choice between an appropriate pair of feeds, may not overcome the reduction in performance variables and carcass characteristics associated with the stress imposed, but will perform as well as pigs fed a fixed lysine content. The most severe social stresses imposed did appear to change the proportion of high protein feed chosen by these pigs over time, but no plausible explanation for this difference could be suggested. A choice-feeding system is therefore unlikely to overcome the effects of stressors that cause pigs to consume less feed and hence grow more slowly. The conclusion reached in the previous chapter therefore still holds, that pigs predicted to grow at a rate below their potential should be offered a feed commensurate with their potential requirements.

CHAPTER 5

GENERAL DISCUSSION

Environmental stress has been identified as one of the many factors responsible for the animal failing to achieve its inherent growth potential. However, in spite of the improvements in genetics, housing, management and nutrition, producers still fail to capitalise on the inherent growth potential. Consequently, this lag in potential growth has sparked the contentious debate of whether an animal should be fed to its genetic potential in spite of this not being achievable due to one or more on-farm constraints. This provided the basis for the research conducted and reported in this thesis.

In order to reduce the inherent growth potential sufficiently, in a non-evasive and non-threatening manner, group size and floor-space allowance were chosen as the stressors to be imposed, and two experiments employing different nutritional strategies to test this were conducted.

In the first experiment, pigs were offered one of four feeds varying in dietary lysine concentration, produced by the summit-dilution technique, to determine whether the amino acid content of a feed should be reduced, when the potential growth of an animal is compromised due to increasing group size or decreasing floor-space allowance. The results indicate that feeding socially stressed pigs high quality feeds does not compensate for the reduction in potential growth, but overall they perform better than those fed low quality feeds. On the other hand, many researchers suggest that there is no merit in feeding such pigs a high quality feed as socially stressed pigs fail to overcome the reduction in growth potential. Although the reduction in growth cannot be overcome by feeding a high quality feed, the social aspect of group penning in relation to individual penning cannot be disregarded. Furthermore, under such circumstances, feed intake and growth rate are already constrained, and by reducing the amino acid content of the feed to match this, it places the animal under additional stress to consume more in an attempt to satisfy the first limiting nutrient resulting in undesirable carcass characteristics.

The logical sequel to the first experiment was to offer pigs a choice between two feeds differing in the protein: energy ratio and determining whether increasing group size and decreasing floor-space allowance alters nutrient content of the feed chosen by pigs. Unfortunately due to an unforeseen number of mortalities occurring during the first three weeks the individually-penned treatment was discontinued to ensure the group sizes remained comparable at similar or dissimilar space allocations between buildings. The proportion of high protein feed chosen declined over time reflecting the change in protein relative to energy requirement for all comparisons except the group of 14 pigs housed at a space allowance of 0.49 m^2/pig. Possible explanations for this observation are that pigs housed under such conditions require less energy for maintenance, because of their close proximity to other pigs, and they spend less time at the feeder, although at high environmental temperatures the close confinement may be a disadvantage, and this together with increased fighting may have the opposite effect. As the feeds applied in this experiment were not fixed and to our knowledge no equivalent experiments or treatments exist, it was compared to the previous experiment where similar conditions prevailed, in order to determine whether pigs would choose differently depending on the degree of stress. The results indicate that choice feeding does not overcome the reduction in potential growth and is also not influenced by large group sizes or limited space. However, choice-fed pigs perform in a similar fashion to pigs fed a fixed lysine content by selecting a dietary combination allowing the best possible growth within the constraints present.

It is widely acknowledged that social stresses present pigs with constraints acting singly or in combination, causing a reduction in the inherent growth potential despite their having the necessary resources available. Furthermore, several researchers have hypothesised that social stress is mediated through biochemical pathways, which reduce the capacity for protein growth, nutrient requirements and voluntary feed intake. This highlights the need for further research to improve our understanding of the molecular mechanism(s) involved during stressful conditions.

Despite the effect of social stress on pig performance being extensively researched, it remains underestimated and ignored in pig growth simulation models. Wellock *et al.* (2005) described the quantification of the effects of social stressors on the performance of growing pigs and how these relationships can be incorporated into a more general pig growth model using the model framework described and tested by Wellock *et al.* (2003a, b) as a reference point. The inputs required are the description of the genotype, its feed and the physical and social environment in which it is reared, making use of the theory of feed intake and growth of Emmans (1981). Furthermore, the model assumes that the down-regulation in lean tissue growth i.e. a decrease in the animal's ability to attain its potential, is the result of social stressors. They proposed that this is equivalent to lowering the growth rate parameter (B). This finding has significant implications in that it is now possible to predict the effect of social stresses on feed intake, and hence determine the optimum feeding programme for growing-finishing pigs kept under these stressful conditions.

A balance between the biological efficiency of the animal and economic efficiency of the operating system needs to be established by determining optimum stocking densities over the growing-finishing period, given that space is at a premium in commercial operations. Furthermore, when animals are expected to perform below their inherent growth potential, due to an on-farm constraint, they should not be penalised further by having the amino acid content of the feed reduced, as profitability is further reduced as a result. It is anticipated that the research reported in this thesis will challenge the way we think, feed and manage our pigs.

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