Effects of *ad libitum* and restricted diets in different feeding regimes on growth and carcass attributes of boars of a selected genetic line

By

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Declaration

I, the undersigned, declare that the thesis, which I hereby submit for the degree of Master Science to the University of Pretoria, is my own work and has not previously been submitted by me or another individual for a degree at this or any other institution.

W.J Steyn

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Abstract

The current modern commercial pig is an animal that has evolved through deliberate breeding programs, controlled environmental influences and nutrition to yield a highly efficient feed converter and fertile animal. The objective of this study was to measure the growth performances and carcass characteristics of entire male grower – finisher pigs which were subjected to different seasonal variations, nutrient dense diets, feeding regimes and group situations under South African circumstances. Period 1 was conducted in the winter from 6 June 2008 to 13 August 2008 and Period 2 in the summer from 3 October 2008 to 10 December 2008. The sire lines that were selected for the experiment had the same genetic breeding values (Topigs Selection Index value), of which two sire lines were the same in both Period 1 and Period 2 and one of two different sires lines was used either in Period 1 or Period 2. The animals were fed two different rations, a high (FH) and a low ration (FL), with the low ration's specifications being 95 % of the high ration. The animals were randomly allocated three different feed regimes throughout the trial; restricted single feeding (RSF), *ad libitum* single feeding (ASF) and *ad libitum* group feeding (AGF). In the winter animals had a greater growth response compared to the summer, with end weight and average daily gain being significant ($P<0.05$) higher. A significant ($P<0.05$) improvement in average daily gain, feed efficiency and protein deposition rate were observed when animals were fed a higher energy and protein content in their diet, especially during summer. A significant ($P<0.05$) improved feed conversion was observed for restricted animals, but end weight, average daily gain and average protein deposition rates were significant ($P<0.05$) lower compared to *ad libitum* group and individually fed animals. In conclusion; the impact of decreasing the nutrient density of the diet for growing pigs through incremental changes in diet composition had a variable impact on overall growth performance and carcass quality. Feeding the high energy and protein ration improved growth performance during summer, but also in the initial stages of growth when feed intake capacity was limited. The objective when formulating diets should be to provide the essential amino acids and energy in amounts needed to support maximal and efficient growth. Using growth models estimated optimal feed intake curves will not deliver optimal results. Only when measuring and calculating the actual feed intake and protein deposition rates optimal performance levels will be reached. Measurements of feed intake and growth performance data derived from pigs penned individually should be adjusted before they can be applied to commercial situations or research conditions in which pigs are penned in groups.

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INTRODUCTION

The pork industry in South Africa is demanding improved information on pig nutrition in order to define more economical feeding programs while at the same time ensuring the best possible product for the consumer. To provide such information it is necessary that the pigs' exact nutrient requirement and feed intake capabilities are known. Pig growth models have been developed by universities and private industry researchers to accurately quantify the daily nutrient requirements of pigs especially that of essential amino acids, based on inputs that affect performance. The efficiency of lean pork production can be improved by using pig growth models to evaluate genetic, nutritional and management alternatives (Whittemore, 1986 and De Lange *et al.*, 2001). Using growth models developed in other countries i.e. The Netherlands, for different performance outcomes does not always guarantee the same outcomes in current situation or country i.e. South Africa. Pig growth models require an estimate of the commercially achievable feed intakes and operational protein and lipid deposition rates. Protein deposition rates are used to predict daily essential amino acid and energy intake requirements of pigs (Schinckel and Craig, 2002). Knowledge of factors influencing growth and more importantly protein deposition capacity is crucial for the design of diets and feeding strategies for growing animals and for predicting the effects of change in feed intake on growth performance and carcass composition. Factors influencing growth or the rate of protein deposition include age, live weight, genotype, sex, nutrition and the environment (De Greef, 1992).

Pigs raised in commercial conditions are normally penned in groups, whereas in nutrition and other experimental studies they are frequently penned individually. Growth performance is usually greater when pigs are penned individually than when they are penned in groups (De Haer and De Vries, 1993 and Hacker *et al.*, 1994). Competition at the feeder, social facilitation and social stress are all factors that may be responsible for the differences in feeding behaviour and production parameters between group housed and individually housed pigs. Little is known about the changes in body composition arising from the social interactions in group-penned pigs compared to those penned individually. These differences should be determined to enable refinements in nutritional recommendations and to identify conditions in group pens that limit productivity.

Voluntary feed intake of pigs determines nutrient intake levels and thus has a great impact on efficiency of pork production. The amount of feed consumed voluntarily by pigs is inconsistent and is affected by many factors (Hyun *et al.*, 1998). A stressor such as hot temperature negatively influences feed intake and growth. The optimum temperature range for finishing pigs is between 10 and 23.9°C (Myer and Bucklin, 2001), temperatures above 23.9°C decrease voluntary feed intake and pig growth (Kouba *et al*., 2001). The inferior growth performance of animals in summer may be due to the redirection of more energy into their maintenance requirements. Animals in warm conditions have increased physical activities, such as respiratory hyperventilation, which are consistent with additional energy costs and higher maintenance requirements. Noblet *et al*. (1985) indicated that higher nutrient dense rations would be tolerated better under warm conditions and concluded that the efficiency of metabolizable energy (ME) utilisation for energy retention and live weight gains improve as the energy concentration of the diet is increased under increasing thermo conditions.

The objective of this study was to measure the growth performances and carcass characteristics of entire male grower – finisher pigs which were subjected to seasonal variations, diets varying in nutrient densities and different management strategies in terms of feeding regime and housing under South African circumstances. The aim of this experiment was to test the following null hypothesises:

- Higher dense protein and energy diets have no positive effect on pigs' growth performances and carcass grading when fed during the summer period.
- No differences exist between the performance of entire male pigs fed restricted quantities of feed which was optimised according to the prescribed growth model for maximum protein deposition and optimum feed conversion ratio and *ad libitum* fed entire males.
- Grower pigs penned in groups have the same performance capabilities than pigs penned individually.

CHAPTER 1
LITERATURE REVIEW

1.1 Introduction

In the latter half of the 18th century Robert Bakewell's theory that animals could be bred especially for the improved production of meat, followed from the acceptance that a given animal genotype was not fixed, but could be changed by the impositions of different selection programmes (Whittemore, 1998). Size, fatness, rate of growth, prolificacy and efficiency are all qualities that can be assessed and improved progressively, generation by generation, to create a farm animal whose main purpose is to produce meat as efficient as possible. The term 'improvement' (1750 -1900) was associated with the creation of special breeds of pig with an increased penchant for fatness. Fat was seen as a beneficial character, a healthy provider of energy to the population and also provided effective cooking lard for meat and other foods in the absence of readily available vegetable oils. As time progressed, the availability of reasonable lean pig types, providing pork and bacon products to the market, was insufficient to meet increased consumer demand. Since then, breeders used different pig improvement strategies and techniques to create improved breed types. As consumers became more health conscious and producers more cost concerned, demand for carcasses with less fat and pigs with greater production efficiencies increased dramatically.

Today the commercial pig is an animal that has evolved through deliberate breeding programmes, controlled environmental influences and nutrition to yield a highly efficient feed converter and fertile animal. The question that arises is how did scientists reach the ultimate performance criteria of pigs within environments, production systems and under the influences of custom-made nutrient sources?

1.2 An overview of the current pig industry

1.2.1 Pig Economics

More than 95 million tonnes of pork is produced annually worldwide making the pork industry the largest meat industry in the world. China produces 50 % followed by the European Union (26%) and the USA (10%). South Africa slaughters around 2.4 million pigs annually and accounts for less than 0.8% of the world pig market. It is estimated that around half of all South African pork is utilised by the meat processing industry to manufacture bacon, sausages, hams and other meat products (Escort Limited, 2005). World pork consumption is on average 15 kg per capita (NPPC, 2004); whereas in South Africa consumption has decreased since the early 1970's from 3.5 kg per capita to 2.7 kg per capita (NDA, 2005). South Africa therefore has a tremendous potential to increase and develop its per capita consumption of pork and pork products.

The economics of pig production have changed noticeably in recent years. Feed usually comprises around 70% of the costs for animal production; therefore a rapid escalation in feed prices constitutes a major increase in production costs. Fluctuations in feed prices have a greater impact on production costs and on profitability than any other single factor. With the recent explosion of grain prices, the costs of pig diets have increased dramatically. Therefore, South African pig producers have to choose between either optimal growth and efficiency at a higher cost, or slower growth using local, cheaper feedstuffs.

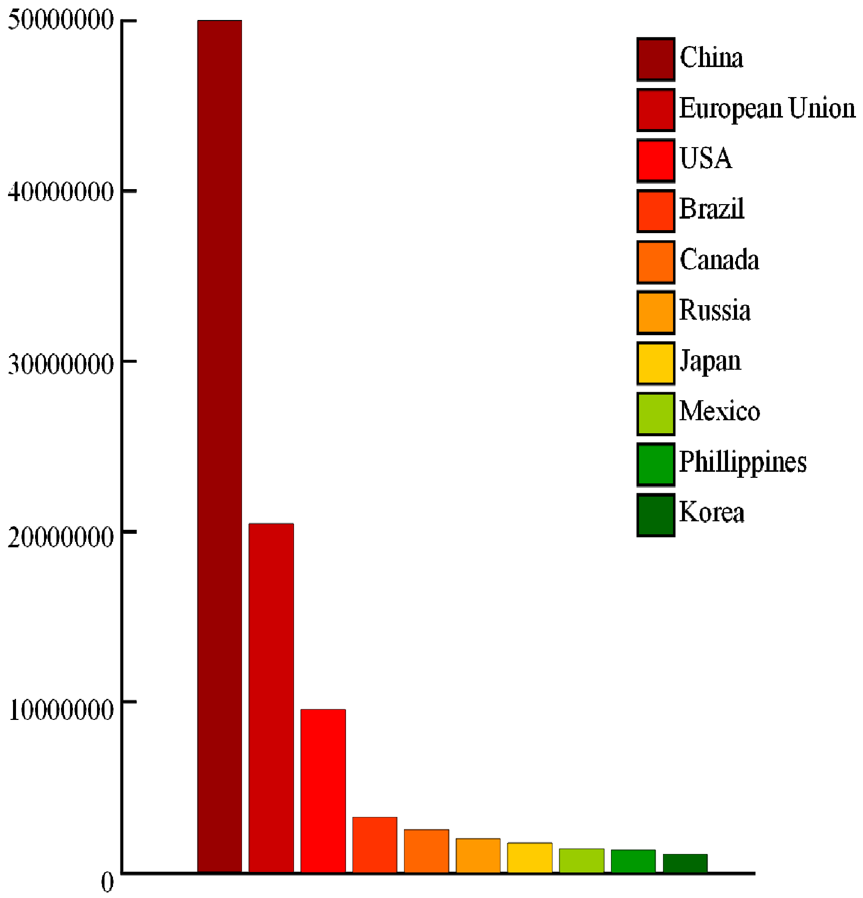

Figure 1.1 World pork production (Escort Limited, 2005)

1.2.2 Consumer perspective and pork quality

More pork is consumed in the world than any other meat, yet there is intense competition in the pork industry world-wide to attract and retain consumers. Food safety, price, nutritive value, meal convenience, appearance as well as the type and cut of meat play an important role in determining whether consumers purchase meat or not. However, it is the eating experience or the quality of the product that influences the consumer to repurchase. Quality pork is the combined result of genetics, nutrition, production management, transportation, slaughter, processing and retailing practices. The modern day consumer demands quality pork i.e. carefully prepared and butchered cuts, low levels of subcutaneous fat, adequate levels of intramuscular fat and a large mass of lean tissue; leading to a high level of eating pleasure perception. Over time an increased selection for leaner and more efficient animals had caused a dramatic reduction in the fat content of pig meat. Subcutaneous and intramuscular fat levels have been reduced by genetics, nutrition and feeding management, producing a more cost efficient animal. The reduction of fat content in carcasses led to an inferior consistency and an increasing susceptibility for perishableness of fat, thus influencing the quality. The pig industry is now faced with a huge dilemma, enough intramuscular fat to satisfy the eating experience of the consumer needs to be produced but at the same time the amount of visible fat needs to be low to alleviate health concerns (Fortin *et al*., 2005). It must, however still be economically worthwhile for producers to produce pork.

Cameron *et al*. (2000) examined the effects of genotype, diet and genotype-diet interaction on fatty acid composition of neutral lipid and phospholipids of intramuscular fat in pigs. It was concluded that the nutritional effects on intramuscular fat characteristics were greater than genetic effects and that nutritional approaches to feed pigs will provide effective methods of reducing the n-6: n-3 fatty acid ratio of human dietary fat from pig meat, resulting in improved human health. It is therefore possible to produce healthier pork by changing the fatty acid composition of intramuscular fat which would satisfy consumer expectations of a healthier product. However, the consuming quality of pig meat can decrease as the fatty acid composition of intramuscular fat changes with selection for increasing carcass lean content (Cameron and Enser, 1991). The pork consuming quality may therefore decline with selection and nutritional strategies that substantially reduce intramuscular fat content. It is thus important to consider the factors that influence pork consuming quality when developing selection criteria for modern day leaner animals.

Pig meat producers need to have a clear view of their target end product, an adequate definition of that target and a means of manipulating the production system to achieve the stated goal. Unfortunately producers are not always financially rewarded for improved meat quality, therefore adoption of any nutritional strategies remain low. Levels of fatness and carcass weight are the prime determinants of value and payment received by the producer. The quality of fat which is of considerable importance to carcass quality does not yet play a functioning part in the payment schedule. Fortunately, there are signs in some countries that the link between consumers, retailers, processors and producers are becoming stronger. It is perhaps only a matter of time before the use of commercial practices to improve pork quality are considered as part of best practices and also will be rewarded for. Production of pig meat with high levels of intramuscular fat and low levels of subcutaneous fat would therefore be advantageous for the industry, producer and consumer (Doran *et al*., 2006).

Oyewumi and Jooste (2006) suggested that the following changes need to take place to ensure a future for pork production in South Africa. Firstly, it is imperative that the pork industry, especially at primary level, undergo a substantial paradigm shift to move closer to the end consumer of pork in an effort to understand changing consumer preferences better and to make the required changes to stimulate and grow pork consumption. Secondly, product research and innovation should be imperative. In addition, determination of consumer needs and adapting to meet these needs is vital for long-term sustainability and profitability of the pork industry. Thirdly, communicating the various quality attributes of pork and pork products to consumers should increase. Promotional activities focusing only on economic factors will only provide part of the required incentive for consumers to purchase more pork and pork products, and may be short lived.

The South African pork industry must therefore do all it can to identify factors that influence pork quality and where possible make changes pre- and post-slaughter to address these issues whilst allowing each sector to make a reasonable profit.

1.2.3 Ractopamine Hydrochloride

The feed additive ractopamine (Paylean®, Elanco, Greenfield, Indiana, USA) is a β-adrenergic agonist and acts as a repartitioning agent, promoting primarily lean tissue deposition in monogastric and ruminant production animals. It has shown to give improvements in growth rate, feed efficiency, dressing percentage and carcass lean content (Gu *et al*., 1991, Crome *et al*., 1996, Main *et al*., 2002, Schinckel *et al*., 2002 and See *et al*., 2002), resulting in enhanced opportunity to improve enterprise profitability. These performance benefits are the result of increased protein synthesis and are also due to the redirection of fat deposition (Adeola *et al*., 1992). Performance improvements associated with feeding ractopamine in pigs are affected by limited nutrient concentrations of the diet, the dietary ractopamine concentration and also the duration of ractopamine feeding (Moody *et al*., 2000). Ractopamine should only be viewed as a management tool to enhance the genetic potential of animals.

Bark *et al*. (1992) examined the influence of genetic capacity for lean tissue growth on responses of pigs to ractopamine in terms of rate and efficiency of body growth and the distribution and accretion rate of body tissues. Two sources of pigs representing low and high lean tissue genotypes were used. Ractopamine significantly increased ($P < 0.01$) weight gain and improved ($P < 0.01$) feed to gain ratio in both genotypes. Ractopamine enhanced the accretion rate and the amount of carcass muscle in both genotypes, but the degree of improvement was greater in pigs with high than in those with low lean tissue genotype.

Xiao *et al*. (1999) investigated the effects of ractopamine on growth, nutrient utilisation, carcass composition and meat quality at high (180 g/kg) and low (130 g/kg) dietary protein levels using 120 finishing pigs. Results suggested that ractopamine improved the carcass characteristics regardless of the dietary protein level. However, the increased response of average daily gain and feed conversion ratio were only evident at a high protein level. This clearly indicated that ractopamine reduced carcass fat and improved carcass leanness independent of the protein level. However, feeding diets not limiting in protein or essential nutrients, enhanced the reaction or responses of ractopamine.

Stoller *et al*. (2003) indicated that feeding ractopamine did not affect most muscle quality and palatability characteristics. In contrast to these findings, Uttaro *et al*. (1993) and Carr *et al*. (2005) showed significant increases in Warner–Bratzler shear force (toughness) of pork from ractopamine fed animals. The impact of ractopamine on the textural properties of pork muscle as related to palatability is not clearly understood and need further investigation. Gonzalez *et al*. (2010) examined the effect of ractopamine–HCl supplementation for 28 days on carcass characteristics and concluded that ractopamine improved carcass parameters without a negative impact on tenderness.

It can be concluded from literature that including ractopamine in finisher diets could result in enhanced opportunities to improve enterprise profitability by improving carcass leanness and production efficiency. However, limited research is available that evaluates the effects of feeding ractopamine on muscle quality and sensory attributes.

1.3 Growth of the pig

1.3.1 The description of growth

"Growth is one of the main attributes of living things and is such an obvious process that it hardly seems to justify any particular formal definition" (Lawrence, 2002). If the dimensions of an animal are measured throughout its life time the data usually follows a sigmoid curve, known as the actual growth curve (Figure 1.2). The curve remains sigmoid for each kind of measure e.g. mass, height and volume. The initial limb of the slope is the self-accelerating phase indicating the considerable rate of growth occurring during this phase. Maximum rate of growth occurs at approximately one third of an adult's weight; known as the point of inflection. Later growth is slowed by a complex of physical and chemical influences. The slowing is gradual at first, starting at the inflection point with the self-retarding phase of growth. Depending on the animal's genetic potential and its environment the curve will reach a plateau.

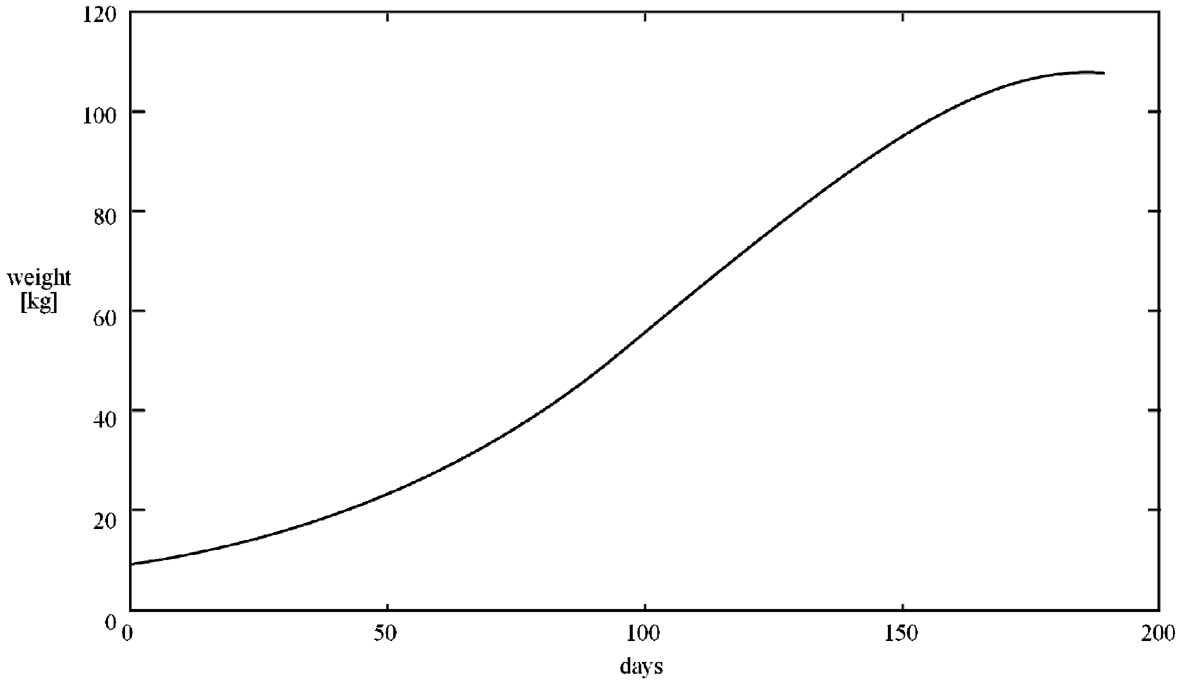

Figure 1.2 Actual growth curve, fitting pig growth data to the logistic equation (McMeekan, 1941)

In farm animals the main interest lies in the growth of specific parts of the animal such as bone, muscle, fat or the development of the mammary gland. In order to determine nutritional requirements and obtain the desired carcass composition it is important to consider the growth of the major body components of the animal as well as the growth of the principle organs. Studies conducted by Hammond (1932) present waves of growth passing through the body as weight and age progresses. Varying rates of growth in different tissues and regions in the body were also revealed. McMeekan (1941) intensively studied aspects of tissue development in growing pigs and concluded that "the major modifications in form and anatomical composition do not occur as isolated effects but rather as orderly changes spread over a number of correlated parts and originating in some deep-seated rhythm of growth". This concept is illustrated in Figure 1.3 where four tissue groups and their differential development in time are shown.

The components of animal growth in which we are interested in, are controllable through the growth rate of the animal (shape of the growth curve). If the animal body is the result of differential relationships between the growths of its constituent parts, and if these relationships are capable of environmental modification, then the imposition of environmental variation throughout the growth period should result in individual form and composition differences (McMeekan, 1941). Knowledge of pig carcass composition, the quantitative accretion of each carcass component and changes in growth patterns at various growth stages is important in nutrition studies and in production system analyses to optimize profit.

A nutritional manipulation and environmental modification will affect tissue deposition, however the relative development of these groups do not change. Hammond (1932) proposed that faster or later developing tissues (e.g. fatty tissue) are more affected by nutritional manipulation than early developing tissues. This concept has been studied and discussed intensively in literature. Although Hammonds' and McMeekans' interpretations were questioned and several deficiencies discovered some general aspects were still noticeable (Walstra, 1980).

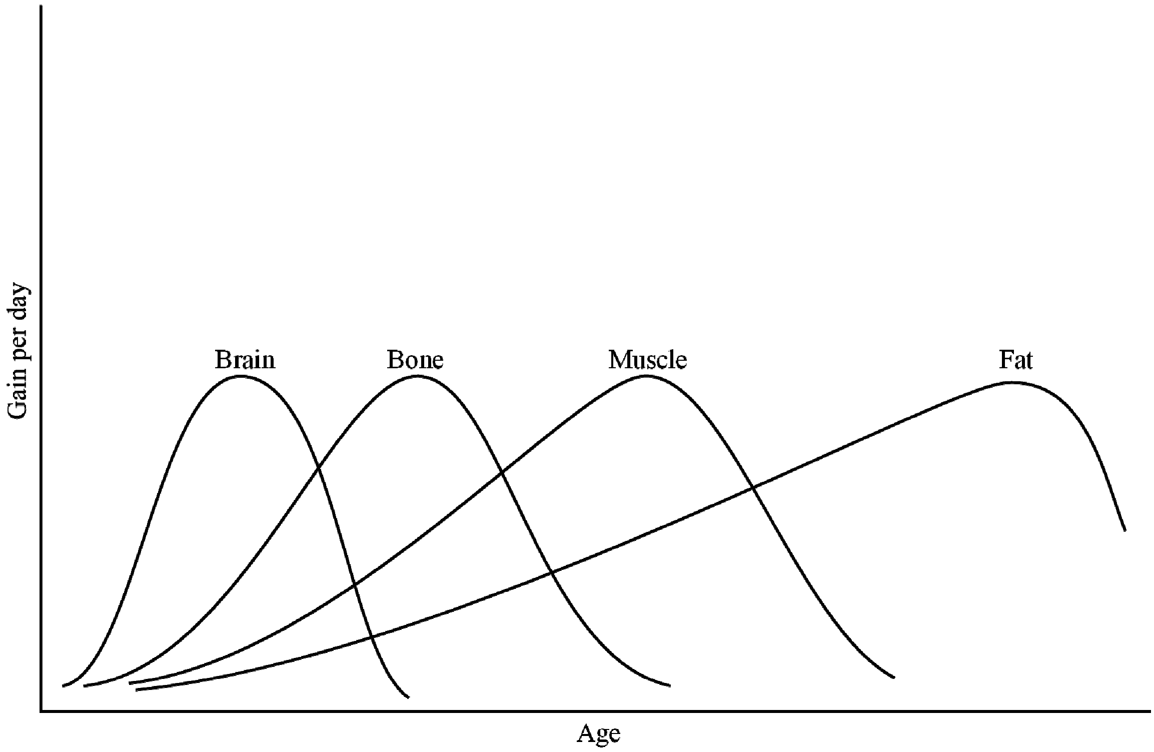

Figure 1.3 Analogy to describe the sequence of growth (Hammond, 1932)

1.3.2 The Linear – Plateau concept

Enhancement of growth rate is a basic goal in animal production. By increasing the growth rate, the biological efficiency of the animal increases, thereby producing more meat for less food. Production of meat from pigs requires an optimisation between lean deposition and fat deposition. Deposition rates of lean and fatty tissue (protein and lipid) determine growth and body composition to a predominant degree. These components are regarded to be relatively independent from each other, but both are affected by nutrition (De Greef, 1992). Protein deposition rates are used to predict daily essential amino acids and energy requirements (Schinckel and De Lange, 1996 and Schinckel and Craig, 2002). Protein and lipid deposition rates are used in pig growth models to predict carcass muscle and fat tissue mass, the primary determinants of carcass cut-out value (Akridge *et al*., 1992 and Schinckel *et al*., 2003). Partitioning of production energy between protein and lipid deposition are therefore principal aspects in pig performance research. The response description in tissue deposition to nutrient intake is crucial, especially for growth prediction. A system used to predict pig growth and body composition using knowledge of its genotype and diet is of both scientific and practical interest and concern. The first pig growth models, as described by Whittemore and Fawcett (1976), proposed that the ratio of lipid to protein deposition is constant when pigs are depositing protein below their maximum; therefore, the ratio of lipid to protein deposition rate is independent of energy intake until maximal protein deposition capacity is reached. This principle was used in various modelling concepts. De Greef (1992) challenged this concept and stated that knowledge of the partitioning of production energy into lipid and protein is needed in order to predict pig performance as a function of animal and feed characteristics. Below maximal protein deposition, a higher intake of energy resulted in a higher ratio of lipid to protein and furthermore, the ratio between lipid and protein deposition increased in live weight at a constant energy available for production. These result indicated a positive effect on both energy intake and live weight on the ratio of lipid to protein deposition rate. De Greef *et al*. (1992) did not support the concept of a constant partitioning between lipid and protein deposition with increasing energy intake below maximum protein deposition and De Greef (1992) developed the Linear –Plateau concept (Figure 1.4) using described concepts to predict protein and lipid deposition. The Linear-Plateau concept describes the relationship between energy intake and protein- and lipid deposition in growing pigs and also assumes that protein deposition increases linearly with an increase in energy intake, up to a maximal protein deposition rate (PDmax), where the relation plateaus. The PDmax has an important constraint on pig growth. Below this plateau a minimal amount of lipid deposition accompanies each unit of protein deposition. There is therefore, a minimal ratio between lipid deposition and protein deposition. Below the intrinsic maximum for protein deposition, production energy is partitioned between protein deposition and lipid deposition according to this minimal ratio (r). Above protein deposition capacity all remaining energy is used for lipid deposition.

Figure 1.5 illustrates the structure of a growth model where the concept of the Linear- Plateau is integrated. Inputs for the model are aspects of nutrition and the pig. Nutrition are feed intake and feed composition (represented by amino acids and energy), whereas aspects of the pig are the initial weight, final weight and characterization parameters. By combining all these inputs with the characterization of the pig (PDmax) and minimal ratio of lipid to protein deposition (r), the protein and lipid deposition rates can be calculated. From protein deposition, body ash and water retention are calculated, resulting in an empty body gain. In addition, from the knowledge of the average gut fill of a pig, the live weight gain can be calculated. These calculations are done before the animal is slaughtered and the physical parameters such as lean meat percentage and back fat thickness are derived based on protein and lipid mass estimations (De Greef, 1992).

The Linear-Plateau concept is very useful in explaining and demonstrating nutritional principles, as illustrated in Figure 1.4. It clearly indicates an upper limit in relevant response (protein deposition) and that nutrition is a major tool in optimizing production (Whittemore, 1983). It also illustrates that the capacity of pigs (PDmax) influences the optimal feed allowance to a substantial degree

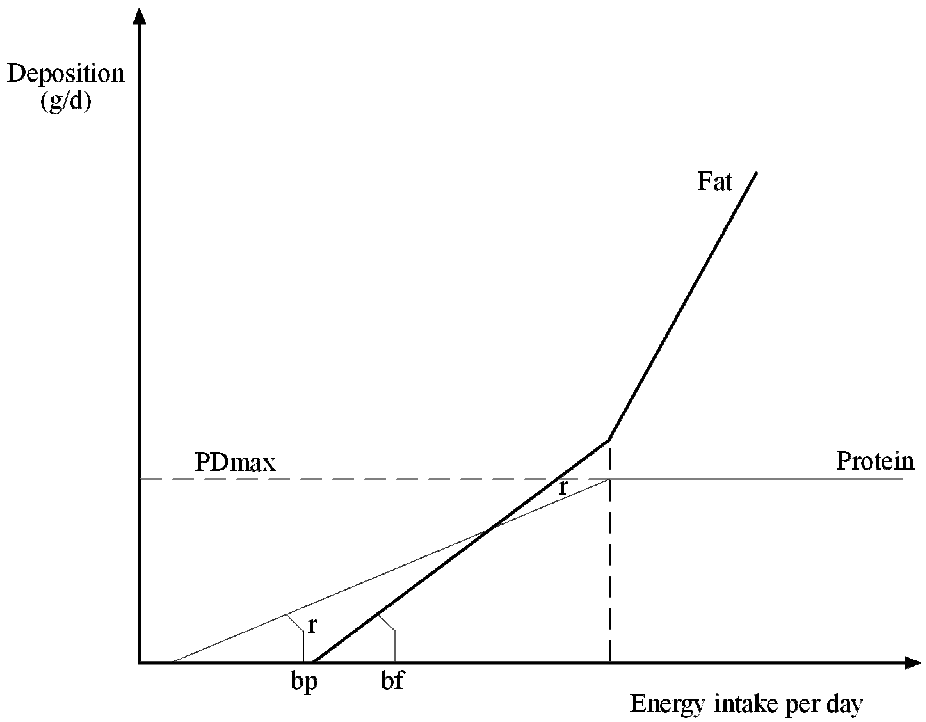

Figure 1.4 The Linear-Plateau concept (De Greef, 1992)

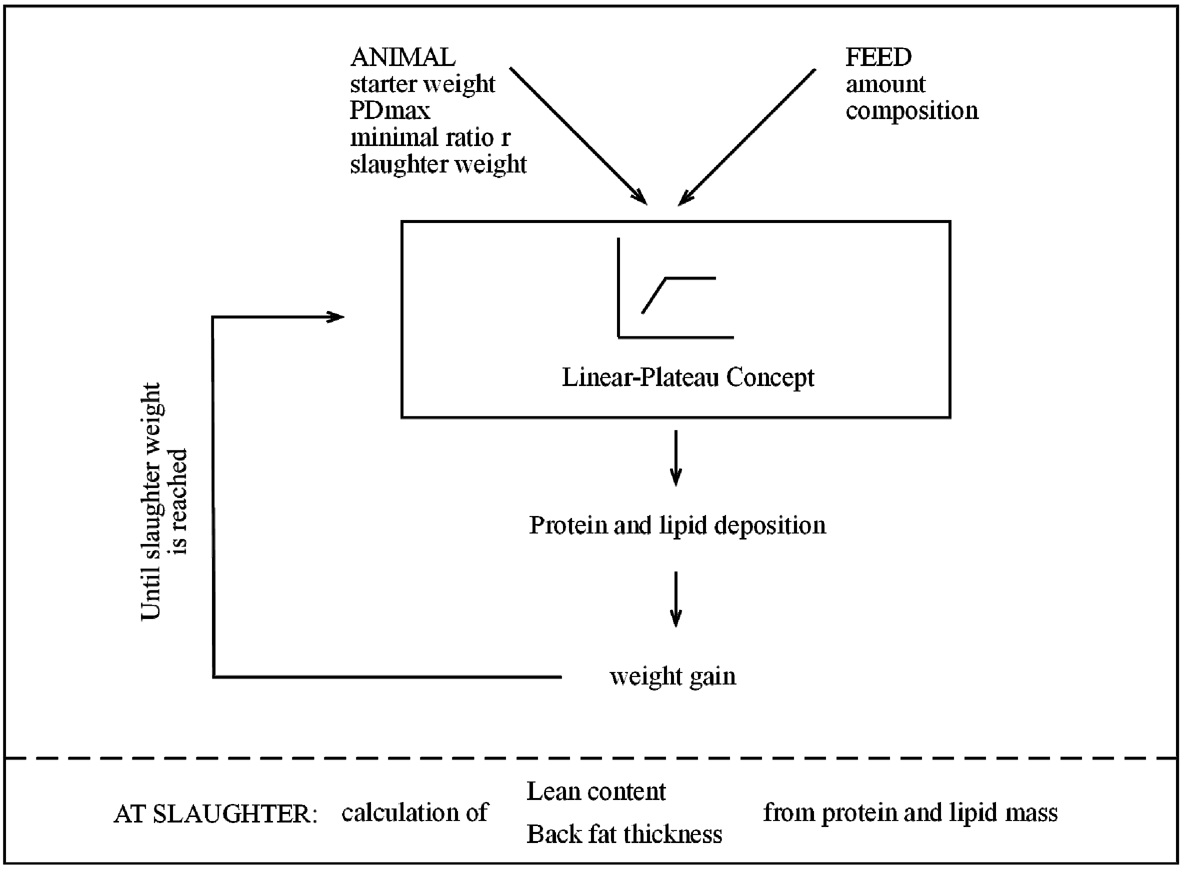

Figure 1.5 Simplified example of the general structure of a growth model (De Greef, 1992)

1.3.3 Factors influencing growth

Knowledge of factors influencing growth, more importantly protein deposition capacity, is crucial for the design of diets and feeding strategies for growing animals and for predicting the effects of change in feed intake on growth performance and carcass composition. The deposition of protein is vital for growth performance as it represents a useful method for measuring the rate of lean tissue growth. Factors influencing growth or the rate of protein deposition include age, live weight, genotype, sex, nutrition and the environment. Each factor will be discussed briefly.

1.3.3.1 Age and Live Weight

The genetic growth potential of pigs in one genetic group may differ from that of another group. Younger pigs in one genetic group can be heavier and larger than older pigs in another genetic group. It is therefore important to differentiate between age and weight when considering their effects on growth.

Within genotype and sex, provided adequate levels of nutrition, it is inevitable that the protein deposition rate will increase during early growth, reach a peak and then decrease as the animal increases in age and live weight (Campbell and Taverner, 1988). As the pig approaches maturity and the rate of protein deposition declines, an increase in lipid deposition occurs (De Greef, 1992). In literature different thoughts concerning the form of the response curve of protein deposition rate and the ratio between lipid to protein deposition, to live weight or age exists. Campbell (1990) suggested that protein deposition rate increases rapidly during early life. This results in the maximum deposition rate occurring at 20 to 40 kg live weight after which it is maintained at plateau until 120 kg live weight. Whittemore (1986) on the other hand, suggested that protein and lipid deposition rate is largely unaffected by live weight and that protein deposition rate reaches its maximum at 70 kg live weight, but that a general plateau of protein deposition exists from 45 to125 kg live weight. It is therefore suggested that the ratio between lipid and protein deposition rate is independent of live weight and of energy intake. In contrast to this, De Greef (1992) results' indicated a positive effect of both energy intake and live weight on the ratio of lipid to protein deposition rate (Figure 1.4). Recent studies conducted with genetically improved pigs suggest that the plateau occurs at high feed intakes and mature weights. In the case of superior boars the plateau might not be reached (Dunshea *et al*., 1998). King *et al*. (2004) concluded that genetically improved boars might not reach their upper limit to protein retention below 120 kg live weight.

Recent studies with new genotypes selected for fast lean growth has shown relatively high values for potential rates of protein deposition, compared to genotypes used previously. Results obtained by Whittemore and Fawcett (1976) indicated maximum protein deposition levels of 130 g/day occurring between 75 and 100 kg live weight. De Greef *et al*. (1994) observed protein deposition rate values as high as 250 g/day between 85 and 105 kg live weight, whereas Van Lunen and Cole (1998) indicated maximum protein deposition rates for boars and gilts, where 236 and 176 g/day, respectively. From these studies it can be concluded that the intensive genetic selection of the pig for leanness has raised the genetic ceiling for protein deposition to heavier body weights and beyond the upper limit for appetite.

1.3.3.2 Genotype

The deposition rate of protein and fat in pigs is determined primarily by its genetic merit, where a high genetic merit is a requirement for good performance. Backfat and muscle depth are highly heritable characteristics, where a coefficient of 0.50 is generally accepted as an average estimate (Whittemore, 1993). Swine breeders and seed stock producers have made rapid progress using genetic principles of selection to improve the breeding stock that is offered to commercial producers. Since then genetic selection for greater rate and efficiency of carcass muscle growth has grown substantially and changed the absolute and relative rates of protein and lipid deposition, feed intakes and nutrient requirements (Schinckel, 1999).

In literature several studies measured the protein deposition and growth performances of superior genetic lines against non-superior genetic lines. Campbell and Taverner (1985) compared two strains of pigs (selected vs. unselected). Results indicated that selected pigs had a faster protein deposition rate than unselected pigs. The slope of the relationship between digestible energy (DE) intake and rate of protein deposition for selected pigs was also higher than that of the linear portion of the relationship for unselected pigs. In addition, the maximum potential protein deposition rate for selected pigs was at, or somewhere above, the limit of voluntary feed consumption, whilst unselected pigs had a genetic protein deposition rate response potential considerably below the level of appetite, as illustrated in Figure 1.6.

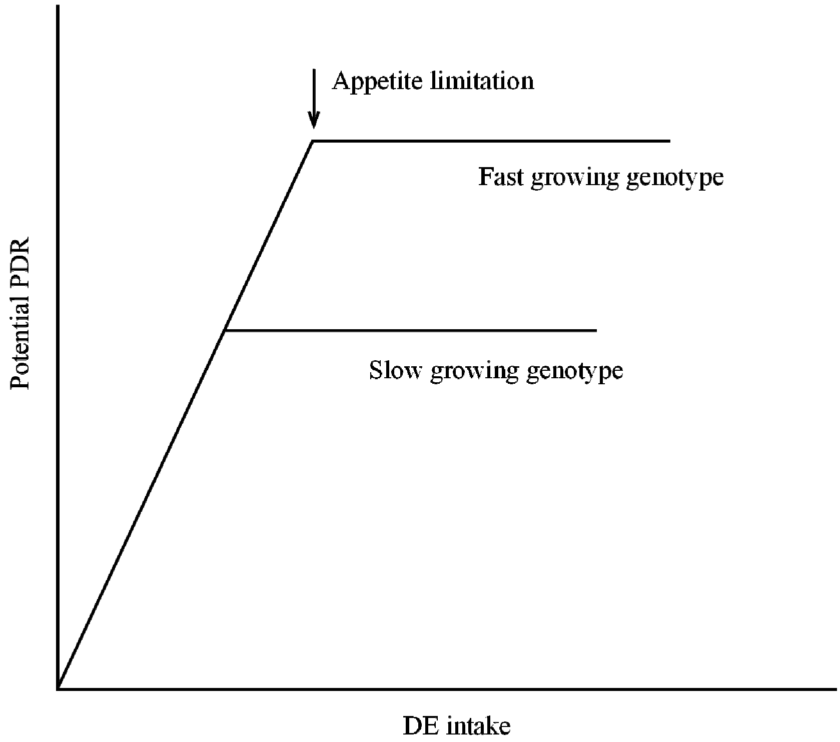

Figure 1.6 Potential protein deposition rates of two genotypes of pigs in relation to digestible energy (DE) intake (Campbell and Taverner, 1985)

Wiseman *et al*. (2007) examined two genetic lines with different lean gains for various body measurements in barrows and gilts from 20 to 125 kg of body weight. Results indicated that differences occurred phenotypically between pigs having either more muscle or fat. As body weight increased, lean tissue in high-lean pigs increased (particularly after 75 kg of body weight), and backfat and bone mineralization decreased. The low-lean pigs had contrasting results with increased backfat and greater bone mineralization. Schinckel *et al*. (2008) studied the compositional growth of two genetic populations differing in carcass lean and fat tissue growth from 20 to 125 kg of body weight. It was concluded that high lean-gain pigs had greater relative rates of protein and moisture deposition and lesser rates of lipid deposition per kg of body weight gain than low lean-gain pigs.

Rao and McCracken (1991) reported that "the response of improved genotypes in protein deposition increases with increasing metabolizable energy (ME) intake above normal appetite levels and any restriction in energy intake would have a greater negative impact on protein deposition than in unimproved pigs". Genotypes with high protein deposition potential therefore have a greater dietary requirement for protein and energy. Unless the improvement in the pigs genetic capacity for muscle growth is matched by a concomitant improvement in its nutritional management and in particular the level of dietary essential amino acids, much of the potential benefit offered by such animals will not be realized. Regardless of the higher growth and potential performance of highly selected pigs, it has been shown by previous studies that these pigs are more sensitive to nutritional deficiencies than their unselected counterparts. It is therefore important to understand the genetic differences that occur over time in order to determine the specific nutrient requirement of superior genetic populations to optimize pork production systems (Boys *et al*., 2007) and to improve the efficiency of nitrogen and phosphorus retention (De Lange *et al*., 2001).

1.3.3.3 Sex

In pigs, the sex of the animal has a strong effect on maximum protein deposition potential as well as on protein deposition response to nutrient levels, in particular above 50 kg live weight. A boar has the highest response, gilts intermediate and castrates the lowest (Campbell and Taverner, 1988). Growth performances, maximum rate of protein deposition and live weight also differ between sexes (Dunshea *et al*., 1993, King *et al*., 2000 and Suster *et al*., 2001). Boars deposit more protein and generally less fat than barrows and gilts.

The major difference between different sexes is the level of sex hormones. Differences between boars, gilts and castrates mainly depend on the growth stage at which measurements were taken; due to endocrine changes that accompany sexual development. As illustrated in Figure 1.7, the superiority of boars over gilts and castrates are not evident until the animal exceeded 50 kg and are most prominent at weights above 70 kg.

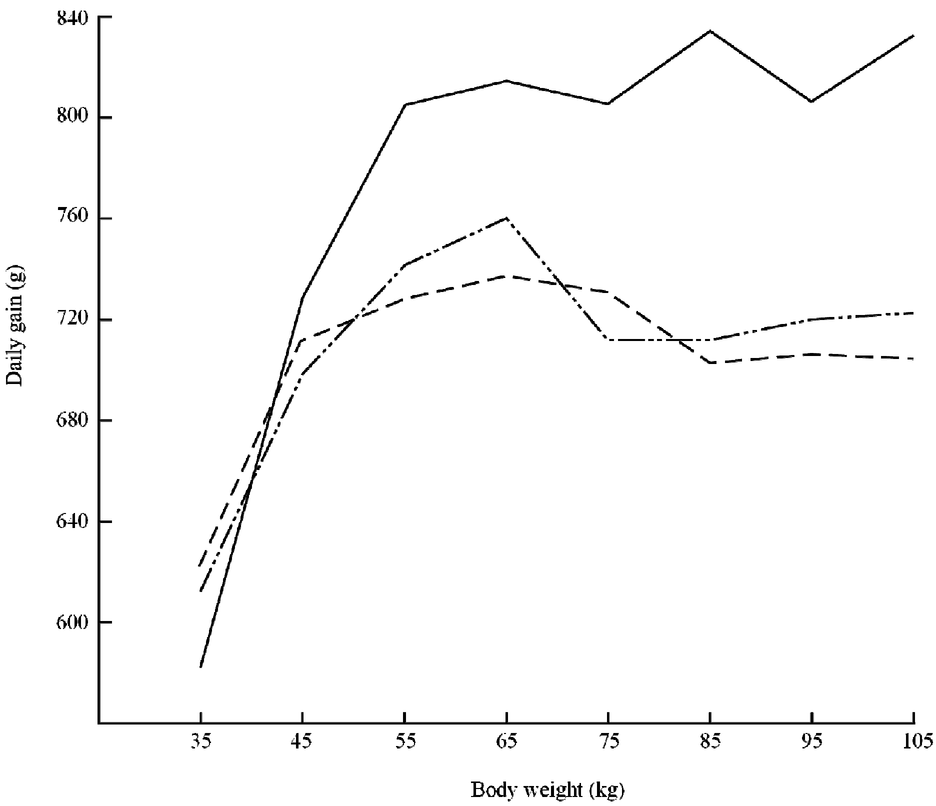

Figure 1.7 The effect of increasing body weight on the comparative growth rate of boars (_____), gilts (------) and castrates (__..__) (Witt and Schröder, 1969)

During early stages of development, up to 50 kg, the rate of protein deposition increases linearly with an increase in energy uptake to the limit of the pigs' appetite. Differences between the sexes are generally only small but increases with live weight (Campbell and Taverner, 1985). The most suitable feeding strategy for period 20 – 50 kg is that of promoting near maximum energy uptake thereby exploiting this high potential for muscle growth. Due to the linear relationship between protein deposition and energy uptake this feeding strategy allows for rapid growth, without excessive fat deposition or deterioration in feed to gain ratio. The digestive capacity of pigs at this stage limits their voluntary energy intake. Offering diets with the correct energy concentrations will fully express growth potential. Above 50 kg live weight differences between the sexes are more prominent. It is evident that at all slaughter weights, boars have more lean tissue and less fat than castrates. These differences increased at higher slaughter weights as illustrated in Figure 1.8.

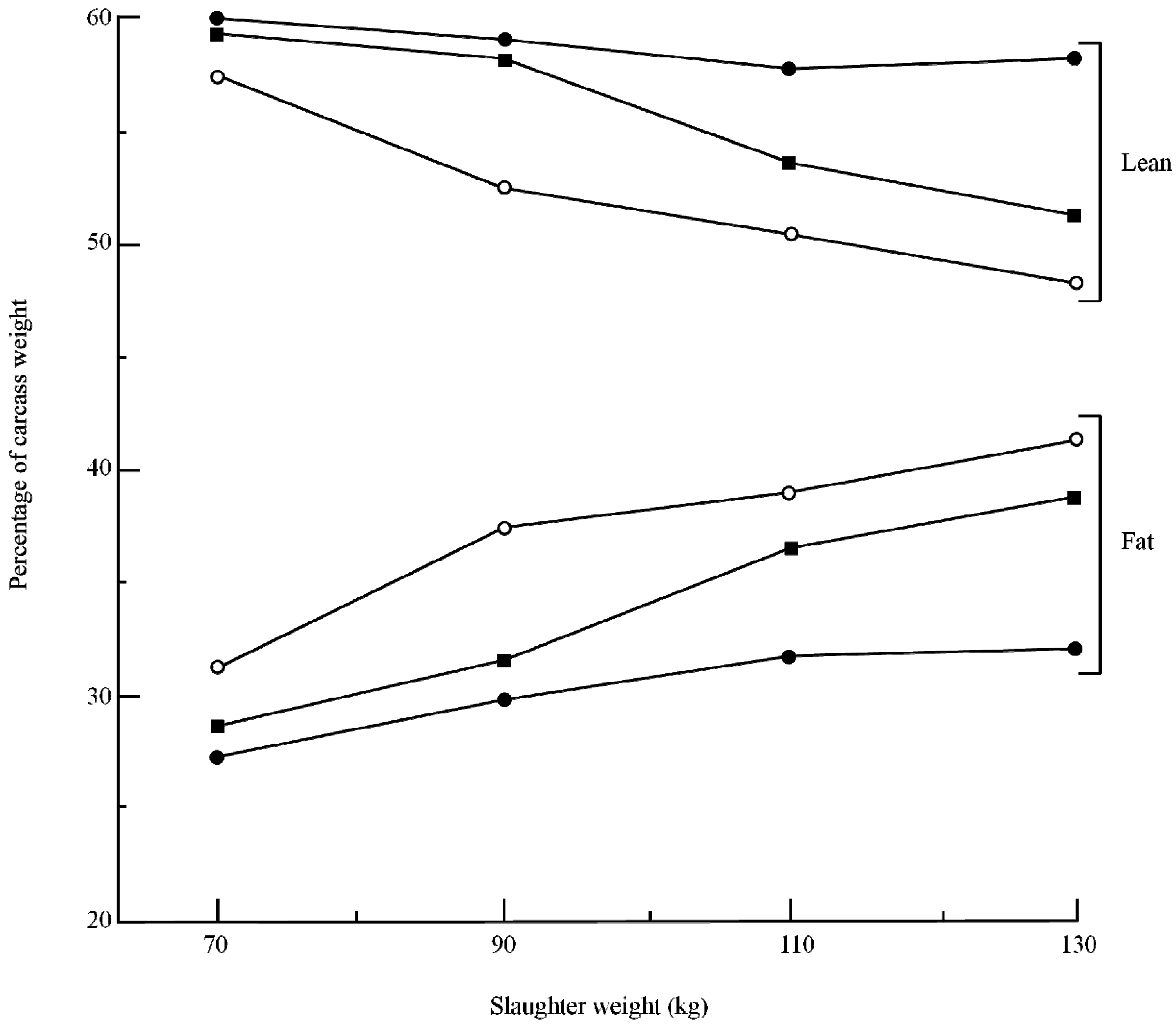

Figure 1.8 The differences in yields of lean meat and of fat by boars (●), gilts (■) and castrates (○) slaughtered at various body weights (Hansson *et al*., 1975)

The superiority of the boar in later production stages is observed in diets containing adequate protein and energy to support the higher rate of weight gain. Diets that do not adequately provide for the requirement of absolute amounts of ideal protein fail to allow maximum protein deposition. Boars have the highest lean tissue growth potential compared to the other sexes and will respond to higher energy intakes before a lean growth plateau is reached; as shown in Figure 1.9.

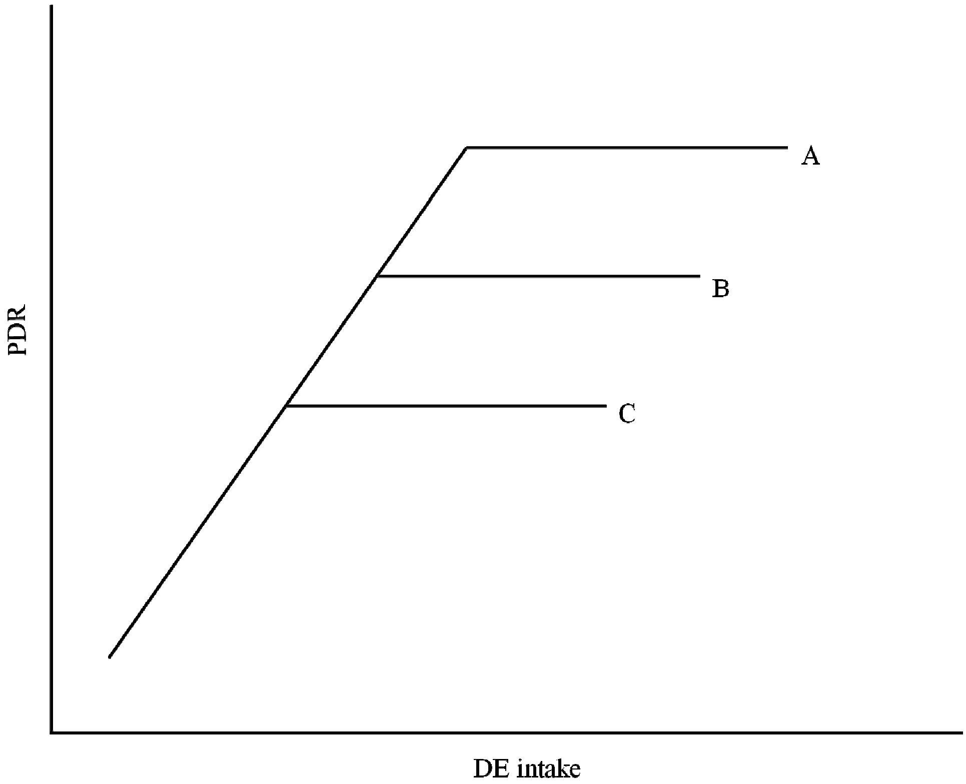

Figure 1.9 Potential protein deposition rates of pigs with different growth capacities in relation to digestible energy (DE) intake. A = Boars, B = Gilts, C = Castrates (Van Lunen and Cole, 1994)

The influences of dietary energy intake on growth performance and tissue deposition using two sexes (boar and gilts) were observed. Genetically improved boars have a higher capacity for lean growth and their upper limit to protein retention might not be reached below 120 kg live weight. This confirms that boars could respond more positive (higher rate of protein deposition, without increased lipid deposition) to increased dietary energy levels (King *et al*., 2004).

The advantage of increased lean tissue growth offered by boars over gilts will only be fully realised if dietary amino acid levels and energy intakes are adjusted according to their specific needs and capabilities. There is considerable scope for improving efficiency of pig production by implementing separate feeding for the sexes during the later stages of production. By formulating diets specific for each sex requirement the cost of production can be reduced and excess carcass fatness often observed in female pigs in the finisher stages can be prevented.

1.3.3.4. Nutrition

1.3.3.4.1 Feed supply

The most effective way to optimise pigs' performances are to control the amount of feed supplied to the pigs. Manipulating tissue deposition, thereby achieving suitable grading standards, can be done by controlling the feed supplied to the growing pig. The diet provides an adequate nutrient balance meeting the animals' requirements for maintenance and production. In a growing pig part of the diet or energy supplied by the feed is deposited as protein and fat. As the amounts of feed consumed daily by the pig increases, the daily gains of both lean and fat respond linearly. When maximum lean tissue growth rate potential of the growing pig is reached, lean growth will not respond to an increased feed supply. Excess energy supplied by the feed will be channelled into fat deposition. The total growth rate will increase at a slower rate only due to a rapid increase in the amount of fat deposited (Van Lunen and Cole, 1994), as illustrated in Figure 1.10.

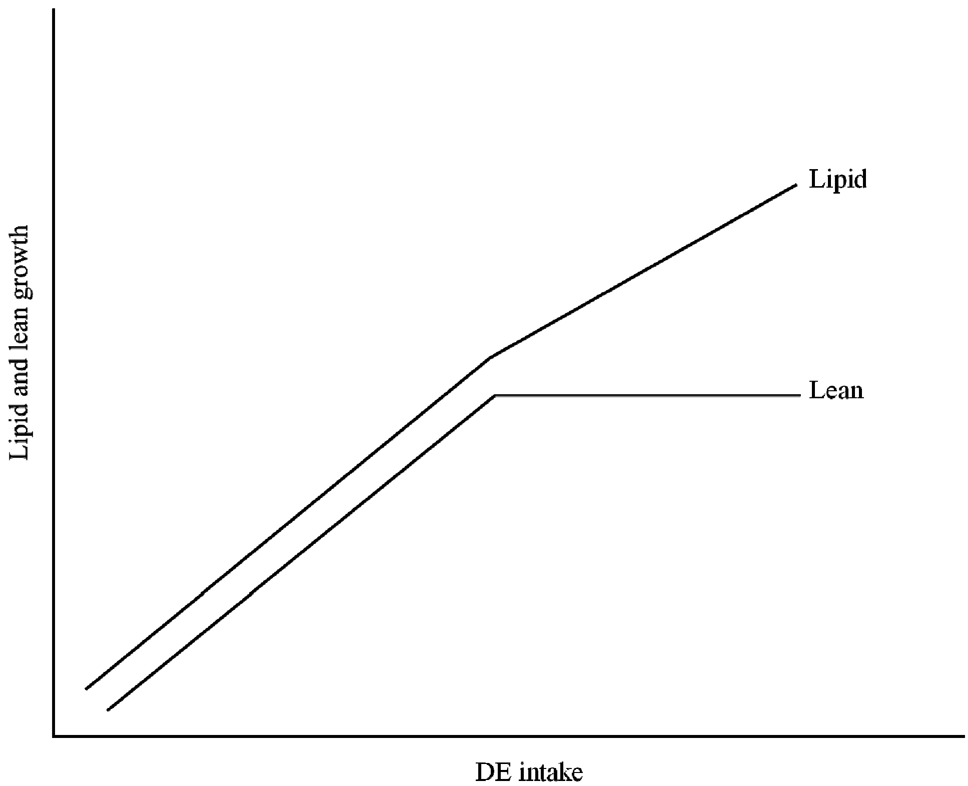

Figure 1.10 Lipid and lean growth in response to feed supply (Van Lunen and Cole, 1994)

The fatness level in a slaughter pig can be modified by controlling the feed supply or the daily energy intake during its growth. In boars or highly superior genotypes the maximum lean tissue growth rate potential is much greater compared to gilts or the conventional pig. Until feed intake is sufficient to maximize lean tissue growth the pig will lay down a minimum of fat during growth (Whittemore, 1993). Boars or superior genotypes can increase protein deposition rates by increasing energy intake up to their appetite limit. During the growth period boars or superior genotypes will not be limited by appetite, due to their high lean deposition potential. It is therefore not advisable to restrict the pigs feed supply (Van Lunen and Cole, 1994). Gilts or less superior pigs have a much lower lean deposition potential and when the level of feed required to maximize lean deposition is reached the fat deposition rate will increase rapidly. If gilts or less superior pigs' feed supply are not restricted, it would lead to excessive carcass fatness. Lipid and lean growth in response to feed supply in boars and gilts are illustrated in Figure 1.11.

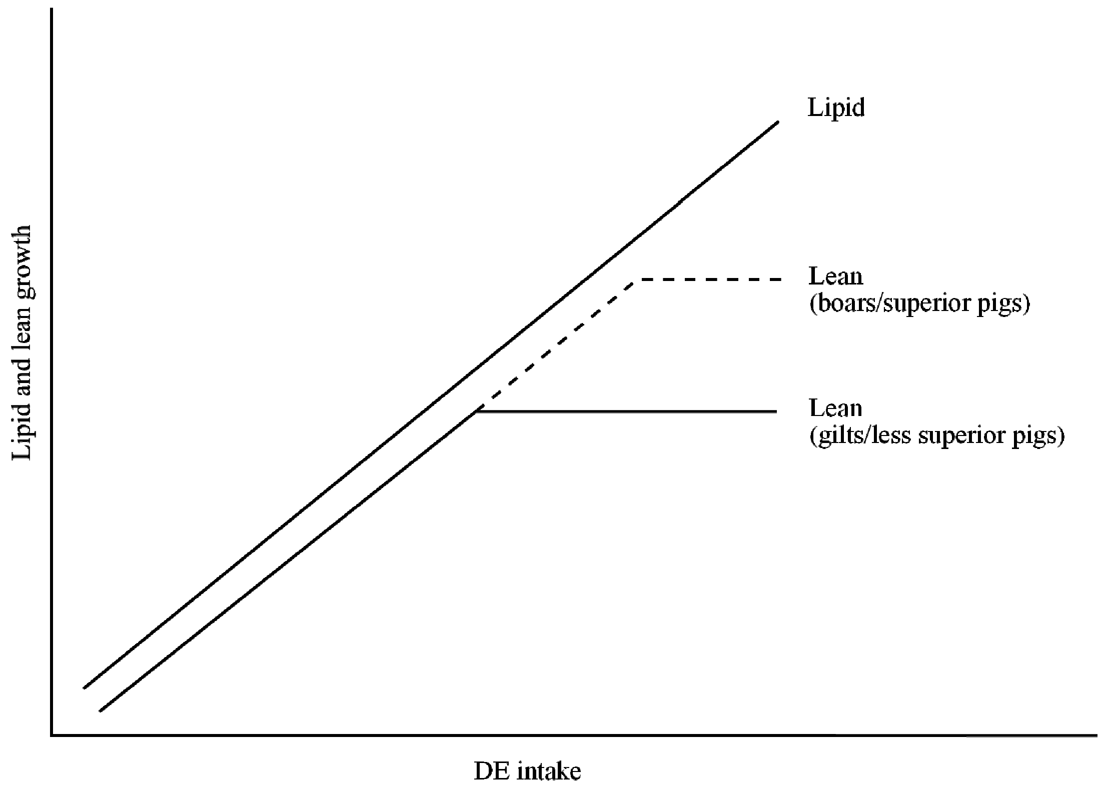

Figure 1.11 Lipid and lean growth in response to feed supply of boars or superior pigs and gilts or less superior pigs (Van Lunen and Cole, 1994)

The primary purpose of restricting feed intake in growing pigs is to reduce the amount of fat in the carcass, especially for gilts and castrates. King *et al*. (2004) indicated that boars have a higher energy intake compared to gilts when fed *ad libitum* (47.7 vs. 40.9 MJ DE/day, P< 0.001). However, back fat depth (mm) and carcass fatness (g/kg) were higher for gilts than for boars when slaughtered at 120 kg live weight (12.3 vs. 13.3 mm, P<0.05; 176 vs. 227 g/kg, P<0.001). The superiority of the boar over the gilt is clearly visible and stress the importance of higher protein deposition capabilities and the corresponding feed strategies involved when optimising feed for boars.

Different feeding strategies must be used between different sexes or genotypes. Restricting gilts and castrates, especially in later growth phase, is an effective feeding strategy to optimise desired levels of body and carcass fatness. Feed restriction can be implemented by restricting the nutrient density of the diet or by restricting the feed allowance. Restricting the feed allowance is not the practical option, because in practise *ad libitum* feeding systems for group-housed pigs are widely used. To reduce the feed or energy intake of *ad libitum* group fed pigs, low energy diets are used (Cole *et al*., 1972). Decreasing the energy density of the diet is the most practical way to restrict *ad libitum* group-housed pigs. Usually, a decrease in energy density is associated with a compensatory increase in daily feed intake, although to a lesser extent; so that the level of energy consumption is slightly lower (Henry, 1979). By decreasing the energy density, a slight decrease in average daily gain will be observed, an increase in feed conversion ratio and most importantly, a significant reduction in carcass fatness (Henry, 1984).

Decrease in energy content is usually associated with increased fibre incorporation. Dietary fibre content, at least within a certain range of variation, has no effect on growth performance provided energy density is adequate (Baird *et al*., 1975). Therefore, energy and more importantly the balance of protein and available amino acids in relation to energy is adequate. The pig can thus tolerate wide ranges of fibre or bulk in the diet. The ability of the pig to compensate for an increase in feed intake after dietary energy dilution by fibre may be enhanced after a period of adaptation to a high-fibre diet. It is evident that in order to optimize production and achieve grading targets feed supply that will maximize lean tissue growth without generating excessive fat is crucial (Knabe, 1996).

1.3.3.4.2. Protein

1.3.3.4.2.1 Ideal protein concept

The most important single factor affecting the efficiency of protein utilisation for production of meat is dietary balance of amino acids. A protein, which has a perfect amino acid balance is referred to as an ideal protein (Agricultural Research Council (ARC), 1981) and supplies the optimum balance of essential amino acids and sufficient nitrogen for the synthesis of non-essential amino acids. The balance of essential amino acids in the diet of the pig is essential for the efficient use of protein in order to maximize growth. Diets which do not adequately provide for the requirement of absolute amounts of ideal protein fail to allow maximum lean tissue growth. Extensive studies have been conducted to define ideal amino acid patterns in the diets for nursery and growing pigs (Fuller *et al*., 1989, Chung and Baker, 1992a and Kim *et al*., 2001). Feeding pigs a diet with an ideal amino acid pattern should enhance the efficiency of protein utilization and reduce the excretion of nitrogen to the environment .The use of crystalline amino acids to balance dietary amino acid ratios may allow reductions in dietary crude protein level and nitrogen excretion for growing pigs (Kerr and Easter, 1995).

The major difference between pigs of different classes is the amount of protein required according to their potential for lean meat deposition (Knabe, 1996). Pigs of different classes require different amounts but an equal quality of ideal protein. The balance of amino acids in an ideal protein applicable to maintenance, growth of lean tissue, pregnancy and lactation will differ, indicating differences in the protein compositions and requirements.

Lysine was chosen as the basis for the concept of balanced amino acids because it is required in large amounts for protein deposition and is almost always the first limiting amino acid in cereal based diets. It is important to know the limiting amino acids in cereal grains, protein supplements, by-product feeds and combinations of feed ingredients and to know that amino acids become limiting as changes occurs i.e. within feed ingredients, but also as pigs increase in body weight and their requirements lessen. The order of the essential limiting amino acid could also change depending on feed intake and tissue mobilization (Kim and Easter, 2001). Knowledge of changing limiting amino acids is therefore essential in order to optimize animal performance by formulated rations.

Assuming that the percentage of lysine needed in a given diet is known, determining the need for other essential amino acids is simpler due to the use of the ideal protein concept which describes the need for other amino acids in relation to lysine. The balance of amino acids in the ideal protein concept is shown in Table 1.1. The proportions of threonine, tryptophan and methionine + cystine in relation to lysine are most important because these will likely be limiting after lysine.

Table 1.1 Pattern of amino acids in the ideal protein for pigs, as proposed by different research groups

Amino acid	ARC[a]	NRC[b]	Wang and Fuller[c]	Chung and Baker[d]
Lysine	100	100	100	100
Leucine	100	74	110	100
Phe + Tyr	96	81	120	95
Valine	70	59	75	68
Threonine	60	59	72	65
Met + Cys	50	52	63	60
Isoleucine	54	56	60	60
Arginine	-	42	42	42
Histidine	32	26	32	32
Tryptophan	14	15	18	18

[a] Agricultural Research Council (1981)
[b] National Research Council (1988)
[c] Wang and Fuller (1987)
[d] Chung and Baker (1992)

1.3.3.4.2.2 Amino acid requirements

To allow maximum lean deposition rate, as established by the pigs' genotype, the growing-finishing pig should consume only enough essential and non-essential amino acids each day. Under these conditions carcass merit, growth performance and nitrogen excretion are optimized. A precise knowledge of amino acid requirements, the biological availability of the amino acids and the factors influencing voluntary feed intake are required to meet these conditions.

Pigs with high protein deposition rates require higher amino acid intakes to express their genetic potential for lean growth, percentage lean and lean efficiency (Stahly, 1991). An increased concentration of amino acids is needed due to greater protein synthesis, a slight higher maintenance requirement for some amino acids and lower daily feed intakes. Campbell and Taverner (1988) reported that the estimate of energy requirements for maintenance was 28 % higher in the better genotype and that is likely associated with the considerably higher lean body mass and higher protein turnover rate. According to Knabe (1996), pigs that have a high lean deposition rate need 20 % more lysine and on average consume 9 % less feed each day, compared to pigs with medium lean deposition rates.

Estimates of amino acid requirements and the ideal amino acid profile depend mainly on the technique and calculation of the digestibility and availability of the amino acids. Amino acids are only digested in the small intestine. Digestibility need to be determined at the terminal ileum due to microbial metabolism in the hindgut (Boisen *et al*., 2000). The measurement of ileal digestibility of amino acids is a more accurate method for estimating the availability to the animal. Digestible amino acids from ileal digesta have been reported to be better correlated to protein deposition in the carcass than digestible amino acids from faecal analyses (Buraczewska and Buraczewski, 1997). Ileal digestibility of amino acids is expressed as apparent ileal digestibility, standardized ileal digestibility or true ileal digestibility. These terms are used to specify how ileal endogenous amino acid losses are reflected in digestibility values. Stein *et al*. (2005) determined whether digestibility of crude protein and amino acids in a mixed diet fed to growing pigs is better predicted when based on standardized ileal digestibility coefficients (SID) or apparent ileal digestibility coefficients (AID). Amino acid requirements tend to be underestimated when using apparent ileal digestibility coefficients, especially for low crude protein diets. This is caused by a relatively greater contribution of endogenous amino acids and crude protein in the ileal digesta collected from pigs fed low-protein diets compared to pigs fed diets containing greater concentrations of crude protein and amino acids (Rademacher *et al*., 2001). The digestibility coefficients for a mixed diet containing low-protein feed ingredients, such as maize, are more accurately predicted using standardized ileal digestibility coefficients than apparent ileal digestibility coefficients (Stein *et al*., 2005). By formulating diets for grower-finisher pigs on the basis of standardized ileal digestibility's rather than on total amino acid content, a better feed to gain ratio and economic benefit could be achieved (Yin *et al*., 1993).

1.3.3.4.2.3 Precise protein feeding

Precise protein feeding is a management tool used to reduce costs and the amount of nitrogen excreted by pigs by matching feed protein to the pigs' requirements. The greatest potential benefits are nutritional manipulation, by matching amino acid supply with requirements through improved diet formulation, the use of phase feeding programs, reduction in dietary protein by maximum use of crystalline amino acids and the use of more digestible feeds.

The advent of feed-grade lysine, threonine, tryptophan, methionine and recently valine makes it possible to improve the balance of amino acids in pig diets whilst reducing dietary protein content. Knabe (1996) showed that by reducing the dietary protein content with 3 % in isolysinic diets of growing pigs did not influence the growth rate, but improved feed efficiency by 5 %. Pigs with the potential to deposit large amounts of lean tissue are often fed high protein diets to match their high lysine requirement. One disadvantage of these high protein diets is the energy cost to get rid of all the excess nitrogen in the body (Le Bellego *et al*., 2001) and the negative impact that it has on organ size (Chen *et al*., 1999). Excessive protein intake has been shown to reduce feed efficiency, but the supplementation of crystalline lysine and other essential amino acids, which replaces part of the dietary protein, may improve feed efficiency. This is achieved by reducing plasma urea nitrogen (Owen *et al*., 1994) and reducing pancreas weight which may indicate lower pancreatic activity and result in a lower energy requirement (Ward and Southern, 1995). Lowering the amount of dietary protein in the diet therefore has various advantages for pigs and also for the environment. The amount of nitrogen excreted by grower pigs can be significantly reduced (Roth *et al*., 1994) and daily live weight can be maintained (Gatel and Grosjean, 1992) when they are offered diets with lower crude protein levels than those commercially available. Reducing the amount of nitrogen excretion requires a better knowledge of the digestibility of nitrogen and amino acid content of feeds. Utilizing all the factors of precise feeding, Knabe (1996) estimated that nitrogen excretion for the growing-finishing pigs in the Netherlands could be reduced by approximately 30 %.

Experiments in which control (normal commercial diets) and ideal protein (lower crude protein with synthetic amino acids) diets have been compared, gave inconsistent results. Feeding ideal protein diets was shown to greatly reduce the amount of nitrogen excreted from pigs, but there were variability in the growth performance and carcass characteristics when these diets were fed (Figueroa *et al*., 2002). Brudevold and Southern (1994), Taylor and Crenshaw (1997) and Smith *et al*. (1998), have reported lower growth performance in pigs fed ideal protein diets, whereas Tuitoek *et al*. (1997), Knowles *et al*. (1998) and Hinson *et al*. (2009), reported similar performance between pigs fed control and ideal protein diets. It could be concluded that further refinements are still required in the different phases of pig production to optimize ideal protein diets, used by the swine industry.

1.3.3.4.2.4 Protein – Energy interaction

Dietary energy is required to fuel various growth and metabolic processes in the body. Pigs require energy for maintenance and for growth (protein and lipid deposition). Energy concentration is the primary dietary factor affecting voluntary feed intake, but some modulation may occur according to protein level and amino acid patterns. Energy levels as well as the overall growth performance are negatively influenced by a severe deficiency or excessive supply of total protein or some essential amino acids. According to Henry (1984) feeding pigs a diet that is slightly deficient in some essential amino acids will lead to an increase in daily feed intake, in attempt to meet more closely its daily requirement. The consequence of this over consumption of feed is an increase in fat deposition and energy cost of gain.

An excess supply of amino acids or protein can lead to self limitation of feed intake, reduced carcass fatness or a reduction in overall energy status. Energy yielded from protein deamination is half of the assumed digestible energy (DE) of protein. The effective energy value of a diet containing excess protein will fall as deamination rate rises, with a result in reduction of energy available for fat deposition (Whittemore, 1983). Further increments of protein above the requirements will continue to increase leanness by effectively reducing the available energy yielded from the diet, but can be expensive to execute and can result in a reduction in growth rate.
By improving the amino acid balance and ensuring a popper protein-energy ratio, more efficient utilization of energy is available for growth.

Animals that are fed diets lower in crude protein, with added amino acid, have a tendency to have fatter carcasses. The increased fatness in pigs fed lower crude protein, amino acid -supplemented diets may be partially due to more dietary energy (Kerr and Easter, 1995 and Knowles *et al*., 1998) being available for body fat synthesis as a result of reduced energy expenditure for catabolizing excess dietary protein. Knowles *et al*. (1998) evaluated the growth performance, carcass characteristics and lean and fat deposition of pigs fed reduced crude protein, synthetic amino acid supplemented diets with adjusted levels of dietary fibre or fat to produce equal or reduced dietary net energy (NE) contents relative to pigs fed higher levels of crude protein. In these experiments, the reduction of net energy (either by dietary fibre addition or dietary fat removal) in low-crude protein, synthetic amino acid supplemented diets had minimal effects on the growth performances and carcass characteristics of animals. This highlights the importance of the relationship between protein and energy and the consequences of imbalanced rations.

1.3.3.5. Environment

1.3.3.5.1 Social environment

Differences in both behaviour and production performance were observe between growing-finishing pigs kept in individual and group housing. Competition and aggressive behaviour to maintain dominant hierarchy, an increase in activity, avoidance of other pigs while eating and physiological responses due to chronic stress of competition and aggressive encounters are all factors that may be responsible for these differences (Gonyou *et al*., 1992, Chapple, 1993 and Stookey and Gonyou, 1994). Growth performance is greater when pigs are penned individually than when penned in groups (De Haer and Merks, 1992, Gonyou *et al*., 1992, Chapple, 1993, De Haer and De Vries, 1993 and Hacker *et al*., 1994).

De Haer and Merks (1992) showed that the feed intake pattern of group-housed pigs was significantly different from the feed intake pattern in individually housed pigs. Feed intake patterns may influence fat and lean growth by affecting the utilisation of nutrients. De Haer (1992) found that pigs kept individually had shorter and more frequent visits to the feeder and ate less per visit than pigs in groups. Individually housed pigs have been found to have improved production in terms of daily feed intake (Gonyou *et al*., 1992), growth rate (De Haer and De Vries, 1993) and feed conversion (Petersen, 1976) compared to group-housed pigs. In addition, pigs housed individually have higher digestibility coefficients related to smaller, more frequent meals. The higher growth rate and backfat thickness in individually housed pigs are due to the higher daily feed intake, higher digestibility and lower level of activity (De Haer and De Vries, 1993). Gomez *et al*. (2000) examined the factors involved in the growth retardation of pigs housed in groups and concluded gilts penned in groups had reductions in daily gain, backfat thickness and apparent digestibility's of dry matter crude protein and energy and increased levels of plasma non esterfied fatty acids (NEFA).

Pigs in groups tend to be more active than pigs housed individually. The partitioning of dietary energy away from tissue deposition and towards the metabolic processes occurring during exercise has shown to reduce the rate of average daily gain and also the efficiency of growth (Clark *et al*., 1985 and Petherick *et al*., 1989). Group-housed pigs modify their feeding behaviour by eating less frequently, consuming more food at a time and at a faster rate compared to pigs housed individually (De Haer and De Vries, 1993). Group-housed pigs also had significantly lower growth rates and less backfat than pigs housed individually. The housing of pigs in large groups has been associated with greater efficiency of building space use, improved mechanisation and reduced labour input per pig. By providing a suitable environment and formulating specific diets growth rate reduction can be reduced.

1.3.3.5.2 Temperature

The effects of temperature on performance and carcass measurements are better defined than other environmental effects. It is well known that the climatic environment has a major influence on the growth and development of an animal. It influences the rate and efficiency with which dietary nutrients are utilised for the many metabolic processes within the body. Animals should be kept within their zone of thermal neutrality since heat production is minimal and the energy available for production is maximal. Homeothermy is maintained mostly by a reduction of heat production at high temperature in connection with reduced feed intake and physical activity (Quiniou *et al*., 2001).

A study conducted with piglets given *ad libitum* access to feed and housed in groups (Collin *et al*., 2001) indicated a 22 % reduction in heat production when ambient temperature was increased from 23 - 33°C. This change was related both to a reduction in feed intake and the associated thermic effect of feed (TEF). The optimum temperature range for finishing pigs is between 10 and 23.9°C (Myer and Bucklin, 2001). Temperatures above 23.9°C decrease voluntary feed intake and pig growth (Kouba *et al*., 2001 and Le Bellego *et al*., 2002).

The environmental conditions in which animals are housed influence the extent to which energy intake is utilised for maintenance and energy retention or growth. At any given energy intake, exposure to temperatures outside the zone of thermal neutrality increases the maintenance energy requirements, with a concomitant reduction in the energy available for production. If energy requirement for maintenance increases, then at any given energy intake there must be a change in the energy available for production and hence energy deposition as protein and fat. White *et al*. (2008) examined the effects of housing temperatures of 23.9 or 32.2°C and spatial allocation of either 0.66 or 0.93 m2/pig on the growth performance and carcass lipid firmness in grower-finisher gilts. The results from this study demonstrate a decrease in growth, carcass lipid quality and bacon quality in pigs housed at temperatures above the thermoneutral zone. However, increasing the space allocation for housing may be a means to ameliorate the negative effects of temperature stress. This clearly indicates the redirection of production energy into maintenance requirements. Lopez *et al*. (1991) showed that fat deposition is highly dependent on environmental conditions within which the animals are maintained, so that at any given intake, the highest depositions occurred between 23 and 25^{o}C. Above 25^{o}C, fat retention was reduced in association with the hyperthermal rise in heat production. The temperature-dependent change in fat deposition was greater than that of protein and was equivalent to a 28 g/day reduction in feed intake, compared to an equivalent reduction of only 4 g/day for protein.

The depression in growth rate associated with a decrease in environmental temperature results from an increase in the animals' maintenance energy requirement and a reduction in the rate at which protein and fat are deposited. When the environmental temperature falls below the lower critical temperature the heat production rises by between 2-4 % per 1 degree fall. This gives an indication of the demands made by the environment on the pig to produce heat, and this heat must be derived from dietary nutrient intake. Verstegen *et al*. (1977) calculated over a wide range of breeds, feeding levels and housing conditions that growth rate was decreased by 8.1 g/day for each degree decrease in temperature below the critical level. Under *ad libitum* feeding conditions feed intake increased by 19.5 g/day for each degree below 15 degrees.

The general requirement for farming practice is to determine the range of environments and nutrition which allow for maximum efficiency of feed utilisation. This necessitates the determination of the zone of thermal neutrality for all classes of livestock and those factors which influence it. If the environmental conditions fall below or above this zone then growth rate is reduced with concomitant effects upon feed conversion efficiency.

CHAPTER 2
MATERIAL AND METHODS

2.1 Trial design

The experiment was performed in a 2x3x2x3 factorial design, consisting of 2 periods (Period 1 and Period 2), 3 sire lines (Sire 1, Sire 2 and Sire 3), 2 feeds (Feed High and Feed Low) and 3 feeding regimes: 1 – Restricted single feeding (RSF), 2 – *Ad libitum* single feeding (ASF), 3 – *Ad libitum* group feeding (AGF). The design is illustrated in Figure 2.1.

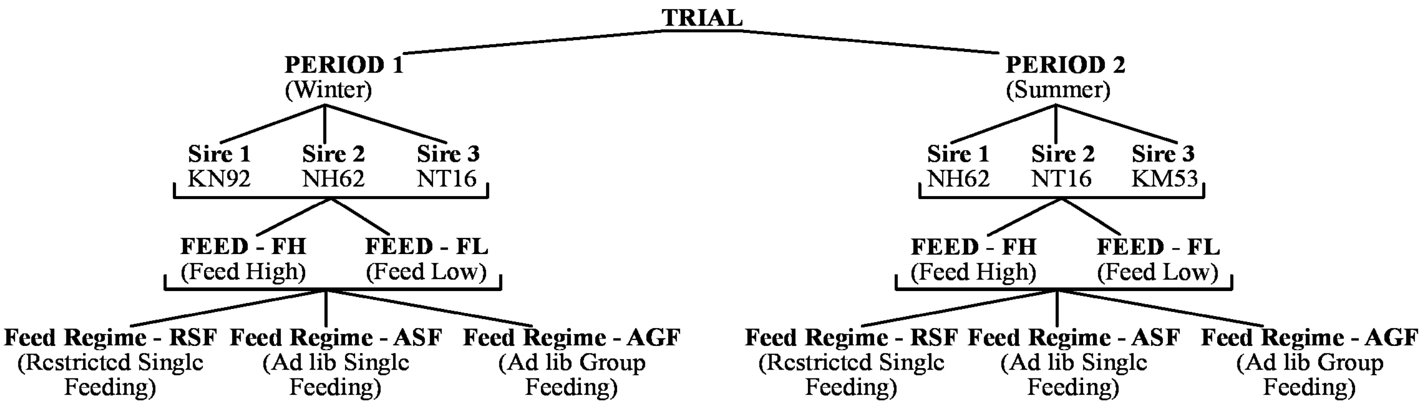

Figure 2.1 Experimental trial design

Period 1 was in the winter from 6 June 2008 to 13 August 2008 and Period 2 was in the summer from 3 October 2008 to 10 December 2008.

The sire lines selected had the same genetic breeding values (Topigs Selection Index (TSI)), of which two sire lines were similar in both Period 1 and Period 2 and one of two different sires lines was used either in Period 1 or Period 2 (Figure 2.1). The interaction between sire lines and parameters measured was not significant ($P<0.05$). Therefore, the different sire lines used, had no influence on the end results and were excluded from this experiment as a variable.

Experimental animals were fed two different rations, a high energy and protein ration (FH) and a low energy and protein ration (FL). "Feed Low" (FL) contained 95% of the energy, crude protein and amino acid levels used in the "Feed High" (FH). Animals were randomly allocated three different feed regimes throughout the trial, i.e. restricted single feeding (RSF), *ad libitum* single feeding (ASF) and *ad libitum* group feeding (AGF). An *ad libitum* group consisted out of six animals. This made provision for six different treatments, which were replicated six times. A total of 96 weaner pigs were randomly divided into the six treatments, as shown in Table 2.1.

Table 2.1 Experimental treatments

Nr	Treatments	Number of replications	Number of animals/replication
1	FH – RSF	6	1
2	FH – ASF	6	1
3	FH – AGF	6	6
4	FL – RSF	6	1
5	FL – ASF	6	1
6	FL – AGF	6	6

2.2 Animals

Animals were obtained from Walt Landgoed farm outside Settlers in the Limpopo province of South Africa. Initial selection consisted of male progeny born from 30 *Topigs-40* sows that had been randomly inseminated with semen from 3 selected *Topigs Tempo* AI boars. After 11 weeks, 32 boars per sire line were randomly selected (no ranking or other selection criteria was applied) to make provision for each period of the trial.

On arrival at the Experimental Farm of the University of Pretoria the animals were weighed, tattooed and tagged. Animals were allocated to either single-pens or group-pens according to their starting mass and particular sire line. Animals were handled only once a week for weighing and P2 fat measurements.

2.3 Health management

The animals originated from a high health unit with specific pathogen free (SPF) housing conditions. No prophylactic treatment against sickness was given. During the trial the animals were kept under high health conditions and bio-secure rules and regulations were followed. The general health of the animals was good.

Nine pigs developed inguinal hernias during period 1, which had no influence on their growth performance. It was in the opinion of a consulting veterinarian that treatment was not necessary. One pig developed a gastric ulcer that was treated with antibiotics. No animals died during period 1.

Twelve pigs developed scours during period 2, but were treated with the antibiotics Advocin® and Duplocillin®. At the end of the trial a few pigs had joint infections, but no treatment was required.

2.4 Ethics approval

The trial conformed to the requirements of the Animal Use and Care Committee of the University of Pretoria, reference number EC080125-003.

2.5 Housing and environmental management

Animals were housed in a closed building with natural ventilation and light was supplemented with electric lighting up to 12 hours per day in both period 1 and period 2.

Space allowance was 3.5 m^2 per pig in single-pens and 1.2 m^2 per pig in group-pens. The single-pens had one water nipple and one single-feeder whereas the group-pens had two water nipples and two single-feeders. Partially slated floors limited animals from lying in the muck.

2.6 Feed Rations

The diets were formulated using a matrix-type programme, Format International® (Londen, UK). Two different feeds were formulated for each of the starter, grower and finisher phases. The one feed had a relative high energy and protein density (Feed High (FH)) while the "Feed Low" (FL) contained 95% of the energy, crude protein and amino acid levels used in the "Feed High". Therefore, the energy: protein ratio of the two diets was kept more or less constant.

The digestible lysine requirements for the three phases used in this trial were specifically recommended for the Tempo sire line by the Institute of Pig Genetics (IPG) (Beuningen, The Netherlands). The requirements are shown in Table 2.2. The specifications of the other amino acids were derived by using the lysine requirements as reference amino acid and the amino acid profile proposed by Chung and Baker (1992a) (Table 2.3). Amino acid requirements were expressed as apparent ileal digestible values. Diets were based on maize and sunflower-and soya oil cake meal. Formulated nutrient specifications of the diets are shown in Table 2.4 and raw material composition in Table 2.5. Analysed nutrient levels of the diets are shown in Table 2.6 (Period 1) and Table 2.7 (Period 2).

Feed allowances for pigs that were housed individually and fed restricted amounts of feed were adjusted weekly according to their live weights and the recommendations of IPG. Feed intake was therefore controlled according to the IPG model's feed intake predictions (Table 2.2).

Table 2.2 Feed intake prediction and lysine inclusion levels (g/kg feed) for the Tempo sire line as recommended by the Institute of Pig Genetics (Beuningen, The Netherlands)

							High	Low (0.95)
Mass (kg)	**Feed Intake (kg/day)**	**Maintenance Lysine**	**Production Lysine**	**Digestibility**	**Total Lysine Intake**	**Lysine (g/kg)**	**Total digestible lysine**	**Total digestible lysine**
25	1.55	0.40	11.88	0.78	25.19	16.25	12.68	12.04
35	1.75	0.52	11.88	0.78	25.43	14.53	11.34	10.77
45	1.90	0.63	11.88	0.78	25.65	13.50	10.53	10.00
55	2.10	0.73	11.88	0.78	25.86	12.31	9.61	9.13
65	2.30	0.82	11.88	0.78	26.06	11.33	8.84	8.40
75	2.45	0.92	11.88	0.78	26.25	10.71	8.36	7.94
85	2.65	1.01	11.88	0.78	26.44	9.98	7.78	7.39
95	2.80	1.10	11.88	0.78	26.62	9.51	7.41	7.04
105	3.00	1.18	11.88	0.78	26.79	8.93	6.97	6.62

Table 2.3 Ideal amino acid profile for grower pigs with lysine as reference amino acid (Chung and Baker, 1992a)

Amino Acid	**Pigs 20-50 kg**	**Pigs 50-110 kg**
Lys	100	100
Met Cys	62	65
Thr	67	70
Trp	18	19
Iso	60	60
Leu	100	100
His	32	32
Val	68	68
Met	30	30
Cys	32	35
Arg	36	30
Phe Tyr	95	95

Switching from the one phase feed to the following phase feed was based on live weight of the animals. The starter was fed from 25-50 kg, the grower from 51-80 kg and the finisher from 81-105 kg.

Table 2.4 Nutrient specifications for the six diets used in the experiment

	Feed High			Feed Low		
					0.95%	
	Starter	Grower	Finisher	Starter	Grower	Finisher
Mass (kg)	25 - 50	51 - 80	81 - 105	25 - 50	51 - 80	81 - 105
Period (days)	21	28	19	21	28	19
Digestible energy (MJ/kg)	13.75	13.5	13.25	13.06	12.83	12.59
Crude protein (g/kg)	215.21	170.88	148.6	206.47	163.78	142.91
Calcium (g/kg)	7.5	7.5	7.5	7.5	7.5	7.5
Available phosphorous (g/kg)	3	3	3	3	3	3
Sodium (g/kg)	2.2	2.2	2.2	2.2	2.2	2.2
AS* Lysine (g/kg)	11.51	8.93	7.39	10.94	8.49	7.02
AS Methionine Cysteine (g/kg)	6.84	5.71	4.88	6.5	5.43	4.68
AS Threonine (g/kg)	7.62	6.16	5.17	7.24	5.85	4.91
AS Tryptophan (g/kg)	1.99	1.67	1.4	1.89	1.58	1.33
AS Methionine (g/kg)	4.13	3.23	2.63	3.83	3.01	2.50
AS Valine (g/kg)	8.33	6.54	5.67	7.89	6.13	5.22
AS Isoleucine (g/kg)	7.36	6.23	5.25	6.69	5.67	4.64

* AS – Apparent ileal digestible amino acid

Table 2.5 The ingredients (%) included in the six diets used in the experiment

	Feed High			Feed Low		
Dietary components	**Starter**	**Grower**	**Finisher**	**Starter**	**Grower**	**Finisher**
Yellow Maize (8%)	54.4	61.1	67.3	49.3	56.2	57.1
Energy 100 Fat Powder*	0.57	1.06	1.06	0	0	0
Wheat Bran (15%)	7.5	10	9	15.4	19.2	24.71
Sunflower oil cake (38%)	7.5	13	13.7	15.71	6.1	0
Soya oil cake (47%)	25.6	11.4	5.5	15.18	15	14.76
Fish meal (65%)	1	0	0	1	0	0
Monocalcium Phosphate	0.79	0.96	1.03	0.75	0.91	0.93
Limestone	1.18	1.22	1.23	1.19	1.25	1.27
Salt	0.49	0.5	0.5	0.48	0.5	0.5
Lysine HCL	0.33	0.33	0.31	0.45	0.38	0.36
DL Methionine	0.099	0.038	0	0.065	0.023	0
L Threonine	0.16	0.082	0.058	0.17	0.092	0.077
Natuphos#	0.01	0.01	0.01	0.01	0.01	0.01
Premix	0.3	0.3	0.3	0.3	0.3	0.3
Total Mix	100	100	100	100	100	100

* Energy 100 is a white coloured, free-flowing fat powder (triglyceride) containing a crude fat percentage of 99.5 (Merrick's, INC., USA)

\# It is a highly efficient 3-phytase that releases bound phosphorus from phytate. Natuphos is produced by fermentation using a non-pathogenic strain of Aspergillus niger (BASF Corporation, USA)

2.7 Chemical Analysis

After mixing, samples for the six feeds of each of the two periods were analysed at the Department of Animal and Wildlife, Nutrilab, University of Pretoria. Chemical components were determined by the following methods:

AOAC (2000) procedure:

Dry matter, ash, moisture, amino acids, crude fat (ether extract) crude fibre and crude protein.

Phosphorous with the Spekol 1300 apparatus using the spectrophotometric method.

Dumas method:

Crude protein.

Performic Acid Oxidation with Acid Hydrolysis-Sodium Metabisulfite method:

Amino acids.

Fibre-Tech apparatus:

Crude fibre in feed and NDF (Robertson and Van Soest, 1981).

ADF (Goering and Van Soest, 1988).

MC-1000 Modular Bomb Calorimeter:

Gross energy content of the feed.

AOAC (1984) procedures:

Starch.

Perkin Elmer Atomic Spectrophotometer-2380:

Calcium (Giron, 1973).

Results of the chemical analysis for the feeds used during period 1 are shown in Table 2.6 and that of period 2 in Table 2.7. We can conclude that differences in growth performance were not due to errors in formulating or manufacturing of the diets.

Table 2.6 Chemical analysis of formulated rations used during period 1 ('as is' basis)

Nutrient Levels (%)	Feed High			Feed Low		
	Starter	**Grower**	**Finisher**	**Starter**	**Grower**	**Finisher**
Dry Matter	89.4	89.3	89.4	89.1	88.9	88.9
Moisture	10.6	10.7	10.6	10.9	11.1	11.1
Ash	5.21	4.9	4.57	5.08	5.08	5.00
Nitrogen	3.48	2.9	2.34	3.32	2.65	2.28
Crude Protein	21.75	18.13	14.63	20.75	16.56	14.25
Gross Energy	16.2	16	16	16.1	15.7	15.7
Crude Fat	3.72	4.57	4.14	3.35	3.39	3.07
Starch	39.2	42.5	48.2	36.8	41.6	44.2
Crude Fibre	5.04	5.98	5.55	7.16	6.74	7.03
NDF	13.3	14.8	14.7	16.8	17.8	19.1
ADF	7.42	8.78	8.87	9.09	9.64	9.18
Calcium	0.62	0.6	0.63	0.65	0.61	0.63
Total Phosphorous	0.64	0.68	0.68	0.66	0.73	0.78
Total Lysine	1.19	0.95	0.71	1.11	0.91	0.76
Total Methionine	0.45	0.32	0.26	0.43	0.31	0.27
Total Isoleucine	0.98	0.66	0.53	0.83	0.66	0.52
Total Threonine	0.91	0.58	0.5	0.77	0.56	0.5
Total Valine	1.1	0.78	0.67	0.96	0.8	0.65
Total Histidine	0.58	0.38	0.36	0.48	0.4	0.38

Table 2.7 Chemical analysis of formulated rations used during period 2 ('as is' basis)

	Feed High			Feed Low		
Nutrient Levels (%)	**Starter**	**Grower**	**Finisher**	**Starter**	**Grower**	**Finisher**
Dry Matter	87.54	86.48	88.39	87.89	86.45	88.24
Moisture	12.46	13.52	11.61	12.11	13.55	11.76
Ash	4.97	4.89	4.52	5.13	4.69	4.89
Nitrogen	3.33	2.59	2.24	3.26	2.48	2.23
Crude Protein	20.82	16.18	14	20.35	15.52	13.96
Gross Energy	15.65	15.57	15.6	15.82	15.11	15.39
Crude Fat	3.51	3.82	3.74	3.01	2.86	3
Starch	39.2	42.47	48.17	36.76	41.63	44.2
Crude Fibre	6.11	5.76	6.84	6.83	6.83	5.97
NDF	13.8	15.55	14.61	16.93	18.14	18.14
ADF	8	8.91	8.53	8.75	9.08	8.78
Calcium	0.71	0.75	0.69	0.73	0.69	0.77
Total Phosphorous	0.6	0.64	0.6	0.66	0.65	0.71
Total Lysine	1.09	0.81	0.78	1.04	0.9	0.73
Total Methionine	0.37	0.34	0.27	0.39	0.29	0.24
Total Isoleucine	0.78	0.65	0.51	0.8	0.55	0.44
Total Threonine	0.63	0.46	0.42	0.65	0.39	0.35
Total Valine	0.88	0.76	0.63	0.94	0.7	0.57
Total Histidine	0.41	0.34	0.3	0.43	0.32	0.27

2.8 Parameters

Feed intake (FI):

Feed intake of the animals were determined weekly. Feed allowances for restricted single fed pigs was adjusted every week according to their live weight and predicted feed intake according to the IPG growth model. The total intake was determined by the end of each week for pigs fed *ad libitum*. Feeders were replenished weekly, by weighing the feed added and subtracting it from the amount that remained in the feeder, to determine weekly feed intake. Average daily feed intake was thereby measured for each individual pig. Pigs were weighed weekly, on the same day, after all feed was removed.

Average daily gain (ADG):

ADG was calculated from weekly weight gains.

Feed conversation ratio (FCR):

FCR was determined by using feed intake and average daily gain to measure the pigs' growth efficiency on a weekly basis.

Fat measurements:

At an age of 15 weeks the P2 fat measurement were measured on a weekly basis until the end of the trial. Weekly fat measurements were taken using the Renco fat-o-meter. Four measuring points, as illustrated in Figure 2.2 were used to measure backfat thickness. Measuring points (1, 2, 3 and 4) are all of equal distance, 5 cm left of the spinal cord stretching from the shoulder (last point of the scapula) to the last rib (Breeding manual of *Topigs International* bimanual-testing-protocol-high health-181001doc, 2001).

Protein and lipid deposition:

IPG calculated the protein and lipid deposition rates using a computerised model based on the principles of De Greef *et al*. (1994). The formulas used in the model are illustrated in Appendix I.

Carcass characteristics:

On completion of each period, pigs were slaughtered at Escort Abattoir in Heidelberg, SA. Hot and cold mass dressing percentage, lean meat percentage and grading and monetary yield of each pig was ascertained. Slaughter percentage and drip-loss percentage were also calculated.

Lean meat percentage:

Lean meat percentage was determined by measuring fat thickness and eye muscle thickness with an electronic thickness meter (Hennessy Grading Probe). Measurements were taken between the 2nd and 3rd last ribs, 45 mm from the mid – back line whilst the carcass is hanging. The lean meat percentage was calculated as follows: Hennessy % Lean = 72.5114 – (0.4618 x fat thickness) + (0.057 x eye muscle thickness) (Visser, 2004).

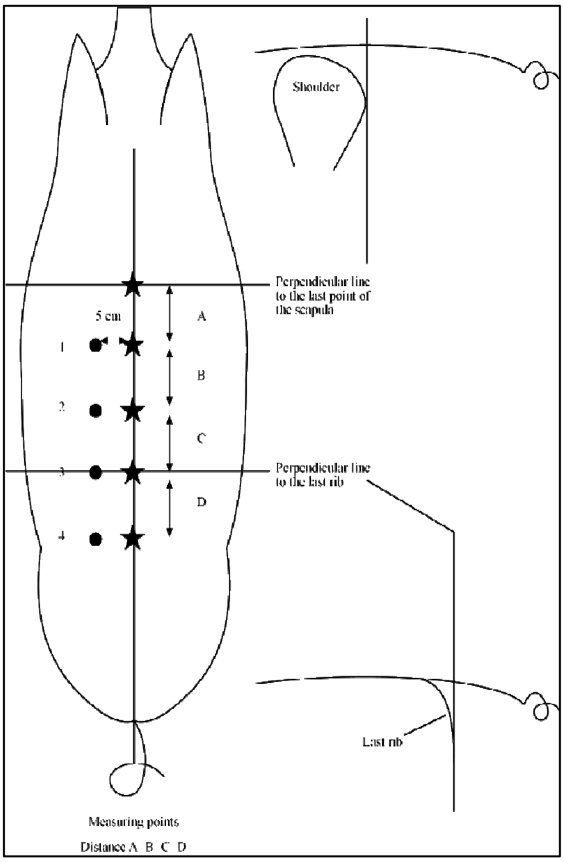

Figure 2.2 Illustration of anatomical positions where fat measurements were taken according to the breeding manual of *Topigs International* (bimanual-testing-protocol-high health-181001doc, 2001)

2.9 Statistical Analysis

The General Linear Models (GLM) procedure by Statistical Analysis System (2009) was used to determine and analyse the significant differences between different groups, lines, feeds, treatments and different combinations of interactions over time. No significant differences (P>0.05) were found between lines and thus excluded from the analysis. The least square means and standard deviations (SD) were calculated for different groups, feeds, treatments and interactions. Significance of difference (5%) between least square means was determined using the Fischer's test (Samuels, 1989).

An analysis of variance using the GLM model (Statistical Analysis System, 2009) was used to determine growth and slaughter parameters. Starting mass was included as a covariant in the growth parameter analysis and was only significant in the final mass.

Repeated measurements were analysed using the GLM Repeated Measure Analyses (SAS, 2009) for repeated week measures. Repeated variables included mass, average daily gain, feed intake and feed conversion ratio.

Relations between digestible lysine intake (DLI) and average daily gain (ADG) or P2 fat measurement (linear and quadratic) was analysed using the GLM procedure by SAS (2009) within three different lysine levels; Lysine level 1 (starter ration), lysine level 2 (grower ration) and lysine level 3 (finisher ration). In the model the effects of different feed treatments, feed regimes, groups and blocks as well as all the interactions were included. All relationships indicate a significant ($P<0.05$) linear relation between DLI and ADG or P2 fat measurement, except for the P2 fat measurement in lysine level 2 that indicated a significant ($P<0.05$) quadratic relationship. Results of the relationship analysis are illustrated in Appendix II.

The statistical model used to analyse the data:

$$Y_{ijk} = \mu + R_i + F_j + P_k + RF_{ij} + RP_{ik} + FP_{jk} + RFP_{ijk} + e_{ijk}$$

Where μ = population mean of the appropriate trait;

R_i	=	effect of the i^{th} feed regime;
F_j	=	effect of the j^{th} feed treatment;
P_k	=	effect of the k^{th} period;
RF_{ij}	=	effect of the interaction of the i^{th} feed regime and j^{th} feed treatment;
RP_{ik}	=	effect of the interaction of the i^{th} feed regime and the k^{th} period;
FP_{jk}	=	effect of the interaction of the j^{th} feed treatment and the k^{th} period;
RFP_{ijk}	=	effect of the interaction of the i^{th} feed regime, j^{th} feed treatment and the k^{th} period;
e_{ijk}	=	random effects

CHAPTER 3
RESULTS

3.1 Overview

The seasonal differences between period 1 and period 2 of this trial, in terms of the minimum and maximum ambient temperatures as recorded in the experimental house, are illustrated in Table 3.1. The ambient temperatures recorded for South Africa was normal and no extreme variations occurred.

Table 3.1 Daily minimum and maximum temperatures recorded in the house during period 1 and period 2

Period 1-Winter#			Period 2-Summer#		
Week of the year*	**Min**	**Max**	**Week of the year***	**Min**	**Max**
23	16	23	40	22	32
24	16	23	41	21	29
25	17	24	42	22	32
26	17	24	43	22	31
27	17	24	44	22	30
28	16	24	45	22	32
29	20	24	46	20	26
30	20	25	47	21	29
31	20	25	48	22	31
32	20	25	49	22	33
33	20	25	50	23	31

* Year 2008
# Winter - 6 June 2008 to 13 August 2008 and Summer - 3 October 2008 to 10 December 2008

Significant differences were observed for production parameters between winter and summer periods (Table 3.2). The data were corrected for starting mass and starting P2 values and significant differences ($P<0.05$) that occurred were due to season effect. Period, therefore had significant ($P<0.05$) effects on end mass, average daily gain (ADG), end P2 and protein deposition (Table 3.2). The differences between drip loss % cannot be attributed to season alone and is discussed later in this chapter (Table 3.18).

Seasonal data was pooled to add statistical power to the end results and conclusions. Corrections were made for the differences that occurred between the different seasons.

Table 3.2 Seasonal effects on growth and production parameters over the two periods, winter and summer (Mean ± SD)

Parameters	Period			
	Winter*		Summer*	
Starting mass (kg)	29.86[b]	(±3.13)	31.27[a]	(±2.97)
End mass (kg)	101.99[a]	(±7.48)	98.34[b]	(±9.11)
Average daily gain (kg/day)	1.05[a]	(±0.11)	1.01[b]	(±0.13)
Feed intake (kg/day)	2.59	(±0.32)	2.54	(±0.31)
Feed conversion ratio	2.48	(±0.19)	2.55	(±0.25)
Starting P2 (mm)	7.90[a]	(±0.62)	5.80[b]	(±0.67)
End P2 (mm)	12.32[a]	(±1.26)	11.72[b]	(±1.25)
Protein deposition (g/day)	160.61[a]	(±16.42)	149.61[b]	(±12.85)
Lipid deposition (g/day)	287.59	(±64.62)	310.43	(±64.51)
Warm carcass mass (kg)	74.41	(±5.94)	73.21	(±7.23)
Cold carcass mass (kg)	71.11	(±5.80)	70.39	(±7.02)
Slaughter percentage	73.53	(±1.99)	73.80	(±1.46)
Lean meat percentage	69.00	(±1.33)	69.20	(±0.80)
Drip loss percentage	4.45[a]	(±0.54)	3.86[b]	(±0.50)

[ab] Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)
* Winter - 6 June 2008 to 13 August 2008 and Summer - 3 October 2008 to 10 December 2008

Pigs that received the higher density feeds (Feed High) had a significant (P<0.05) higher growth response than the pigs on the low density feeds (Feed Low). The "Feed High" pigs performed significantly (P<0.05) better than the "Feed Low" pigs in terms of end mass, average daily gain, feed conversion ratio and average protein deposition rate. Growth results for the different feed treatments are shown in Table 3.3.

Group *ad libitum* fed (AGF) pigs had significant (P<0.05) lower end masses, average daily gains and feed intakes than individually *ad libitum* fed (ASF) pigs (Table 3.4). End mass, average daily gain and feed intake were corrected for season effects and dietary treatment. Although *ad libitum* group fed pigs had a lower performance compared to *ad libitum* single fed pigs, *ad libitum* group fed pigs had a significant (P<0.05) better lean meat % and there were no significant (P<0.05) differences in feed conversion ratio between these two regimes. Restricted single fed (RSF) pigs had significant (P<0.05) lower end masses, average daily gains, feed intakes, end P2, average protein and lipid deposition rates and slaughter % compared to *ad libitum* single fed pigs. Restricted single fed pigs had a significant (P<0.05) better feed efficiency and lean meat % compared to *ad libitum* single fed pigs.

Table 3.3 Effect of high and low density diets on growth and production parameters (Mean ± SD)

	Feed Treatment			
Parameters	**Feed High***		**Feed Low***	
Starting mass (kg)	30.67	(±3.36)	30.47	(±2.88)
End mass (kg)	103.12[a]	(±7.55)	97.22[b]	(±7.98)
Average daily gain (kg/day)	1.07[a]	(±0.11)	0.99[b]	(±0.11)
Feed intake (kg/day)	2.55	(±0.26)	2.58	(±0.36)
Feed conversion ratio	2.39[a]	(±0.14)	2.63[b]	(±0.23)
Starting P2 (mm)	6.88	(±1.23)	6.82	(±1.26)
End P2 (mm)	12.11	(±1.29)	11.93	(±1.29)
Protein deposition (g/day)	159.49[a]	(±14.54)	150.73[b]	(±15.36)
Lipid deposition (g/day)	304.72	(±65.15)	293.30	(±65.06)
Warm carcass mass (kg)	76.42[a]	(±6.02)	71.20[b]	(±6.12)
Cold carcass mass (kg)	73.28[a]	(±5.93)	68.22[b]	(±5.87)
Slaughter percentage	74.02	(±1.44)	73.32	(±1.96)
Lean meat percentage	69.13	(±0.99)	69.06	(±1.20)
Drip loss percentage	4.12	(±0.57)	4.19	(±0.63)

[ab] Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)
* Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

Table 3.4 Effect of feeding regime (restricted single fed - RSF, *ad libitum* single fed – ASF and *ad libitum* grouped fed - AGF) on growth and production parameters (Mean ± SD)

	Feed Regimes					
Parameters	**RSF**		**ASF**		**AGF**	
Starting mass (kg)	31.92[a]	(±3.92)	30.88[a]	(±2.64)	28.90[b]	(±1.59)
End mass (kg)	93.33[c]	(±7.02)	106.44[a]	(±8.38)	100.74[b]	(±4.42)
Average daily gain (kg/day)	0.93[c]	(±0.08)	1.12[a]	(±0.11)	1.03[b]	(±0.07)
Feed intake (kg/day)	2.23[c]	(±0.09)	2.85[a]	(±0.29)	2.61[b]	(±0.11)
Feed conversion ratio	2.43[a]	(±0.17)	2.57[b]	(±0.32)	2.54[b]	(±0.12)
Starting P2 (mm)	6.73[ab]	(±1.18)	7.10[a]	(±1.36)	6.71[b]	(±1.19)
End P2 (mm)	10.93[b]	(±0.82)	12.77[a]	(±1.43)	12.37[a]	(±0.66)
Protein deposition (g/day)	149.68[b]	(±15.94)	160.96[a]	(±18.77)	154.68[ab]	(±9.38)
Lipid deposition (g/day)	274.61[b]	(±69.66)	321.14[a]	(±80.68)	301.27[ab]	(±25.50)
Warm carcass mass (kg)	68.98[c]	(±5.54)	78.89[a]	(±6.28)	73.56[b]	(±3.58)
Cold carcass mass (kg)	65.99[c]	(±5.36)	75.69[a]	(±6.18)	70.57[b]	(±3.24)
Slaughter percentage	72.70[b]	(±2.10)	73.89[a]	(±1.54)	74.42[a]	(±0.89)
Lean meat percentage	69.61[a]	(±0.76)	68.45[b]	(±1.50)	69.24[a]	(±0.47)
Drip loss percentage	4.33	(±0.74)	4.08	(±0.51)	4.06	(±0.48)

[abc] Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

3.2 Production parameters

Production parameters for each period (winter and summer) were analysed separately (Appendix IV). Data from each period was used as a unit to add statistical power to the trial's end results. Results of each parameter are shown individually.

Table 3.5 The mean starting mass (kg) and standard deviation (±SD) at the beginning of the trial

		Feed Treatment			
		Feed High#		**Feed Low#**	
Feed Regimes	**RSF***	32.33 $_{1}$	(±4.16)	31.50 $_{1}$	(±3.80)
	ASF*	31.00 $_{1}$	(±2.83)	30.76 $_{12}$	(±2.56)
	AGF*	28.67 $_{2}$	(±1.77)	29.14 $_{2}$	(±1.42)

[ab] Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fisher, 1925)

Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

* Restricted single feeding (RSF), *ad libitum* single feeding (ASF), *ad libitum* group feeding (AGF)

As shown in Table 3.5, there were no significant (P<0.05) differences between the starting masses of "Feed High" and "Feed Low' pigs. Significant (P<0.05) differences occurred between the different feeding regimes i.e. RSF, ASF and AGF for starting mass. The average starting weight for all the pigs in winter (period 1) was 29.86 kg and for summer (period 2) 31.27 kg. This difference in initial weight was significant (P<0.05). Starting mass was included as a covariant in the growth parameter analysis and was only significant in the final mass.

Table 3.6 Effect of prior feeding and treatment on the mean end mass (kg) and standard deviation (±SD)

		Feed Treatment	
		Feed High#	**Feed Low#**
Feed Regimes	**RSF***	$96.39^{a}{}_{3}$ (±5.88)	$90.26^{b}{}_{2}$ (±6.40)
	ASF*	$110.42^{a}{}_{1}$ (±4.79)	$102.46^{b}{}_{1}$ (±9.39)
	AGF*	102.54_{2} (±5.00)	98.94_{1} (±3.27)

^{ab} Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fisher, 1925)

Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

* Restricted single feeding (RSF), *ad libitum* single feeding (ASF), *ad libitum* group feeding (AGF)

Table 3.7 Effect of prior feeding and treatment on the mean average daily gain (kg/day) and standard deviation (±SD)

		Feed Treatment	
		Feed High#	**Feed Low#**
Feed Regimes	**RSF***	$0.97^{a}{}_{3}$ (±0.07)	$0.89^{b}{}_{2}$ (±0.08)
	ASF*	$1.17^{a}{}_{1}$ (±0.06)	$1.07^{b}{}_{1}$ (±0.13)
	AGF*	1.06_{2} (±0.08)	1.01_{1} (±0.05)

^{ab} Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fisher, 1925)

Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

* Restricted single feeding (RSF), *ad libitum* single feeding (ASF), *ad libitum* group feeding (AGF)

Significant differences (P<0.05) in end mass indicated the effect of different feed treatments and feed regimes on growth during the trial. End weights (Table 3.6) and average daily gains (Table 3.7) were significantly (P<0.05) lower for restricted single fed pigs, compared to pigs on the *ad libitum* feeding regimes. There were no significant differences (P<0.05) between the *ad libitum* fed grouped pigs for the different feed treatments, Feed High and Feed Low. Differences were however significant (P<0.05) for restricted single fed and *ad libitum* single fed pigs between these two feed treatments. End weights and average daily gains differed significantly (P<0.05) between the different feed regimes, RSF, ASF and AGF.

Table 3.8 Effect of prior feeding and treatment on the mean feed intake (kg/day) and standard deviation (±SD)

		Feed Treatment			
		Feed High#		**Feed Low#**	
Feed Regimes	**RSF***	2.27_{3}	(±0.08)	2.19_{3}	(±0.09)
	ASF*	2.77^{b}_{1}	(±0.23)	2.93^{a}_{1}	(±0.33)
	AGF*	2.60_{2}	(±0.11)	2.61_{2}	(±0.10)

^{ab} Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fisher, 1925)

Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

* Restricted single feeding (RSF), *ad libitum* single feeding (ASF), *ad libitum* group feeding (AGF)

The different feed regimes (RSF, ASF and AGF) had an enormous effect on the pigs' feed intakes over the different trial periods. Restricted single fed (RSF), *ad libitum* single fed (ASF) and *ad libitum* group fed (AGF) pigs' feed intakes differed significantly (P<0.05) from each other. The restricted pig's feed was given at a fixed amount daily, where *ad libitum* animal's feed was freely available. The influence of the group effect explained the differences in feed intake between pigs kept in groups compared to those housed individually. Pigs housed in groups had a significant (P<0.05) lower feed intake compared to pigs in single pens. Table 3.8 indicates the pig's feed intake capability when fed *ad libitum*. The feed intake of *ad libitum* single housed pigs differed significantly (P<0.05) between the two feed treatments, Feed High and Feed Low, with the pigs on the lower density feed having higher feed intakes.

Table 3.9 Effect of prior feeding and treatment on the mean feed conversion ratio and standard deviation (±SD)

		Feed Treatment	
		Feed High#	**Feed Low#**
Feed regimes	**RSF***	2.35[a] (±0.15)	2.50[b] $_1$ (±0.15)
	ASF*	2.36[a] (±0.15)	2.79[b] $_2$ (±0.31)
	AGF*	2.48 (±0.09)	2.61 $_1$ (±0.11)

[ab] Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fisher, 1925)

Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

* Restricted single feeding (RSF), *ad libitum* single feeding (ASF), *ad libitum* group feeding (AGF)

The pigs that received the higher energy and protein diet (Feed High) had a significant (P<0.05) better feed conversion ratio, than pigs receiving the lower energy and protein diet (Feed Low). Pigs fed the lower energy and protein diet (Feed Low) *ad libitum* and individually housed had a significant (P<0.05) worse feed conversion ratio compared to pigs within the different feed regimes (RSF and AGF). The different feed conversion ratios are illustrated in Table 3.9.

Table 3.10 The mean starting P2 fat measurement (mm) and standard deviation (±SD)

		Feed Treatment	
		Feed High#	**Feed Low#**
Feed Regimes	**RSF***	6.77 $_{12}$ (±1.17)	6.69 (±1.25)
	ASF*	7.21 $_1$ (±1.34)	6.99 (±1.42)
	AGF*	6.66 $_2$ (±1.21)	6.76 (±1.23)

[ab] Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fisher, 1925)

Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

* Restricted single feeding (RSF), *ad libitum* single feeding (ASF), *ad libitum* group feeding (AGF)

Table 3.11 Effect of prior feeding and treatment on the mean end P2 fat measurement (mm) and standard deviation (±SD)

		Feed Treatment			
		Feed High#		Feed Low#	
Feed Regimes	RSF*	10.85 $_2$	(±0.64)	11.00 $_2$	(±0.99)
	ASF*	12.91 $_1$	(±1.32)	12.63 $_1$	(±1.59)
	AGF*	12.58 $_1$	(±0.65)	12.15 $_1$	(±0.61)

^{ab} Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fisher, 1925)

Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

* Restricted single feeding (RSF), *ad libitum* single feeding (ASF), *ad libitum* group feeding (AGF)

The restricted single fed pigs produced lean carcasses with no excessive body fat. The P2 fat measurements illustrated in Table 3.11 shows the significant differences (P<0.05) between the fat thickness of restricted pigs and pigs receiving their feed *ad libitum*. There were no significant differences (P<0.05) between the different feed treatments (Feed High and Feed Low).

Table 3.12 Effect of prior feeding and treatment on the mean protein deposition rate (g/day) and standard deviation (±SD)

		Feed Treatment			
		Feed High#		Feed Low#	
Feed Regimes	RSF*	153.80 $_2$	(±15.77)	145.57 $_2$	(±15.67)
	ASF*	165.41$^a{}_1$	(±16.69)	156.51$^b{}_1$	(±20.18)
	AGF*	159.24 $_{12}$	(±8.49)	150.11 $_{12}$	(±8.11)

^{ab} Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fisher, 1925)

Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

* Restricted single feeding (RSF), *ad libitum* single feeding (ASF), *ad libitum* group feeding (AGF)

Pigs fed *ad libitum* of the high density feeds in individual pens deposited on average 165.41 grams of protein per day (Table 3.12). Restricted pigs on the same feed deposited significantly (P<0.05) less protein (153.80 g/day). Significant (P<0.05) differences between feed treatments (Feed High and Feed Low) only occurred between pigs fed *ad libitum* and housed individually. There were high variation between average lipid deposition values over the different feed treatments and feed regimes (Table 3.13).

Table 3.13 Effect of prior feeding and treatment on the mean lipid deposition rate (g/day) and standard deviation (±SD)

		Feed Treatment			
		Feed High#		**Feed Low#**	
Feed Regimes	**RSF***	274.87_{2}	(±68.24)	274.36	(±74.08)
	ASF*	327.23_{1}	(±81.92)	315.05	(±82.63)
	AGF*	312.06_{12}	(±23.52)	290.48	(±22.47)

^{ab} Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fisher, 1925)

\# Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

* Restricted single feeding (RSF), *ad libitum* single feeding (ASF), *ad libitum* group feeding (AGF)

3.3 Slaughter parameters

Warm and cold carcass mass gives an indication of the pigs' muscle, fat and bone development during the growing phases. Warm and cold carcass mass is a representation of the final mass obtained by the pigs. Restricted single fed pigs had significantly (P<0.05) lower warm and cold carcass masses (Table 3.14 and Table 3.15), because of their lower end body weights. The higher percentage lean and lower percentage fat in restricted pigs also contributed to the differences in carcass mass. The significant differences (P<0.05) between different feed treatments (Feed High and Feed Low) and feed regimes (RSF, ASF and AGF) were a reflection of the final mass obtained by animals.

Table 3.14 Effect of prior feeding and treatment on the mean warm carcass mass (kg) and standard deviation (±SD)

		Feed Treatment	
		Feed High#	**Feed Low#**
	RSF*	71.85$^{a}{}_{2}$ (±4.40)	66.10$^{b}{}_{2}$ (±5.17)
Feed Regimes	**ASF***	82.43$^{a}{}_{1}$ (±3.77)	75.36$^{b}{}_{1}$ (±6.46)
	AGF*	74.98 $_{2}$ (±4.14)	72.14 $_{1}$ (±2.30)

^{ab} Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

$_{12}$ Column means with the same subscript do not differ significantly P>0.05 (Fisher, 1925)

Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

* Restricted single feeding (RSF), *ad libitum* single feeding (ASF), *ad libitum* group feeding (AGF)

Table 3.15 Effect of prior feeding and treatment on the mean cold carcass mass (kg) and standard deviation (±SD)

		Feed Treatment	
		Feed High#	**Feed Low#**
	RSF*	68.63$^{a}{}_{2}$ (±4.48)	63.35$^{b}{}_{2}$ (±4.97)
Feed Regimes	**ASF***	79.25$^{a}{}_{1}$ (±3.70)	72.13$^{b}{}_{1}$ (±6.29)
	AGF*	71.96 $_{2}$ (±3.71)	69.17 $_{1}$ (±1.99)

^{ab} Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fisher, 1925)

Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

* Restricted single feeding (RSF), *ad libitum* single feeding (ASF), *ad libitum* group feeding (AGF)

Slaughter percentage is an indicator of the usefulness of a carcass. The restricted single fed regime had significantly (P<0.05) lower slaughter percentages compared to the other regimes (ASF and AGF) for both feed treatments (Table 3.16).

Table 3.16 Effect of prior feeding and treatment on slaughter percentage and standard deviation (±SD)

		Feed Treatment			
		Feed High#		**Feed Low#**	
Feed Regimes	**RSF***	73.02 $_{2}$	(±1.72)	72.37 $_{2}$	(±2.46)
	ASF*	74.32 $_{1}$	(±1.17)	73.45 $_{12}$	(±1.84)
	AGF*	74.71 $_{1}$	(±0.71)	74.12 $_{1}$	(±0.99)

^{ab} Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fisher, 1925)

Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

* Restricted single feeding (RSF), *ad libitum* single feeding (ASF), *ad libitum* group feeding (AGF)

The feed optimising objective is to feed animals to develop leaner carcasses that are acceptable by the end consumer. Restricted single fed and *ad libitum* group fed pigs' lean meat % were significantly (P<0.05) higher compared to *ad libitum* single fed pigs (Table 3.17). Although there were no significant differences between restricted and group fed animals, their lean meat % differed according to the PORCUS classification system of South Africa (Appendix II). Most of the restricted single fed pigs were graded as P (Lean meat percentage > 69.5) and *ad libitum* group pigs as O (Lean meat percentage <69.5). These differences had lesser economic implications or advantages, because no price difference exists between P and O carcass delivered to an abattoir in South Africa. The *ad libitum* single fed animals' lean meat % was significantly (P<0.05) lower compared to the other two feed regimes (RSF and AGF).

Table 3.17 Effect of prior feeding and treatment on lean meat percentage and standard deviation (±SD)

		Feed Treatment			
		Feed High#		**Feed Low#**	
Feed Regimes	**RSF***	69.68 $_{1}$	(±0.75)	69.54 $_{1}$	(±0.79)
	ASF*	68.58 $_{2}$	(±1.28)	68.32 $_{2}$	(±1.76)
	AGF*	69.15 $_{12}$	(±0.49)	69.33 $_{1}$	(±0.46)

^{ab} Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fisher, 1925)

Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

* Restricted single feeding (RSF), *ad libitum* single feeding (ASF), *ad libitum* group feeding (AGF)

The significant differences (P<0.05) between drip loss %, between the two different periods (Table 3.2) were likely due to the time the carcasses spent in the cooler. Pigs in period 1 were slaughtered on a Friday and the cold carcasses were weighed 3 days later (3 days in freezer). Pigs in period 2 were slaughtered on a Thursday and the cold carcasses were weighed the following day (1 day in freezer). The significant differences (P<0.05) between the two periods were mainly due to higher moisture loss in the carcasses of period 1. Drip loss % is illustrated in Table 3.18.

Table 3.18 Effect of prior feeding and treatment on drip loss percentage and standard deviation (±SD)

		Feed Treatment	
		Feed High#	**Feed Low#**
Feed Regimes	**RSF***	4.50 $_1$ (±0.60)	4.16 (±0.85)
	ASF*	3.87 $_2$ (±0.47)	4.29 (±0.50)
	AGF*	4.01 $_2$ (±0.46)	4.11 (±0.51)

^{ab} Row means with the same superscript do not differ significantly P> 0.05 (Fisher, 1925)

$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fisher, 1925)

Feed Low contained 95% of the energy, crude protein and amino acid levels used in Feed High

* Restricted single feeding (RSF), *ad libitum* single feeding (ASF), *ad libitum* group feeding (AGF)

3.4 Repeated measurements

The growth trial was based on the recommendations and predictions by The Institute of Pig Genetics (IPG) (Beuningen, The Netherlands). A feed scheme (growth model) was developed and used as a guide line to formulate rations (Table 3.19). Pigs allocated to the restricted feeding regime were fed according to the predicted feed intake curve of the growth model. During the trial, repeated measurements were taken to compare the pig's growth performances. IPG predicted growth performances were compared to the growth performances of South African animals fed according to the predicted feed intake curve (restricted animals), but were also compared to the growth performances of animals being fed *ad libitum* (grouped and single housed). Tables 3.20, 3.21 and 3.22 give a summary of the pigs' growth performances on a weekly basis. The data in these tables were corrected for the differences between the two periods, winter and summer and only the data for pigs on the high energy and protein (Feed High) treatment are shown.

Table 3.19 Recommended growth model and feeding curve for the Topigs 40 and Tempo progeny as predicted by the Institute of Pig Genetics (IPG)

Mass (kg)	**Feed Intake (kg)**	**DE Intake (MJ)**	**Gain (kg)**	**Protein deposition (g/day)**	**Lipid Deposition (g/day)**	**Digestible Factor (Lysine)**	**Total Lysine Intake (g/day)**	**Total Lysine (g/kg)**	**Digestible Lysine (g/kg)**
25	1.55	20.93	0.98	180	112.85	0.78	25.19	16.25	12.68
35	1.75	23.63	0.99	180	128.30	0.78	25.43	14.53	11.34
45	1.90	25.65	0.99	180	133.95	0.78	25.65	13.50	10.53
55	2.10	28.35	1.02	180	153.38	0.78	25.86	12.31	9.61
65	2.30	31.05	1.04	180	174.11	0.78	26.06	11.33	8.84
75	2.45	33.08	1.05	180	183.78	0.78	26.25	10.71	8.36
85	2.65	35.78	1.07	180	206.44	0.78	26.44	9.98	7.78
95	2.80	37.80	1.08	180	217.74	0.78	26.62	9.51	7.41
105	3.00	40.50	1.10	180	241.79	0.78	26.79	8.93	6.97

Repeated measurements of restricted single fed pigs receiving high density ration (Feed High) are illustrated in Table 3.20. The repeated measurements indicate the actual feeding curves of pigs in this experimental trial. In comparison to IPG's predicted growth performances and actual obtained growth performances, the main differences were the inability of the experimental pigs to grow effectively.

Ad libitum single housed pigs (Table 3.21) gave an indication of their feed intake capabilities and corresponding growth performances if their feed intake is not limited. Experimental pigs fed *ad libitum* reached the target weight of 105 kg within 64 days. Single *ad libitum* fed pigs had very high feed intakes and growth rates in comparison to other feed regimes (RSF and AGF) and the prescribed growth model (Table 3.19).

The repeated measurements in Table 3.22 represent the *ad libitum* group fed pigs fed the high density ration. Social constrains and competition, based on the lower average daily feed intakes and average daily gains, are evident in grouped fed pigs (Table 3.22) compared to *ad libitum* single fed pigs (Table 3.21). Competition at the feeding trough and differences in feeding patterns could cause lower daily feed intake and lower overall growth performance.

Table 3.20 Repeated measurements of restricted single fed pigs on the high density ration

Days	Mass	Feed intake	DE feed intake	Average daily gain	P2 Fat	Protein deposition	Lipid deposition	Total lysine intake	Dig factor	Digestible lysine intake	Total lysine/kg	Digestible lysine/kg
	kg	kg/day	DE MJ/day	kg/day	mm	g/day	g/day	g/day	%	g/day	g/kg	g/kg
1	32	-	-	-	-	-	-	-	-	-	-	-
8	39	1.72	23.24	0.94	-	-	-	25.40	0.78	19.81	14.77	11.52
15	45	1.86	25.09	0.89	-	-	-	27.42	0.78	21.39	14.74	11.50
22	51	2.00	27.10	0.83	-	-	-	29.63	0.78	23.11	14.82	11.56
29	57	2.12	28.58	0.98	6.77	153.80	187.67	24.23	0.78	18.90	11.43	8.92
36	64	2.25	30.38	0.85	7.65	153.80	272.00	25.76	0.78	20.09	11.45	8.93
43	70	2.36	31.89	0.98	9.19	153.80	393.42	27.05	0.78	21.10	11.46	8.94
50	77	2.47	33.36	0.97	9.52	153.80	204.08	28.29	0.78	22.07	11.45	8.93
57	83	2.61	35.22	0.84	10.04	153.80	308.67	24.71	0.78	19.28	9.47	7.39
64	90	2.71	36.57	0.95	10.60	153.80	330.92	25.66	0.78	20.01	9.47	7.39
71	98	2.81	37.91	1.70	10.83	153.80	240.92	26.61	0.78	20.75	9.47	7.39

DE feed intake based on 13.5 MJ DE energy content in feed
Protein deposition is an average over the whole period in time
Efficiency of lysine utilization (dig factor) fixed at 0.78
Corrections made for different periods, winter and summer
All data were statistical analyses using SAS (2009)
Digestible lysine – apparent ileal digestible lysine

Table 3.21 Repeated measurements of *ad libitum* single fed pigs on the high density ration

Days	Mass	Feed intake	DE feed intake	Average daily gain	P2 Fat	Protein deposition	Lipid deposition	Total lysine intake	Dig factor	Digestible lysine intake	Total lysine/kg	Digestible lysine/kg
	kg	kg/day	DE MJ/day	kg/day	mm	g/day	g/day	g/day	%	g/day	g/kg	g/kg
1	31	.	.	.	.	.	.	.	.	.	.	.
8	38	1.77	23.95	1.05	.	.	.	26.18	0.78	20.42	14.79	11.54
15	45	1.95	26.29	0.95	.	.	.	28.73	0.78	22.41	14.73	11.49
22	53	2.26	30.46	1.14	.	.	.	33.29	0.78	25.97	14.73	11.49
29	61	2.57	34.73	1.16	7.21	165.41	200.50	29.45	0.78	22.97	11.46	8.94
36	69	2.76	37.26	1.16	8.38	165.41	278.50	31.60	0.78	24.65	11.45	8.93
43	78	2.92	39.40	1.27	9.89	165.41	409.58	33.41	0.78	26.06	11.44	8.92
50	87	3.18	42.94	1.22	10.40	165.41	312.50	36.41	0.78	28.40	11.45	8.93
57	95	3.52	47.58	1.26	11.44	165.41	384.33	33.39	0.78	26.05	9.49	7.40
64	104	3.44	46.43	1.24	12.19	165.41	321.75	32.59	0.78	25.42	9.47	7.39
71	111	3.58	48.35	1.37	12.90	165.41	397.17	33.93	0.78	26.46	9.48	7.39

DE feed intake based on 13.5 MJ DE energy content in feed
Protein deposition is an average over the whole period in time
Efficiency of lysine utilization (dig factor) fixed at 0.78
Corrections made for different periods, winter and summer
All data were statistical analyses using SAS (2009)
Digestible lysine – apparent ileal digestible lysine

Table 3.22 Repeated measurements of *ad libitum* group fed pigs on the high density ration

Days	Mass	Feed intake	DE feed intake	Average daily gain	P2 Fat	Protein deposition	Lipid deposition	Total lysine intake	Dig factor	Digestible lysine intake	Total lysine/kg	Digestible lysine/kg
	kg	kg/day	DE MJ/day	kg/day	mm	g/day	g/day	g/day	%	g/day	g/kg	g/kg
1	29	-	-	-	-	-	-	-	-	-	-	-
8	35	1.65	22.26	0.94	-	-	-	24.33	0.78	18.98	14.75	11.50
15	41	1.76	23.73	0.84	-	-	-	25.94	0.78	20.23	14.74	11.50
22	47	2.07	27.91	0.93	-	-	-	30.51	0.78	23.79	14.74	11.50
29	55	2.41	32.50	1.11	6.66	159.24	170.80	27.56	0.78	21.49	11.44	8.92
36	63	2.66	35.93	1.10	7.97	159.24	292.01	30.47	0.78	23.77	11.45	8.93
43	70	2.75	37.13	1.05	9.45	159.24	377.36	31.49	0.78	24.56	11.45	8.93
50	78	3.00	40.41	1.13	10.09	159.24	268.73	34.27	0.78	26.73	11.42	8.91
57	86	3.29	44.42	1.16	11.07	159.24	381.43	31.72	0.78	24.75	9.64	7.52
64	94	3.25	43.82	1.14	11.85	159.24	368.24	30.76	0.78	23.99	9.46	7.38
71	100	3.38	45.59	1.28	12.58	159.24	340.86	31.99	0.78	24.95	9.46	7.38

DE feed intake based on 13.5 MJ DE energy content in feed
Protein deposition is an average over the whole period in time
Efficiency of lysine utilization (dig factor) fixed at 0.78
Corrections made for different periods, winter and summer
All data were statistical analyses using SAS (2009)
Digestible lysine – apparent ileal digestible lysine

CHAPTER 4
DISCUSSION

4.1 Season effect

The effect of high ambient temperature on the growth performance in pigs is well documented in literature. The growth performance of pigs in tropical conditions is often regarded as low (Egbunike, 1986). Numerous studies show the negative effect of increasing temperature on voluntary food intake, daily weight gain and fat- and energy retention (Close, 1989, Quiniou *et al*., 2000 and Rinaldo *et al*., 2000). The optimum temperature range for finisher pigs is between 10 and 23.9 ºC (Myer and Bucklin, 2001). Temperature above 23.9 ºC has negative effects on the animals' growth performances (Kouba *et al*., 2001). The high air temperature and relative high humidity during summer are characteristics of the sub-tropical climate of South Africa.

The experimental trial conducted over different seasons resulted in the winter animals having a greater growth response compared to the summer animals, with end weight and average daily gain being significantly ($P<0.05$) higher. Feed intake is the limiting factor influencing growth rate in tropical areas. Lower feed intakes contribute to lower average daily gains and a decline in energy availability for tissue deposition, thus lower productivity. During the summer the animals did not have a significant ($P>0.05$) lower feed intake compared to the feed intake during winter. Interestingly, this was inconsistent with data from various researchers (Nienaber and Hahn, 1983 and Rinaldo and Le Dividich, 1991) that stated significant lower feed intakes during the warmer seasons. Rinaldo *et al*. (2000) tested the effects of the tropical climate on voluntary feed intake and performance of growing pigs. No depressive effects during the hot season on feed conversion ration were found, but there was a reduction in average daily gain and feed intake. The reduction in average daily gain was mainly attributed to a decline in feed consumption. This discrepancy may be due to firstly, the lower rate in the reduction of feed consumption during summer which could be related to the favourable night time temperature. The minimum temperatures during summer were within the range of thermo neutral temperatures of 20–22 ºC. Secondly, the parental lines used for the cross bred progeny were the Topigs 40 and Tempo. Both these lines are known for their adaptability and efficiency in the tropical conditions and were bred and selected for high voluntary feed intakes under high environmental temperatures.

Backfat measurements were significantly ($P<0.05$) lower for animals in the summer, considering starting P2 and end P2, in comparison to backfat measurements during winter. Animals in summer had less backfat, but had a higher lipid deposition rate compared to animals in the winter. The reduction in body fatness during the warm season in tropical conditions is consistent with previous literature (Straub *et al*., 1976, Nienaber *et al*., 1987 and Ronaldo and Le Dividich, 1991). A reduction in backfat and an increase in lipid deposition, especially in the internal sites such as leaf fat, were reported. It has been argued that the modification in body fat distribution reflects an adaptation to warm conditions as heat loss is promoted through reduced thermal insulation (Katsumata *et al*., 1996). High ambient temperature also had a negative effect on the average protein deposited. Animals deposited on average less protein ($P<0.05$) during summer than winter (149.61 g/kg vs. 160.61 g/kg). Kloareg *et al*. (2005) reported that high temperature affected the partitioning of ingested energy between protein and lipid deposition, and that protein deposition was limited by heat stress.

The inferior growth performance of animals in summer may be due to the redirection of more energy into their maintenance requirements. Animals in warm conditions have increased physical activities (respiratory hyperventilation) which are consistent with additional energy costs and higher maintenance requirements. Higher temperatures also negatively influenced the energy utilisation of the animals. Le Bellego *et al*. (2002) reported that energy retention at high temperatures was 0.39 MJ/day lower compared to pigs within their thermo neutral zone.

Results from growth parameters (average daily gain and feed conversion ratio), indicated improved performances when pigs received higher dense or concentrated rations during summer. Noblet *et al*. (1985) showed that higher energy rations would be tolerated better under warm conditions. It was concluded that the efficiency of metabolizable energy (ME) utilisation for energy retention and live weight gains improves as the energy concentration of the diet is increased under increasing thermo conditions.

4.2 Feed Treatments

A lot of research has focused on the influence of dietary energy concentration on feed intake, growth performance and carcass characteristics. For this trial, an increased incorporation of dietary fibre was used to decrease the energy content of low energy rations, with the consequence that low energy rations were more bulky. Within a certain range of variation dietary fibre content has no effect on growth performance, provided energy density is adequate (Baird *et al*., 1975). Therefore if the energy level is adequate, the pig can tolerate quite wide ranges of fibre or bulk in the diet. The effects of dietary fibre, associated with bulkiness, gut fill, mean retention time and nutrient availability are well documented in literature (Kyriazakis and Emmans, 1995, Shriver *et al*., 2003 and Wilfart *et al*., 2007). Higher inclusion of dietary fibre in low energy rations had a negative effect on the growth performance of the animals, this was more prominent during summer. High energy diets were fed for better growth performance, rather than those diluted by fibrous components, especially in warm conditions (Noblet *et al*. 1985). The lower growth performance during summer was a synergistic effect of high temperature, high levels of fibre and lower energy levels combined, resulting in an amplified response of a lower growth performance. Despite some negative impacts, farmers in tropical areas use extensive fibrous crop by-products and forages as an alternative to prohibitive cereals in pig diets. However, the use of fibrous ingredients in pig diets may not always be efficient in terms of animal's performance, but the economical asset of the operation is mostly at the advantage of the producer (Ogle, 2006).

Beaulieu and Patience (2006) evaluated the impact of feeding increasing dietary energy levels under commercial conditions. The diets varied from 12.5 to 15.0 MJ DE/kg. No major advantages of feeding high energy rations were found and the cost of high energy rations made the animals uneconomical to feed. Beaulieu *et al*. (2009) determined how changes in dietary digestible energy (DE) concentration, achieved through graded changes in diet composition, could affect the performance and carcass composition of growing pigs. An improvement ($P<0.05$) in average daily gain with increased energy content in the diet was observed. Feed intake decreased ($P<0.05$) whereas feed efficiency and daily energy intake improved ($P<0.05$) with increased digestible energy content. On a commercial pig farm the average daily gain remained unaffected by dietary energy content, although an improvement in growth (up to 80 kg of body weight) was observed with higher energy concentrations. These results supported previous studies where it was reported that the capacity of a pig for growth exceeded its ability to consume sufficient energy between 20 and 50 kg. This limitation in energy intake is removed in heavier animals (Campbell and Dunkin, 1990). It was therefore suggested to feed grower/finisher pigs a higher energy density during the early stages of growth (20 – 50 kg) and less dense diets containing lower energy concentrations during the later stages (50 – 105 kg).

Results obtained from current study showed a significant ($P<0.05$) improvement in average daily gain, feed efficiency and protein deposition rate when animals were fed a higher energy content in their diet. This is indicative of the animals' capability of utilising the additional energy available. Increased digestible energy content improved animal performances, but not necessarily delivered the best economic results.

The response to different dietary energy concentrations is not easy to predict. Changes in energy concentration inevitably lead to changes in ingredients, making it difficult to distinguish ingredient effects from energy effects. Studies investigating energy are also confounded by feed intake, which in turn is affected by genotype, health status, the physical environment, diet palatability and prior nutritional history (Bikker and Verstegen, 1994 and Nyachoti *et al*., 2004).

The increased concentration of pig herds, improved genetics and environmental constrains necessitated new feeding strategies for growing pigs. It is extremely important to precisely determine the energy value of feeds and also knowing the actual feed intake curves, for adapting feed supply to energy requirements of animals. The goal is that a pig should daily consume only enough of the essential and nonessential amino acids and energy for maximum growth potential or maximum lean deposition rate, as established by its genotype. Feeding different energy levels (diets) that differ in density for various seasons of the year, as well as for different age/weight groups and for a specific sex and genotype, are the best way to optimise feed utilisation of grower/finisher pigs.

The differences in animals' performances and feed intakes after being fed two diets differing in energy density are illustrated in Figure 4.1.

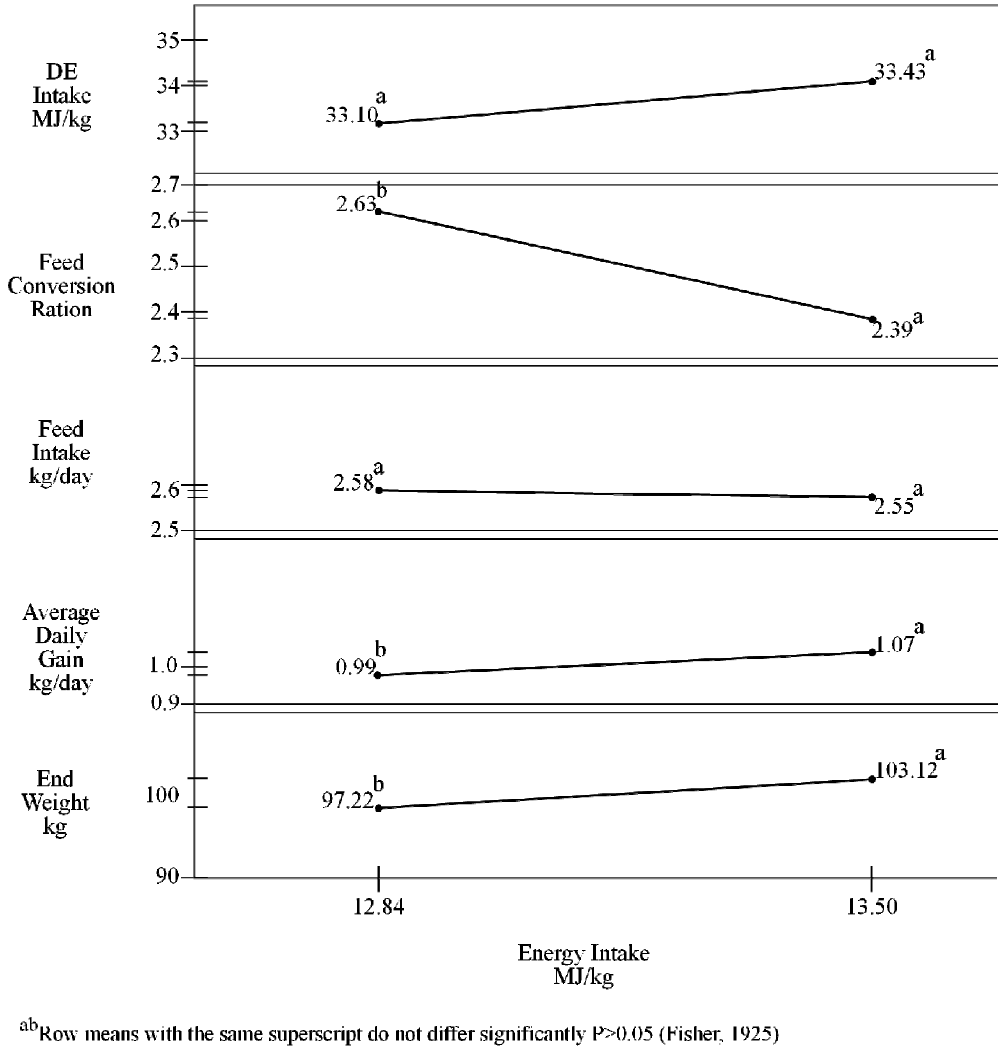

Figure 4.1 Effects of dietary energy concentration on end weight, average daily gain, feed intake, feed conversion ratio and digestible energy intake in pigs

4.3 Feed regimes

Modern pig production units aim to achieve high daily growth rates with minimal feeding requirements in order to reach specific target slaughter weights. The minimum level of feed intake to reach maximum protein deposition is called optimum feed intake (De Vries and Kanis, 1992). A simulation study in 1995 indicated that the highest returns per pig per year were achieved when feed intake was just sufficient to meet requirements for maximum protein deposition (Kanis, 1995). The optimal feed intake minimises feed conversion ratio and maximises lean meat growth.

Under ideal conditions, pigs should daily consume only enough of essential amino acids, nonessential amino acids and energy needed for maximum lean deposition as established by its genotype (Knabe, 1996). Under these conditions optimal pig growth performance and nitrogen excretion will be achieved. A growth model developed by Institute of Pig Genetic (IPG) was used to determine the maintenance and production requirements for lysine, specific for this line of grower animals. The model developed is a mathematical model designed to accurately quantify the daily nutrient requirements of pigs, especially essential amino acids, based on inputs that affect performance. The goal was to improve the efficiency of lean pork production by deriving protein deposition and lipid deposition rates and by integrating current knowledge of genetic potential of specific lines and their nutrient intake levels. Pigs have been intensively selected for various growth traits i.e. high lean tissue deposition, resulting in pigs with higher maximum protein retention than the unimproved strains. To determine the amino acid requirements of these improved strains accurate estimates of whole body protein deposition is required. The rate of maximum protein deposition will determine the pigs' nutrient requirements for growth and its response to nutrient or management changes. Feeding rations, according to the exact nutrient requirements of the specific genetic line used and the specific daily feed allowance were determined (optimal feed intake curve). The exact feeding curve was followed. Various factors throughout the trial could have had a negative influence on the restricted animal's growth performances i.e. genetic capabilities, health status, tropic environment, raw materials used and effects of different feeding patterns. Restricted single fed animals were very efficient in converting feed into tissue, however overall growth performances were poor. The mean lean meat percentages of carcasses were high, but no significant differences were observed between restricted and *ad libitum* group animals. For restricted animals a significant ($P<0.05$) improvement in feed conversion was observed. End weight, average daily gain and average protein deposition rates were significantly ($P<0.05$) lower compared to the *ad libitum* group and individually fed animals.

Literature has shown that the feed intake pattern has an influence on the digestive capacity of the pig. Restricted animals received their daily feed allowance early in the mornings. Within the first growth phase (30–50 kg) their physical gut capacity limited the feed intake and the whole day was needed to ingest the given feed allowance. It is evident that the differences in growth performances within the different feed regimes occurred after 50 kg live weight. During the final stages of growth (50–105 kg) restricted animals consumed their daily allowance of feed within a few minutes. The *ad libitum* group and individual animals had access to feed the whole day, and consumed it through different meals. Pigs with a few meals during the day will have a more continuous flow of digesta through the intestines (Sissins and Jones, 1991), thereby increasing contact time between feed and enzymes. A more balanced supply of essential amino acids will occur resulting in better utilisation of these amino acids (Den Hartog *et al*., 1989 and De Haer, 1992).

Energy sources used, could also have had an effect on the feeding pattern and growth performance. Consumption of large quantities of maize could result in the availability of large amounts of highly and readily available fermentable energy. This will positively influence the pig's blood sugar levels and various physiological processes, that will reduce feed intake, will be activated. Using barley as the main energy source will result in energy being released more uniformly due to the physical composition of the cereal. The rate at which cereals release energy will influence the rate and amount of fat deposited by the animal. Unfortunately, no scientific literature was found to support this phenomenon.

In grower/finisher research programmes most animals are tested in individual housing systems, whereas commercially grown pigs are kept in groups. De Haer and De Vries (1993) reported that the housing system (individual vs. group fed) had a significant influence on growth rate, backfat thickness and most feed intake traits. The lower growth rate and backfat thickness in group pens are a result of lower feed intake, lower digestibility and also a higher level of activity due to social interaction. Performance results from the current trial confirmed this statement with significant ($P<0.05$) differences shown in performance between group housed and individually kept pigs. *Ad libitum* single fed animals showed a significantly ($P<0.05$) higher growth rate and final mass. No significant differences were observed between backfat thickness and feed conversion ratio between the individual and group housed animals. In literature the effect on growth performance of pigs kept in groups, in comparison to individual housed pigs are shown to have large significant differences, mainly due to differences in the feed intake pattern and also social behaviour between pigs (Nielsen *et al*., 1995, Ramaekers *et al*., 1996 and Bornett *et al*., 2000). In addition it has been found that group housed pigs modify their feeding behaviour by eating less frequently, but consuming more food once of at a faster rate, compared to pigs housed individually (De Haer and Merks, 1992). Pigs housed individually gained more weight, had higher growth rates and higher feed intakes compared to pigs housed in groups of five (Gonyou *et al*., 1992). Social stress, social facilitation and competition at the feeder are all factors that contribute to differences in feeding behaviour and production parameters between groups housed and individually housed pigs. Animals in group housing stimulate each other to eat, however it could lead to competitive behaviour at the feeders.

Individually *ad libitum* housed and fed animals consumed more feed than needed to reach maximum performance and maximum protein deposition rates (residual feed intake). Residual feed intake is defined as the amount of feed consumed in excess of that required for lean tissue deposition. It is the difference between the feed consumed by an animal and its consumption as predicted from a model involving its production and maintenance requirements i.e. the error term of the prediction equation (Rauw *et al*., 2006). Residual feed intake is used as an alternative measure for feed efficiency and also as an indicator for maintenance energy requirements in pigs. *Ad libitum* single fed animals consumed daily on average 620 g more feed than restricted animals that were fed according to exact nutrient requirements. The *ad libitum* single fed animals had a positive residual daily feed intake. This is indicative of an inefficient animal, thus an animal eating more than necessary on average for its metabolic weight and performance. This caused an increased amount of fat deposited (321.14 g/kg *vs.* 274.61 g/kg). It is therefore important to restrict feed intakes in latter stages of growth and also to select for lower residual feed intakes. Selecting for a low residual feed intake in growing pigs (having *ad libitum* access to feed) makes it possible to improve feed efficiency without compromising growth rate, in spite of the reduction in voluntary feed consumption (Gilbert *et al*., 2007).

When considering overall growth performance of animals within the different feeding regimes, restricted single fed animals tend to have a slower growth rate, higher fat deposition rates and lower protein deposition rates. It can therefore be concluded that the optimal feeding curve predicted for the specific genotype, using the prescribed model was not necessarily the optimal feed curve for the animals used in the trial. The animals were not supplied with sufficient essential and nonessential amino acids, compared to *ad libitum* fed animals. Results indicated a deficiency in protein supply due to insufficient feed allowance. If an animal has a protein and lipid deficiency the correction of one usually assists the other (Ferguson and Theeruth, 2002). Various authors indicated that an animals' attempt to overcome protein deficiency will result in an increased food intake and a consequential increase in lipid deposition due to the over-consumption of energy (Kyriazakis and Emmans, 1991, Ferguson and Gous, 1997 and Ferguson *et al*., 2000). Amino acid requirements determined by the growth model used in the current experiment, takes various factors into consideration. Due to the different amino acid requirements for maintenance and body protein deposition (animals in sub-tropical areas such as South Africa), the amino acid requirements varied according to the level of protein growth and its changing relationship to maintenance. Feed intake varies greatly amongst herds, lines and countries. Measuring feed intake will aid in the prediction of the actual nutrient requirements needed by these animals. This underscores the fundamental importance of actual feed intake curves as a basic component of nutritional management for commercial pig herds.

CHAPTER 5
CONCLUSION

A decrease in energy density of the diet for growing pigs through incremental changes in diet composition had a variable impact on overall growth performance and carcass quality. Changes in energy concentration lead to changes in ingredients making it difficult to distinguish ingredient effects from energy effects. Benefits of the low energy ration, due to higher levels of fibre, had an economical advantage over the higher and dense energy ration. Feeding the high energy ration improved growth performance during summer, but also during the initial stages of growth, when feed intake capacity was limited. Animals should be allowed to fully exploit their genetic potential for growth and lean tissue deposition, especially in the early stages of growth. Improving feeding strategies by feeding low energy diets during winter and higher energy diets during summer will not only have a positive effect on animal performance, but also on the producer's income. The null hypothesis was rejected, therefore higher dense diets had a positive effect on pigs' growth performances and carcass grading when fed during the summer period.

Rations need to be formulated according to the animal's exact nutrient requirements considering the effects of genetics, different sexes and environmental influences. The objective when formulating diets should be to provide the essential amino acids and energy in sufficient amounts needed for maximum and efficient growth. Animals fed according to the prescribed (IPG growth model) optimal feeding curve showed an improved feed efficiency, but slower growth rate compared to *ad libitum* fed animals. This emphasises the importance of measuring and calculating the actual feed intake and protein deposition rates to reach optimal performance levels. The null hypothesis was therefore not accepted as differences did exist between the performance of entire male pigs fed restricted quantities of feed and *ad libitum* fed males.

It is vital to feed animals according to both their nutrient requirements, as well as to market requirements. If there is no economical advantage in producing lean meat or carcasses, feeding strategies need to be adjusted to support such system.

Growth performance was greater when pigs were penned individually rather than in groups. Competition, aggressive behaviour, an increase in activity i.e. standing, different feeding patterns and physiological responses due to chronic stress of competition and aggressive encounters were all factors influencing the growth performance of group housed animals. In group-penned finishing pigs, lower feed intake may reflect willingness to wait and the avoidance of competition for feeders, leading to a reduction in weight gain. Thus, measurements of feed intake and growth performance data derived from pigs penned individually should be adjusted before it can be applied to commercial situations or research conditions in which pigs are penned in groups. The null hypothesis that grower pigs penned in groups have the same performance capabilities than pigs penned individually, were rejected.

CHAPTER 6
CRITICAL EVALUATION

The aim of this chapter is to critically evaluate the current limitations in the pork industry and shortcomings of the experimental trial.

6.1 Pricing system

The current classification system used in South Africa to classify and to determine the value of a carcass is mainly based on the lean meat percentage of the carcass. A lean meat percentage of 69.5 % and above is classified as a P, where a lean meat percentage of 68 % to 69.5 % is classified as an O. Between the classification of a P and an O there is an average variation of 5 mm of backfat. Regardless if the carcass is a P or O; it is assigned the same economic value per kg carcass weight. Therefore, there is no price advantage in delivering leaner carcasses to the abattoir. The major selection goals in past years were to increase lean meat production and decrease the amount of fat deposition in the carcass. The leaner carcass, in the current situation, has no higher economic value to the producer. Changes and improvement have to take place to ensure a future for pork production in South Africa. It is imperative that the pork industry undergo a substantial paradigm shift focussing more on the consistency and uniformity of the end product.

6.2 Dietary formulations

The key importance when formulating rations is to optimise the diet so that the nutrients supplied is exactly what the animal requires, for both maintenance and growth. It is therefore important to express the feed energy value on the same system, both energy supply (a dietary characteristic) and energy requirement (an animal characteristic). The energy system used in South Africa is based on digestible energy (DE), but most of the energy requirements for animals are expressed as net energy (NE). Due to differences in digestibility and associated endogenous energy losses the actual contribution of nutrients to apparent DE supply in growing pigs is highly variable. Amino acid requirements (predominantly lysine) are expressed as total or digestible lysine and are therefore an over estimation of the actual requirements of the animal. Standardized ileal digestible (SID) lysine requirements are a more precise expression of the lysine requirements of the animal, which takes basal endogenous losses into account. By making use of the NE system and SID lysine, diets could be formulated closer to the animal’s actual requirements. Unfortunately, these values/expressions are not applied in South Africa.

6.3 Environmental influences

The trial was conducted at the research facilities of the University of Pretoria, RSA. The facility was however not designed to effectively control the external environment. The variation between the minimum and maximum temperature was extreme, which could have caused a negative influence on animal performances. Temperature was the only variable measured to make valid conclusions regarding the effect of season on animal performance. Other important environmental factors could also influence animal's performance, but these were not taken into account.

6.4 Growth model

With the use of growth models the animal's requirements and optimal feeding curves could only be used as a base for determining the nutrient requirements. Actual feed intake curves and production performances of the herd should be the basic component of nutritional management.

6.5 Raw materials

It is assumed that the inclusion of by-products always has an economic advantage, but the availability and price of by-products fluctuate throughout the year. Formulating lower density rations, by a higher inclusion of by-products, is not necessarily a cheaper alternative these days.

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APPENDIX

APPENDIX I – PROTEIN AND LIPID DEPOSITION FORMULAS

Formulas used to estimate the protein and lipid deposition rates.

% fat = $\dfrac{ultrasonicbackfat(mm) - 1.87}{53.3}$

% protein = $0.165 - \left\{0.00025 * \left(\dfrac{Startweight + finalweight}{2} - 80\right)\right\}$

Maintenance = $\dfrac{(Finalweight^{1.75} - startweight^{1.75}) * 420}{(Finalweight - startweight) * 1.75}$ (De Haer,1993)

Water_protein_ratio = $5.39 * \left(\% protein * \dfrac{Startweight + finalweight}{2}\right)^{-0.145}$ (De Greef, 1994)

Lipid deposition = $\dfrac{Finalweight^{0.95} * \% fat\_end - Startweight^{0.95} * \% fat\_start}{testlength}$

Protein deposition = $\dfrac{Dailygain - Lipiddeposition}{Water\_protein\_ratio + 1}$

APPENDIX II – ECONOMIC RESULTS

An economic analysis was conducted using long – term average prizes. The economic results were determined by using gross income values of carcasses slaughtered subtracted from the feed costs. No other expenses were taken into account. Carcass prizes are determined by the PORCUS classification system. The PORCUS classification system determines the prize of a carcass mainly by the lean meat percentage and warm carcass mass. Lean meat percentage is measured with the Hennessy probe. Prizes were fixed during both trials at R15.30 per kilogram warm carcass mass for P and O grading. The prize for R grading was R14.10 per kilogram warm carcass mass. The prizes for raw materials were also fixed throughout the trial (Maize R1900/t, Bran R1375/t, Soya oilcake meal R3700/t, Fishmeal R7620/t, Sunflower oilcake R2220/t). The economic results in Table 2, indicates the better revenue when feeding the high energy ration during summer and the lower energy ration during winter. The higher density and bulkiness of the low energy ration had negative influences on the already depressed feed intake of the pigs during summer.

Table 1 PORCUS Classification System

PORCUS Classification System		
Percentage Lean Meat	MM Fat	Class
$\gg$ 69.5	$\ll$ 12	P
68 – 69.5	13-17	O
66 - 67	18-22	R

Table 2 Calculated returns over grow out feed costs accruing from the use of a High and Low energy ration under three different feed regimes (RSF – Restricted Single Feeding, ASF – *ad libitum* Single Fed & AGF – *ad libitum* Group Fed) during two periods, Winter and Summer

		PERIOD 1 (WINTER)			PERIOD 2 (SUMMER)		
		RSF	ASF	AGF	RSF	ASF	AGF
Total Nr Pigs Started		12 (6 High) (6 Low)	12 (6 High) (6 Low)	72 (36 High) (36 Low)	12 (6 High) (6 Low)	12 (6 High) (6 Low)	72 (36 High) (36 Low)
Final Live Weight (kg)	High	96.43	110.17	105.97	96.34	110.68	99.12
	Low	91.93	106.56	100.91	88.6	98.35	96.97
Warm Carcass Mass (kg)	High	70.53	80.6	77.63	73.17	84.27	72.33
	Low	67.93	76.15	73.64	64.27	74.57	70.63
Total Feed Usage (kg) Starter	High	237.80	266.35	1,446.29	231.55	235.70	1,257.70
	Low	235.20	275.70	1,477.55	218.13	242.35	1,310.70
Grower	High	382.90	458.05	2,646.71	389.90	502.20	2,652.35
	Low	380.45	518.34	2,745.75	367.50	526.55	2,719.50
Finisher	High	303.65	385.95	2,270.50	311.45	413.85	2,107.55
	Low	297.00	440.58	2,223.60	292.70	387.50	2,124.00
Total Feed Cost (Rand) Starter	High	648.42	726.26	3,943.67	631.38	642.70	3,429.43
	Low	577.31	676.72	3,626.75	535.42	594.87	3,217.20
Grower	High	943.82	1,129.06	6,523.93	961.07	1,237.89	6,537.51
	Low	825.50	1,124.70	5,957.73	797.40	1,142.51	5,900.78
Finisher	High	713.88	907.37	5,337.95	732.22	972.96	4,954.85
	Low	599.95	889.99	4,490.78	591.27	782.77	4,290.59
Total Feed Cost (Rand)	High	2,306.12	2,762.69	15,805.55	2,324.67	2,853.55	14,921.79
	Low	2,002.76	2,691.41	10,448.51	1,924.09	2,520.15	13,408.57
Feed Cost R/pig Starter	High	108.07	121.04	109.55	105.23	107.12	95.26
	Low	96.17	112.79	100.74	89.24	99.15	89.36
Grower	High	157.30	188.18	181.22	160.18	206.31	181.59
	Low	137.58	187.45	165.49	132.90	190.42	163.91
Finisher	High	118.98	151.23	148.28	122.04	162.16	137.64
	Low	99.99	148.33	124.74	98.54	130.46	119.18
Feed Cost R/pig	High	384.35	439.05	439.05	387.45	475.59	414.49
	Low	333.74	390.97	390.97	320.68	420.03	372.45
Low energy ration Rand cheaper		50.61	11.88	48.08	66.77	55.56	42.04
Average Total Income	High	6,474.96	7,399.08	42,758.60	6,716.70	7,638.00	39,471.66
	Low	6,236.58	675,706.00	40,560.30	5,899.68	6,845.27	38,898.08
Average Income R/pig	High	1,079.16	1,233.18	1,187.73	1,119.45	1,273.00	1,096.43
	Low	1,039.43	1,126.18	1,126.67	983.28	1,140.88	1,080.50
Total Revenue (Rand)	High	4,168.84	4,636.39	26,953.05	4,392.03	4,784.45	24,549.87
	Low	4,233.82	4,065.65	30,111.79	3,975.59	4,325.12	25,489.51
Revenue R/pig	High	694.81	772.73	748.70	732.00	797.41	681.94
	Low	705.63	677.61	836.43	662.60	720.85	708.04

APPENDIX III – RELATIONSHIP ANALYSIS

The relationship between digestible lysine intake (DLI) and average daily gain (ADG) or P2 fat measurement (linear and quadratic) was analyzed, within three different lysine levels. Lysine level 1 (starter ration), lysine level 2 (grower ration) and lysine level 3 (finisher ration). The effects of different feed treatments, feed regimes and groups as well as all the interactions were included in the relationship analysis. Lysine levels used are the averages between the high density ration and low density ration's lysine levels, to be a representation of the relationship between DLI and ADG or P2 fat measurement, over the whole trial's results.

Lysine level 1 = 11.23

Lysine level 2 = 8.71

Lysine level 3 = 7.21

Figure 1, Figure 2 and Figure 3 indicates the relationship between digestible lysine intake and average daily gain for the three different lysine levels. The linear relationship were highly significant ($P<0.05$). The linear relation between DLI and ADG is an excellent presentation of the expected growth rate of the Tempo x Topigs 40 progeny on a give digestible lysine intake. The positive slope in Figure 1 (lysine level 1) is the steepest compare to the other lysine levels (+0.08 vs. +0.56 and +0.57) indicating the sensitivity and importance of the correct lysine level in young animals. Only a small improvement in digestible lysine intake would have a huge effect on the growth performance of the animals. The quantity and quality of lysine source, has an enormous influence on the young grower pig's growth potential.

Figure 1, Figure 2 and Figure 3 each have a location point indicating average digestible lysine intake and average daily gain of animals during the specific growing phases. These location points for DLI and ADG were determined using the average for each phase or lysine level, as given estimated by the IPG model.

Point A: (19.83; 0.989)

Point B: (20.32; 1.034)

Point C: (20.76; 1.086)

The location points had given the expected performances of animals and could be compared to the performances of animals measured in the trial (linear relationship in Figure). Animals used in the trial did not perform as expected, in relation to the model's estimations.

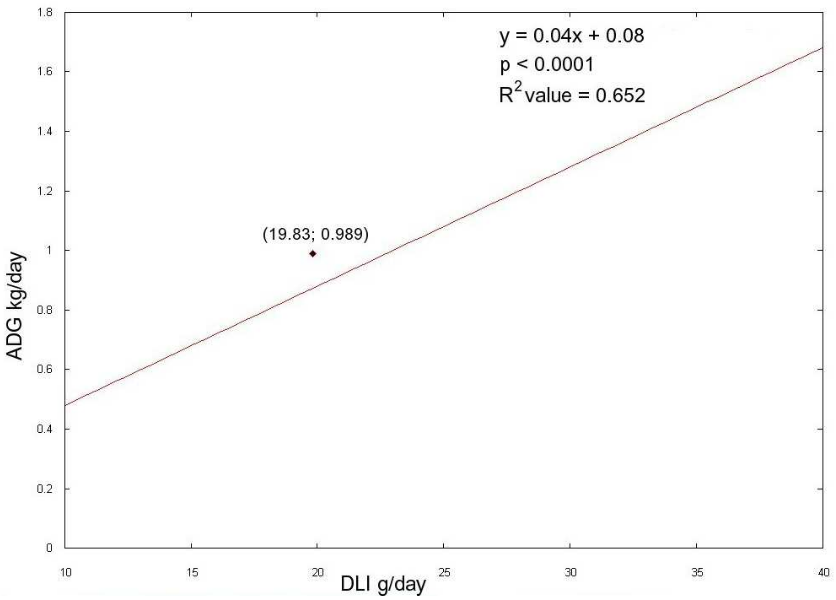

Figure 1 The relationship between average daily gain and digestible lysine intake for lysine level 1

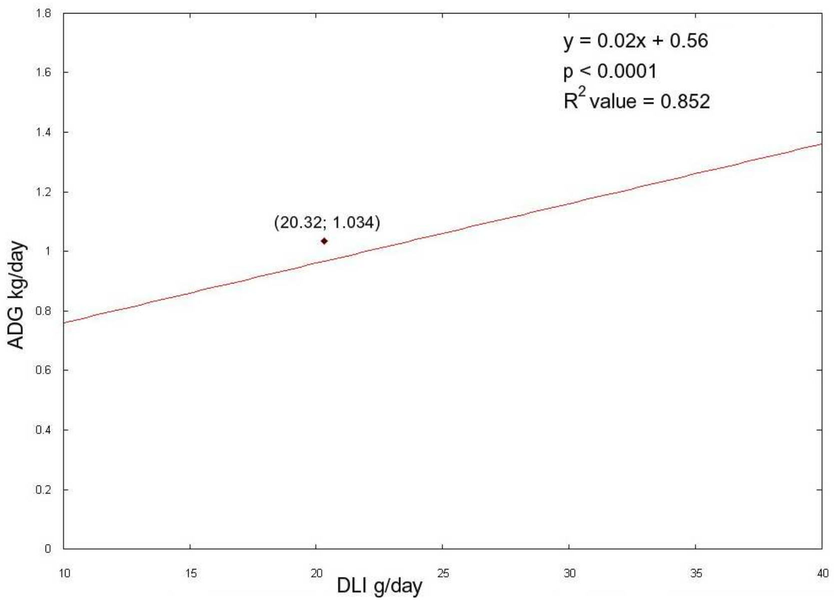

Figure 2 The relationship between average daily gain and digestible lysine intake for lysine level 2

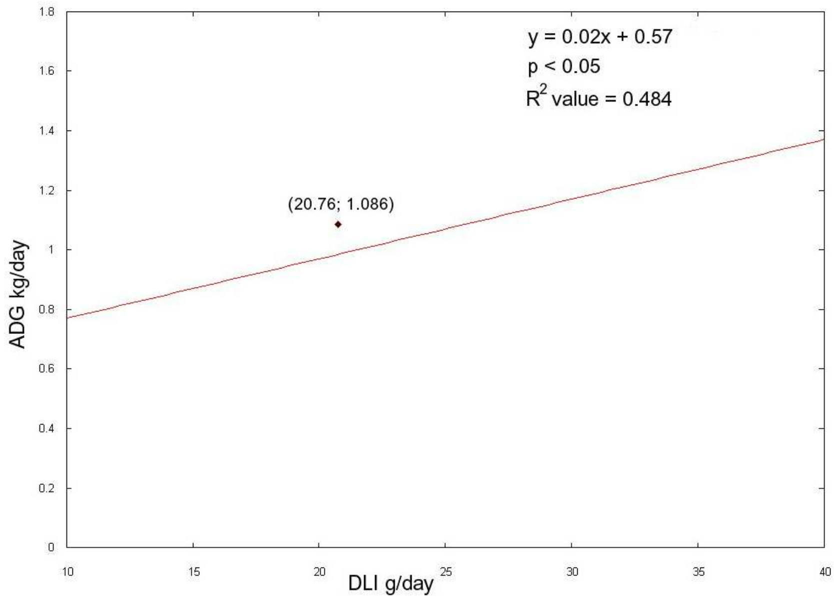

Figure 3 The relationship between average daily gain and digestible lysine intake for lysine level 3

Figure 4, Figure 5 and Figure 6 illustrates the linear and quadratic relationship between DLI and P2 Fat measurement, for the three different lysine levels or growth phases during the trial. The relationship between DLI and fat measurement were highly significant ($P<0.05$). The relationship gives an indication of the millimetre (mm) backfat to expect, depending on the digestible lysine intake of the animal. The importance of regulating the feed intake of grower pigs in the latter stages of growth is shown in Figure 6. Increasing digestible lysine intake is linear to increasing P2 fat measurement. Animals have the capability for high feed intakes in the latter stages, and thus need to be restricted to avoid excess lipid deposition.

The three graphs is a good presentation of increasing lysine intake and increasing fat thickness over the different growth phases of grower pigs.

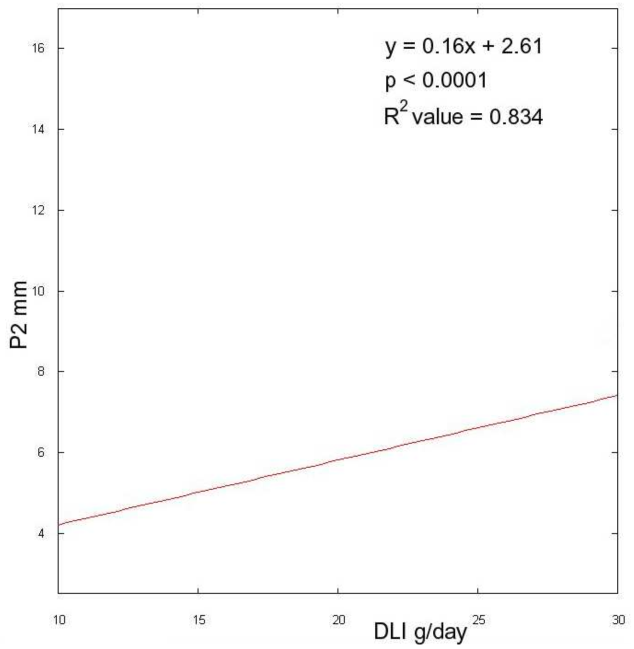

Figure 4 The relationship between P2 fat measurement and digestible lysine intake for lysine level 1

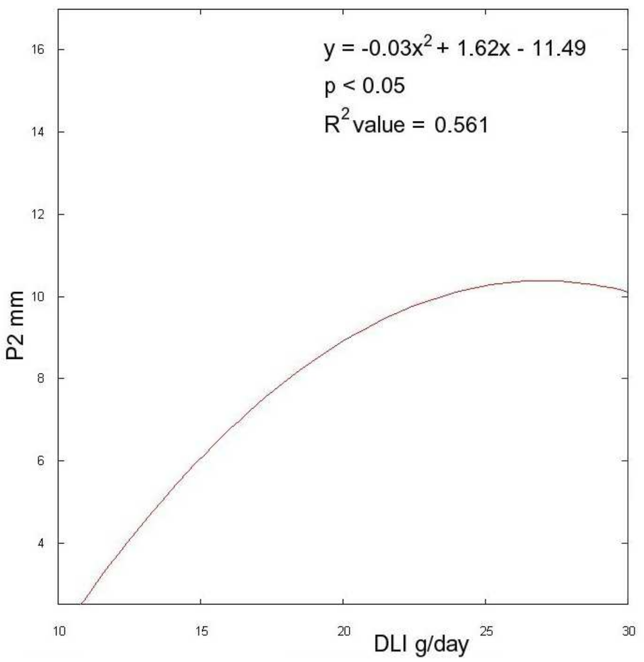

Figure 5 Relationship between P2 fat measurement and digestible lysine intake for lysine level 2

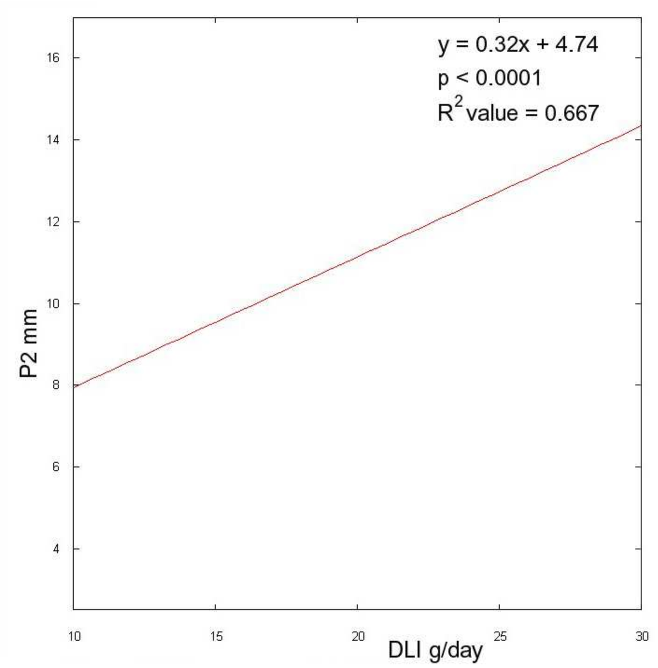

Figure 6 Relationship between P2 fat measurement and digestible lysine intake for lysine level 3

APPENDIX IV – GROUP TABLES

Production data for animals subjected to different feed treatments and regimes are shown in Table 3 to 16, within different periods, winter and summer.

Table 3 The mean starting mass and standard deviation (±SD) at the beginning of the trial

		Period 1 (Winter)			Period 2 (Summer)		
		Feed			Feed		
		1 (High)	2 (Low)	Mean	1 (High)	2 (Low)	Mean
Treatment	1 (RSF)	31.50 (±4.09)	31.50 (±4.81)	**31.50_4 (±4.25)**	33.17_1 (±4.45)	31.50 (±2.95)	**32.33_4 (±3.70)**
	2 (ASF)	28.83^b (±2.32)	29.51^b (±2.61)	**29.17^h_{45} (±2.34)**	$33.17^a{}_1$ (±0.98)	32.00^{ab} (±2.00)	**32.58^g_4 (±1.62)**
	3 (AGF)	28.50 (±1.58)	29.33 (±1.77)	**28.92_5 (±1.66)**	28.83_2 (±2.08)	28.95 (±1.10)	**28.89_5 (±1.58)**
	Mean	**29.61^e (±3.02)**	**30.12^{de} (±3.32)**		**31.72^d (±3.43)**	**30.82^{de} (±2.44)**	

[ab] Row means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
[12] Column means with the same subscript do not differ significantly P> 0.05 (Fischer, 1925)
[def] Row feed means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
[gh] Row feed x treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
[456] Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)

Table 4 Effect of prior feeding, treatment and period on the mean end mass and standard deviation (±SD)

		Period 1 (Winter)			Period 2 (Summer)		
		Feed			Feed		
		1 (High)	2 (Low)	Mean	1 (High)	2 (Low)	Mean
Treatment	1 (RSF)	$96.43^a{}_2$ (±7.77)	$91.93^{ab}{}_2$ (±6.87)	**94.18_6 (±7.37)**	$96.34^a{}_2$ (±3.73)	$88.60^b{}_2$ (±6.02)	**92.47_6 (±6.95)**
	2 (ASF)	$110.17^a{}_1$ (±4.62)	$106.56^a{}_1$ (±8.11)	**108.37_4 (±6.25)**	$110.68^a{}_1$ (±3.33)	$98.35^b{}_1$ (±10.39)	**104.52_4 (±10.25)**
	3 (AGF)	$105.97^a{}_1$ (±2.74)	$100.91^{ab}{}_1$ (±2.96)	**103.44^g_5 (±3.46)**	$99.12^b{}_2$ (±4.73)	$96.97^b{}_1$ (±1.82)	**98.04^h_5 (±3.57)**
	Mean	**104.19^d (±6.81)**	**99.80^e (±7.77)**		**102.04^{de} (±8.42)**	**94.64^f (±7.89)**	

[ab] Row means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
[12] Column means with the same subscript do not differ significantly P> 0.05 (Fischer, 1925)
[def] Row feed means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
[gh] Row feed x treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
[456] Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)

Table 5 Effect of prior feeding, treatment and period on the mean average daily gain and standard deviation (±SD)

		Period 1 (Winter)					Period 2 (Summer)				
		Feed					Feed				
		1 (High)		2 (Low)		Mean	1 (High)		2 (Low)		Mean
Treatment	1 (RSF)	$0.97^{a}{}_{2}$	(±0.09)	$0.91^{ab}{}_{2}$	(±0.07)	**0.93_{6} (±0.08)**	$0.97^{a}{}_{2}$	(±0.05)	$0.87^{b}{}_{2}$	(±0.08)	**0.92_{6} (±0.08)**
	2 (ASF)	$1.17^{a}{}_{1}$	(±0.04)	$1.12^{a}{}_{1}$	(±0.08)	**1.14_{4} (±0.07)**	$1.18^{a}{}_{1}$	(±0.08)	$1.02^{b}{}_{1}$	(±0.15)	**1.10_{4} (±0.14)**
	3 (AGF)	$1.10^{a}{}_{1}$	(±0.03)	$1.03^{ab}{}_{1}$	(±0.05)	**$1.07^{g}{}_{5}$ (±0.05)**	$1.02^{ab}{}_{2}$	(±0.10)	$0.98^{b}{}_{1}$	(±0.04)	**$1.00^{h}{}_{5}$ (±0.07)**
	Mean	**1.08^{d} (±0.09)**		**1.02^{e} (±0.11)**			**1.06^{de} (±0.12)**		**0.96^{f} (±0.11)**		

^{ab}Row means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fischer, 1925)
^{def}Row feed means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
^{gh}Row feed x treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{456}$ Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)

Table 6 Effect of prior feeding, treatment and period on the mean average daily feed intake and standard deviation (±SD)

		Period 1 (Winter)					Period 2 (Summer)				
		Feed					Feed				
		1 (High)		2 (Low)		Mean	1 (High)		2 (Low)		Mean
Treatment	1 (RSF)	2.26_{2}	(±0.09)	2.24_{3}	(±0.10)	**2.25_{6} (±0.09)**	2.29_{3}	(±0.07)	2.15_{3}	(±0.08)	**2.22_{6} (±0.10)**
	2 (ASF)	$2.72^{b}{}_{1}$	(±0.22)	$3.03^{a}{}_{1}$	(±0.35)	**2.87_{4} (±0.31)**	$2.82^{ab}{}_{1}$	(±0.26)	$2.84^{ab}{}_{1}$	(±0.32)	**2.83_{4} (±0.28)**
	3 (AGF)	2.68_{1}	(±0.06)	2.63_{2}	(±0.10)	**2.66_{5} (±0.08)**	2.53_{2}	(±0.10)	2.59_{2}	(±0.11)	**2.56_{5} (±0.11)**
	Mean	**2.55 (±0.25)**		**2.63 (±0.38)**			**2.55 (±0.27)**		**2.52 (±0.35)**		

^{ab}Row means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fischer, 1925)
^{def}Row feed means with the same superscript do not differ significantly P> 0.05 (Fischer,1925)
^{gh}Row feed x treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{456}$ Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{456}$ Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer,1925)

Table 7 Effect of prior feeding, treatment and period on the mean average feed conversion ratio and standard deviation (±SD)

		Period 1 (Winter)					Period 2 (Summer)				
		Feed					Feed				
		1 (High)		2 (Low)		Mean	1 (High)		2 (Low)		Mean
Treatment	1 (RSF)	2.35	(±0.16)	2.48 $_{2}$	(±0.19)	**2.42 (±0.18)**	2.36	(±0.15)	2.52 $_{2}$	(±0.11)	**2.44$_{4}$ (±0.15)**
	2 (ASF)	2.33^{b}	(±0.12)	2.71^{a} $_{1}$	(±0.26)	**2.52 (±0.27)**	2.39^{b}	(±0.18)	2.87^{a} $_{1}$	(±0.36)	**2.63$_{5}$ (±0.37)**
	3 (AGF)	2.43^{b}	(±0.04)	2.56^{ab} $_{12}$	(±0.10)	**2.49 (±0.10)**	2.53^{ab}	(±0.09)	2.66^{a} $_{2}$	(±0.09)	**2.59$_{5}$ (±0.11)**
	Mean	**2.37^{d} (±0.12)**		**2.58^{e} (±0.20)**			**2.42^{df} (±0.16)**		**2.68^{e} (±0.25)**		

^{ab}Row means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fischer, 1925)
^{def}Row feed means with the same superscript do not differ significantly P> 0.05 (Fischer,1925)
^{gh}Row feed x treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{456}$ Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)

Table 8 The mean starting P2 fat measurement and standard deviation (±SD)

		Period 1 (Winter)					Period 2 (Summer)				
		Feed					Feed				
		1 (High)		2 (Low)		Mean	1 (High)		2 (Low)		Mean
Treatment	1 (RSF)	7.67^{a}	(±0.65)	7.75^{a}	(±0.65)	**7.71^{g} (±0.62)**	5.88^{b}	(±0.80)	5.63^{b}	(±0.54)	**5.75^{h} (±0.67)**
	2 (ASF)	8.29^{a}	(±0.73)	8.04^{a}	(±0.84)	**8.17^{g} (±0.75)**	6.13^{b}	(±0.77)	5.96^{b}	(±1.04)	**6.04^{h} (±0.88)**
	3 (AGF)	7.77^{a}	(±0.29)	7.89^{a}	(±0.51)	**7.83^{g} (±0.40)**	5.55^{b}	(±0.40)	5.64^{b}	(±0.17)	**5.59^{h} (±0.30)**
	Mean	**7.91^{d} (±0.62)**		**7.89^{de} (±0.64)**			**5.85^{de} (±0.69)**		**5.74^{e} (±0.66)**		

^{ab}Row means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fischer, 1925)
^{def}Row feed means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
^{gh}Row feed x treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{456}$ Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)

Table 9 Effect of prior feeding, treatment and period on the mean end P2 fat measurement and standard deviation (±SD)

		Period 1 (Winter)					Period 2 (Summer)				
		Feed					Feed				
		1 (High)		2 (Low)		Mean	1 (High)		2 (Low)		Mean
Treatment	1 (RSF)	11.07_{2}	(±0.42)	11.55_{2}	(±0.46)	**11.31_{5} (±0.49)**	10.63_{2}	(±0.77)	10.46_{2}	(±1.11)	**10.54_{5} (±0.92)**
	2 (ASF)	13.12_{1}	(±1.66)	12.80_{1}	(±1.95)	**12.96_{4} (±1.71)**	12.71_{1}	(±0.98)	12.46_{1}	(±1.39)	**12.58_{4} (±1.15)**
	3 (AGF)	12.92_{1}	(±0.44)	12.45_{12}	(±0.64)	**12.68_{4} (±0.58)**	12.25_{1}	(±0.69)	11.85_{1}	(±0.43)	**12.05_{4} (±0.59)**
	Mean	**12.37^{d} (±1.35)**		**12.27^{de} (±1.20)**			**11.80^{de} (±1.20)**		**11.58^{e} (±1.31)**		

^{ab}Row means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fischer, 1925)
^{def}Row feed means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
^{gh}Row feed x treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{456}$ Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)

Table 10 Effect of prior feeding, treatment and period on the mean protein deposition rate and standard deviation (±SD)

		Period 1 (Winter)					Period 2 (Summer)				
		Feed					Feed				
		1 (High)		2 (Low)		Mean	1 (High)		2 (Low)		Mean
Treatment	1 (RSF)	156.69^{a}_{2}	(±16.92)	139.28^{b}_{3}	(±14.03)	**147.99_{6} (±17.41)**	150.92^{ab}	(±15.49)	151.85^{ab}	(±15.76)	**151.38 (±14.91)**
	2 (ASF)	176.92^{a}_{1}	(±8.10)	171.54^{a}_{1}	(±12.65)	**174.23^{g}_{4} (±10.24)**	153.90^{b}	(±15.06)	141.47^{b}	(±13.83)	**147.68^{h} (±15.24)**
	3 (AGF)	164.22^{a}_{12}	(±4.70)	154.97^{ab}_{2}	(±8.55)	**159.59_{5} (±8.19)**	154.27^{ab}	(±8.70)	145.25^{b}	(±3.88)	**149.75 (±7.97)**
	Mean	**165.96^{d} (±13.56)**		**155.26^{e} (±17.40)**			**153.03^{ef} (±12.73)**		**146.19^{f} (±12.38)**		

^{ab}Row means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fischer, 1925)
^{def}Row feed means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
^{gh}Row feed x treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{456}$ Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)

Table 11 Effect of prior feeding, treatment and period on the mean lipid deposition rate and standard deviation (±SD)

		Period 1 (Winter)			Period 2 (Summer)		
		Feed			Feed		
		1 (High)	2 (Low)	Mean	1 (High)	2 (Low)	Mean
Treatment	1 (RSF)	225.61^{b}_{2} (±34.85)	232.87^{b}_{2} (±29.62)	**229.24^{h}_{5} (±30.89)**	324.13^{a} (±60.48)	315.85^{a} (±84.04)	**319.99^{g} (±69.94)**
	2 (ASF)	337.37_{1} (±66.44)	324.32_{1} (±93.04)	**330.85_{4} (±75.86)**	317.08 (±99.99)	305.78 (±80.57)	**311.43 (±86.78)**
	3 (AGF)	314.19_{1} (±19.66)	291.15_{12} (±28.86)	**302.67_{4} (±27.42)**	309.93 (±28.11)	289.82 (±16.65)	**299.88 (±24.40)**
	Mean	**292.39 (±65.00)**	**282.78 (±65.25)**		**317.05 (±65.46)**	**303.82 (±64.73)**	

[ab] Row means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fischer, 1925)
[def] Row feed means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
[gh] Row feed x treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{456}$ Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)

Table 12 Effect of prior feeding, treatment and period on the mean warm carcass mass and standard deviation (±SD)

		Period 1 (Winter)			Period 2 (Summer)		
		Feed			Feed		
		1 (High)	2 (Low)	Mean	1 (High)	2 (Low)	Mean
Treatment	1 (RSF)	70.53^{ab}_{2} (±5.63)	67.93^{bc}_{2} (±4.95)	**69.23_{5} (±5.23)**	73.17^{a}_{2} (±2.60)	64.27^{c}_{2} (±5.11)	**68.72_{5} (±6.05)**
	2 (ASF)	80.60^{ab}_{1} (±3.65)	76.15^{bc}_{1} (±5.98)	**78.37_{4} (±5.13)**	84.27^{a}_{1} (±3.14)	74.57^{c}_{1} (±7.32)	**79.42_{4} (±7.38)**
	3 (AGF)	77.63^{a}_{1} (±2.74)	73.64^{ab}_{1} (±1.92)	**75.63^{g}_{4} (±3.07)**	72.33^{b}_{2} (±3.66)	70.63^{b}_{1} (±1.59)	**71.48^{h}_{5} (±2.83)**
	Mean	**76.26^{d} (±5.86)**	**72.57^{e} (±5.50)**		**76.59^{d} (±6.34)**	**69.82^{e} (±6.58)**	

[ab] Row means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fischer, 1925)
[def] Row feed means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
[gh] Row feed x treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{456}$ Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)

Table 13 Effect of prior feeding, treatment and period on the mean cold carcass mass and standard deviation (±SD)

		Period 1 (Winter)					Period 2 (Summer)				
		Feed					Feed				
		1 (High)		2 (Low)		Mean	1 (High)		2 (Low)		Mean
Treatment	1 (RSF)	67.17$^{ab}{}_{2}$	(±5.68)	65.03$^{bc}{}_{2}$	(±4.74)	**66.10$_5$ (±5.11)**	70.10$^{a}{}_{2}$	(±2.59)	61.67$^{c}{}_{2}$	(±5.02)	**65.88$_5$ (±5.82)**
	2 (ASF)	77.27$^{ab}{}_{1}$	(±3.52)	72.70$^{bc}{}_{1}$	(±6.00)	**74.98$_4$ (±5.12)**	81.23$^{a}{}_{1}$	(±2.87)	71.57$^{c}{}_{1}$	(±7.04)	**76.40$_4$ (±7.19)**
	3 (AGF)	74.20$^{a}{}_{1}$	(±2.57)	70.31$^{ab}{}_{1}$	(±1.80)	**72.25$_4$ (2.93)**	69.73$^{ab}{}_{2}$	(±3.43)	68.03$^{b}{}_{1}$	(±1.55)	**68.89$_5$ (±2.69)**
	Mean	**72.88^{d} (±5.83)**		**69.35^{e} (±5.28)**			**73.69^{d} (±6.16)**		**67.09^{e} (±6.36)**		

^{ab}Row means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fischer, 1925)
^{def}Row feed means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
^{gh}Row feed x treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{456}$ Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)

Table 14 Effect of prior feeding, treatment and period on the mean slaughter percentage and standard deviation (±SD)

		Period 1 (Winter)					Period 2 (Summer)				
		Feed					Feed				
		1 (High)		2 (Low)		Mean	1 (High)		2 (Low)		Mean
Treatment	1 (RSF)	72.36$^{ab}{}_{2}$	(±1.84)	73.11^{ab}	(±3.26)	**72.74$_5$ (±2.55)**	73.68^{a}	(±1.45)	71.63$^{b}{}_{2}$	(±1.19)	**72.65$_5$ (±1.65)**
	2 (ASF)	74.52$^{a}{}_{1}$	(±1.29)	72.30^{b}	(±1.56)	**73.41$_{45}$ (±1.79)**	74.12^{ab}	(±1.13)	74.61$^{a}{}_{1}$	(±1.36)	**74.37$_4$ (±1.22)**
	3 (AGF)	74.92 $_{1}$	(±0.90)	73.99	(±1.22)	**74.54$_4$ (±1.13)**	74.50	(±0.43)	74.26 $_{1}$	(±0.80)	**74.38$_4$ (±0.62)**
	Mean	**73.93 (±1.75)**		**73.13 (±2.21)**			**74.10 (±1.08)**		**73.50 (±1.74)**		

^{ab}Row means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fischer, 1925)
^{def}Row feed means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
^{gh}Row feed x treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{456}$ Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)

Table 15 Effect of prior feeding, treatment and period on the mean lean meat percentage and standard deviation (±SD)

		Period 1 (Winter)					Period 2 (Summer)				
		Feed					Feed				
		1 (High)		2 (Low)		Mean	1 (High)		2 (Low)		Mean
Treatment	1 (RSF)	69.68_{1}	(±0.85)	69.88_{1}	(±0.86)	**69.78_{4} (±0.82)**	69.67	(±0.73)	69.20	(±0.59)	**69.43 (±0.67)**
	2 (ASF)	68.37^{ab}_{2}	(±1.27)	67.68^{b}_{2}	(±2.41)	**68.03_{5} (±1.81)**	68.78^{ab}	(±1.37)	68.95^{a}	(±0.82)	**68.87 (±1.08)**
	3 (AGF)	69.17_{12}	(±0.39)	69.20_{1}	(±0.56)	**69.19_{4} (±0.46)**	69.14	(±0.61)	69.46	(±0.34)	**69.30 (±0.49)**
	Mean	**69.07 (±1.02)**		**68.92 (±1.63)**			**69.19 (±0.98)**		**69.20 (±0.61)**		

^{ab}Row means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fischer, 1925)
^{def}Row feed means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
^{gh}Row feed x treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{456}$ Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)

Table 16 Effect of prior feeding, treatment and period on the mean drip loss percentage and standard deviation (±SD)

		Period 1 (Winter)					Period 2 (Summer)				
		Feed					Feed				
		1 (High)		2 (Low)		Mean	1 (High)		2 (Low)		Mean
Treatment	1 (RSF)	4.80^{a}_{1}	(±0.66)	4.26^{ab}	(±0.79)	**4.53 (±0.75)**	4.20^{b}_{1}	(±0.35)	4.05^{b}	(±0.97)	**4.12_{4} (±0.70)**
	2 (ASF)	4.14^{ab}_{2}	(±0.47)	4.55^{a}	(±0.62)	**4.34^{g} (±0.56)**	3.59^{b}_{2}	(±0.27)	4.03^{ab}	(±0.20)	**3.81^{h}_{45} (±0.32)**
	3 (AGF)	4.43^{a}_{12}	(±0.15)	4.52^{a}	(±0.18)	**4.47^{g} (±0.16)**	3.59^{b}_{2}	(±0.16)	3.70^{b}	(±0.38)	**3.64^{h}_{5} (±0.28)**
	Mean	**4.45^{d} (±0.53)**		**4.44^{d} (±0.57)**			**3.79^{e} (±0.39)**		**3.93^{e} (±0.60)**		

^{ab}Row means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{12}$ Column means with the same subscript do not differ significantly P> 0.05 (Fischer, 1925)
^{def}Row feed means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
^{gh}Row feed x treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)
$_{456}$ Column treatment means with the same superscript do not differ significantly P> 0.05 (Fischer, 1925)