Economic Optimum Nutrition of Growing Pigs

by

Chantel Pennicott

Submitted in fulfillment of the requirements for the degree

MASTER OF SCIENCE IN AGRICULTURE

in

The School of Agricultural, Earth and Environmental Sciences
College of Agriculture, Engineering and Science
University of KwaZulu-Natal
Pietermaritzburg
2022

DECLARATION

I CHANTEL PENNICOTT declare that:

(i) The research reported in this thesis, except where otherwise indicated, is my original research.

(ii) This thesis has not been submitted for any degree or examination at any other university.

(iii) This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from those persons.

(iv) This thesis does not contain other author's writing, unless specifically acknowledged as being sourced from other authors. Where other written sources have been quoted, then:

a) their words have been re-written but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced.

(v) This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections.

Signed: [redacted] Date 1 APRIL 2023

As the candidate's Supervisor I agree to the submission of this thesis.

Signed: [redacted] Date 1 April 2023

Table of Contents

Acknowledgements

I am grateful for the cooperation of Myles van Deventer, Managing Director, and WJ Steyn, Senior Nutritionist, who made the experience a most valuable and enjoyable one. I would like to thank my supervisor Prof Rob Gous for his endless time, patience and wisdom in guiding me through the entire process of learning the practicality of the EFG Pig Growth Model and Optimiser, as well as the theory of animal growth and feed intake. Both formed the basis of my pig trials and the write-up of my thesis. I am also appreciative of the financial and moral support from my family and friends; SAPPO, SASAS and Joseph Baynes Estate. I realise the privilege of having the opportunity to conduct my trials at the Baynesfield Swine Research Unit. I could not have successfully completed this postgraduate study without the above individuals and organisations.

Abstract

In two trials, a total of 504 boars and 504 gilts were used to determine the most profitable feeding strategy for the Topigs TN60 strain under current economic circumstances, using margin over feed cost as the objective function. The trials started when the pigs were 10 weeks old and were terminated after a 12-week trial period in each case. In the first trial the EFG Pig Model and Optimiser was used to assess the current feeding strategy used on the Baynesfield Estate, and to determine how the optimum strategy might change under different economic scenarios. An added objective was to evaluate the Pig Growth Model by comparing the predictions made by the model with the actual outcomes of the trial. Significant differences in gains, feed intake and carcass parameters were measured across sexes and feed treatments, and hence margin over feed cost, under the different economic scenarios applied. The Growth Model accurately predicted the optimum feeding strategy although the predicted feed intakes were marginally lower than those measured in the trial.

The response to a series of feeds differing in balanced protein was measured in the second trial, the main objective being to develop equations that would describe the response of boars and gilts of this strain to dietary protein. These equations could then be used in the future to calculate the optimum economic level of dietary protein as economic circumstances on the farm changed. The results of both the simulation exercise and the trial provided strong evidence that the optimum economic level of dietary protein differs for gilts and boars, and that this difference widens as profitability in the enterprise is reduced, either through an increase in the cost of feed ingredients or when pork prices decline. Uniformity in body and carcass weight was increased with dietary protein content. The results of both trials provide convincing evidence that gilts and boars should be reared separately, and fed different dietary protein levels, if margin over feed cost is to be maximized, and that the economic optimum feeding strategy is not static but varies with economic circumstances.

General Introduction

I have always been interested in animal production and research, specifically with pigs, as they are intelligent, robust and efficient animals. When the opportunity arose to conduct research on swine for an MSc Agric. degree under the supervision of Prof Rob Gous at the University of KwaZulu-Natal I did not hesitate. The proposed research project was to be conducted at the newly completed Baynesfield Swine Research Unit on Baynesfield Estate outside Pietermaritzburg. This is a large multifunctional farm founded by the agricultural pioneer Joseph Baynes in 1856 who introduced the bacon industry to South Africa. The farm remains the largest wean to finish piggery in KwaZulu-Natal with a breeding herd of over 2250 sows. Baynesfield Estate is committed to agricultural research and development and offers an annual bursary to a student to perform research that might improve productivity on the Estate. I was awarded this bursary in 2020 and 2021, the objective of which was to demonstrate how performance, productivity and profitability of the grower to finisher swine units on the farm might be improved with the use of simulation modelling. This gave me the chance to perform research that would not only be acceptable for postgraduate study, but that might also improve the nutrition and economics of pig production on the Baynesfield Estate as well as on other pig farms in South Africa.

To attain the objectives of improved performance, productivity and profitability, I used the EFG Pig Growth Model and Optimiser developed by Prof Gous and his colleagues to determine firstly, whether the current feeding programme at Baynesfield could be improved, and secondly, to ascertain whether the Optimiser would accurately predict how to maximise profitability under different economic circumstances. Multiple interdependent factors need to be considered within a piggery in order to maximise profitability. Feed ingredient availability and prices change, as does the market demand for pigs, and one needs an accurate means of predicting performance so that the enterprise can take account of these different economic scenarios when designing feeding strategies for growing pigs. Tables of nutrient requirements are inadequate for making such economic decisions which rely on the ability to predict feed intake, growth and changes in carcass composition as genotypes, feed composition and environmental conditions change.

Feeding to meet a fixed requirement is vastly different from feeding to meet a desired objective, such as maximising margin over feed cost or minimising feed conversion ratio. Feeding to reach a desired objective requires adaptive feeding strategies that usually change with economic circumstances making objectives dynamic and farm specific. Simulation modelling accounts for these differences, thereby improving the farm and pig industry's adaptability and profitability.

Opportunities arising from changing economics, good or bad, need to be grasped immediately to gain the largest benefit and this can only be achieved by predicting performance.

The advantage of using simulation modelling when making decisions is that performance and profitability can be predicted without having to perform a lengthy and costly trial as a means of obtaining the information necessary for decision making. The EFG Pig Growth Model (EFG Software, 2019) has been shown to predict feed intake, growth and carcass composition accurately for different genotypes, feed compositions and environmental conditions and is an extremely useful aid to understanding the concepts of nutrient requirements and responses of pigs. I spent some time learning the theory of feed intake and growth incorporated into this Model before embarking on the optimisation exercises that formed the basis of my research. Figure 1 shows how the price of pork is cyclical, meaning that it can be predicted and used in simulation models for optimising feeding strategies and pork production.

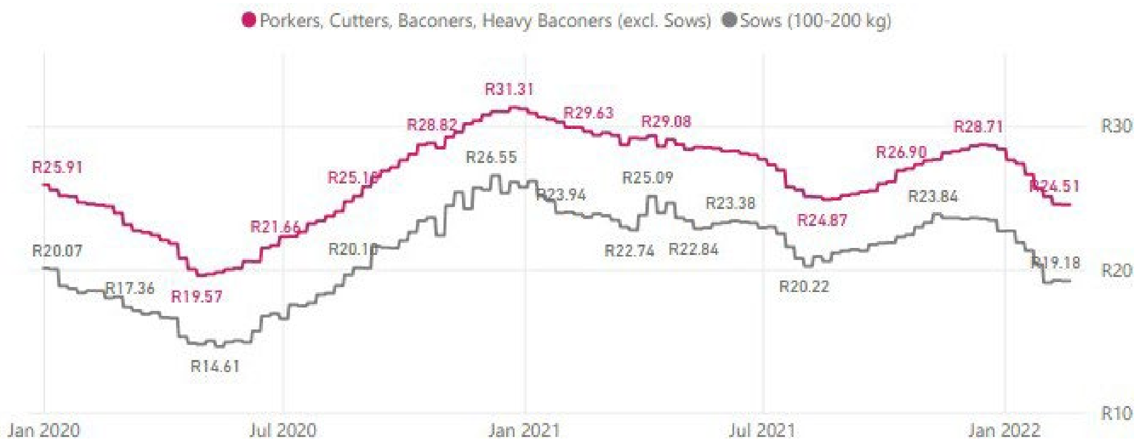

Figure 1. Weekly average abattoir purchase price in South Africa (SAPPO, 2022a)

It was both a huge challenge and a privilege to be the first student to conduct a trial at the Baynesfield SwiNE Research Unit. I learnt valuable applied pig nutrition and research knowledge as well as physical on-farm management practices. While conducting my trial, the soybean oilcake price increased by 70 % as a result of the Covid-19 pandemic influencing the supply of raw materials to the farm, shown in Figure 2. This increase was far more than I had originally anticipated, making one particular treatment more relevant to the profitability of a pig farm enterprise than anyone had imagined.

South Africa’s pork industry is small but possesses immense growth potential. Domestic pork consumption is increasing and is projected to rise by over 40 % within the next decade; second only to chicken; most of which comes from domestic production (BFAP, 2020). Although demand for pork is rising, the revenue received by the producer per kilogram of pork has not changed significantly in the last 10 years when compared to other red meat products (Figure 3). In contrast, the cost of pork production has increased significantly as a result of increases in raw material prices and hence the cost of feeding. The combination of stagnant producer prices and extremely high feed costs have strained producer profit margins. Figure 4 shows the correlation between the price of pork and the price of feed. In an intensive industry where feed costs comprise up to 75% of input costs, the ratio between input and output costs is a key factor which determines whether the enterprise will be profitable or not.

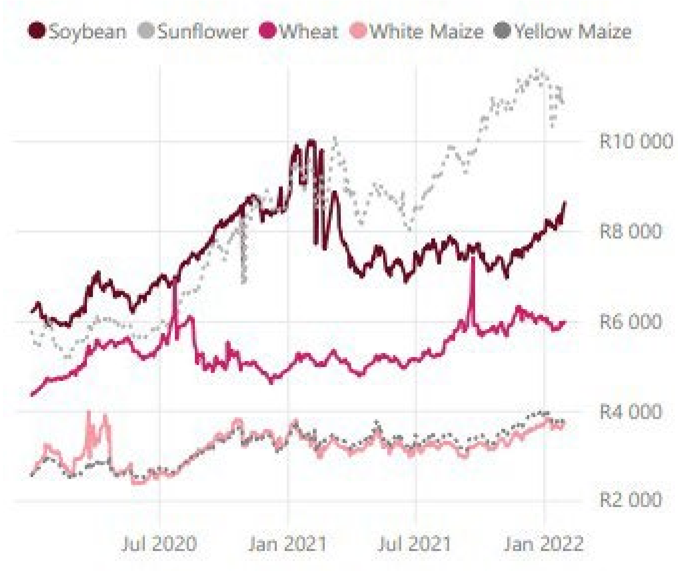

Figure 2. Monthly average SAFEX price, R/ton (SAPPO, 2022b)

It is through difficult times that innovation must prevail, reiterating the significance of simulation models which consider different economic scenarios, current and future, when creating adaptive feeding strategies to maximise margin over feed cost through economic optimum nutrition.

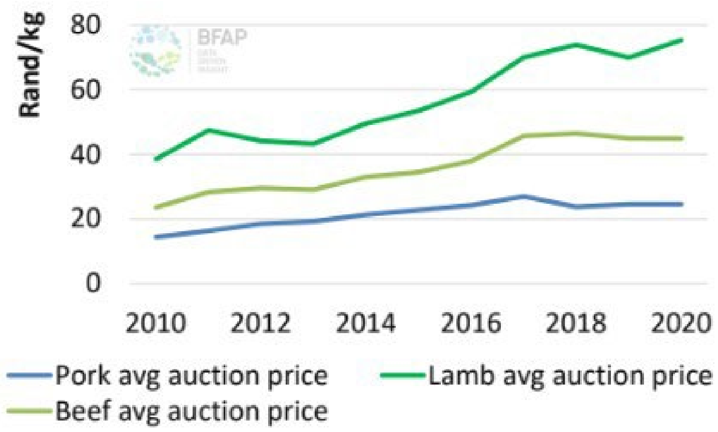

Figure 3. Relative meat prices in South Africa (BFAP, 2020)

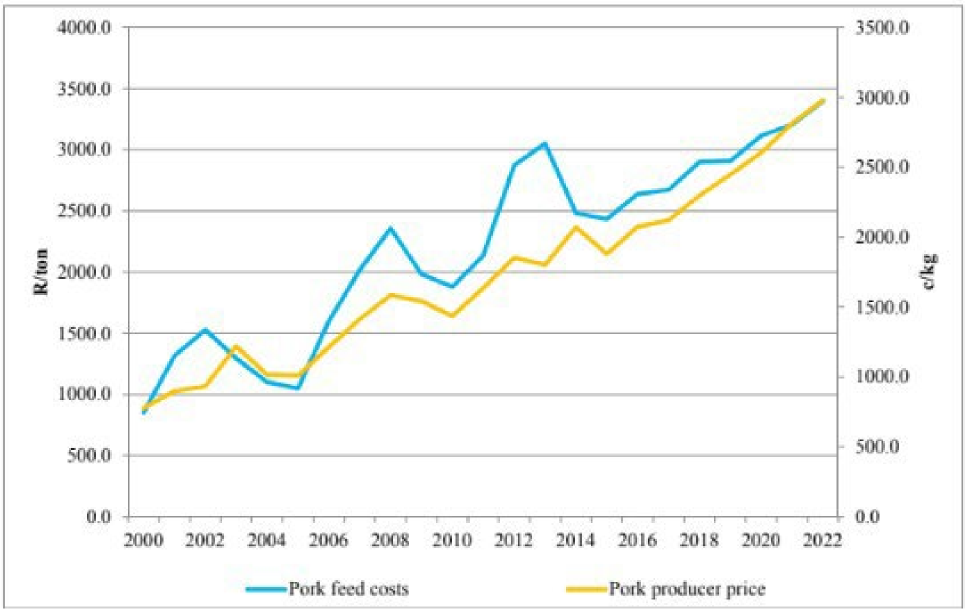

Figure 4. Pork producer price versus feed price (BFAP, 2013)

Review of Literature

Describing Animal Growth

"We can perhaps begin to see how growth, feed intake, efficiency and body composition may be connected in a way that suggests that the whole complex has to be understood before the different parts can be adequately explained" (Roberts, 1979).

Simulation models that predict the performance of a pig on a given feed and housed in a given environment are relatively recent and coincide with the advent of computers. Whereas the early pig simulation models of Whittemore and Fawcett (1976), Moughan (1987) and Black (1987) were relatively simple in that they did not predict feed intake, which instead was an input to their models, they stimulated useful and purposeful research targeted at filling the gaps in our knowledge of critical aspects of the theory incorporated into a later model produced by Emmans (1981; 1987b), this being useful in improving the scientific value of research (Gous, 2014).

Simulation modelling provides a means of predicting performance, nutrient requirements and carcass characteristics of pigs as well as the consequences of genetic selection, identification of any limiting factors and the resultant financial outcomes of different commercial feeding practices. The theory of how a pig grows and interacts with its environment is a fundamental requirement of any model when predicting pig growth and voluntary feed intake. Use was made, in this investigation, of the EFG Pig Growth Model and Optimiser, the premise on which this model is based being that the pig will always attempt to achieve its potential growth rate, defined by its genetic potential, so the amount of feed consumed is dependent on the characteristics of the pig, the feed and the environment (Emmans, 1981; 1987a). Characteristics of the feed which may have a constraining effect on performance include low nutrient density (high water holding capacity) and high heat increment, while characteristics of the pig which may prevent it from consuming sufficient feed to meet its potential requirement include gut capacity, the ability to maintain thermal-neutrality, and health status. Most commercial environments limit the capability of a pig to achieve its potential growth and as a result, the accuracy of a pig model lies in its ability to take account of these constraints in addition to needing an adequate description of the pig, its environment and health status, as well as the quantitative and qualitative characteristics of the feed. A combination of these factors provides the basis for predicting the growth response of pigs under different production scenarios, allowing the pig model to have multiple commercial applications (Gous, 2014).

The EFG Pig Model was created 30 years ago by Emmans, Ferguson and Gous; since then, the progress that has been made in predicting the performance of pigs has been revolutionary. This progress is attributed to the prediction of voluntary feed intake as opposed to using a controlled feeding approach. The theory used to predict feed intake (Emmans, 1981; 1987a) accounts for the effect of changes in dietary amino acid and energy content, environmental temperature, social stress and more. It has led to feed intake being an output rather than an input function of models, which has enabled this model to be used to optimize feeds and feeding programs, a process that would otherwise not be possible if feed intake were not accurately predicted. Many useful scientific studies have been conducted to improve the accuracy of the model (Kyriazakis & Emmans, 1992a, b; Kyriazakis & Emmans, 1997; Ferguson & Gous, 1997; Ferguson & Theeruth, 2002;) and to describe the potential growth and carcass composition of different strains of pig (Ferguson & Gous, 1993; Ferguson & Kyriazis, 2003a, b), whilst others have been designed to corroborate the theory (Ferguson, 2015). Because it is necessary to account for the heat generated by the processes of eating, moving, growing etcetera in order to determine whether this amount of heat may successfully be lost to the environment, a simplified and unified version of the net energy system was needed. The effective energy system (Emmans, 1994) was developed for this purpose. The effective or net energy value of a feed is a function of both the feed and the pig being fed, making its accurate description invaluable when describing feeds and their value to the pig itself (Gous, 2014).

Genotype

Asian-type pigs (Image 1) were domesticated for feeding on agricultural by-products, while ancient European-type pigs (Image 2) had to find feed in forests, producing a leaner and wilder type. The clearing of European forests created the incentive for improved pig management and breeding. Chinese pigs were imported to improve European varieties in the eighteenth (White, 2011) and nineteenth (Amills, 2010) century as Northern European agriculture intensified. These new breeds, with their enhanced fertility and capacity for rapid weight gain, played a vital role in the modern-day pig's transformation from a subsistence animal into the industrial meat producer it is today (White, 2011). Domestication through artificial selection is the equivalent of adaptation, only at an accelerated rate (Amills, 2010). The increasing desire for pigs with faster growth rates, better feed efficiencies and leaner carcasses in intensive commercial piggeries has led to the disappearance of the smaller, fatter Chinese-types. Consumer pressure for better quality meat products with a greater amount of intramuscular fat; known as marbling; and subcutaneous fat with better taste and texture, has resulted in the introduction of slower maturing breeds such as the Duroc, which are prized for their superior meat quality. It is now uncommon to find pure breeds of pig on commercial grow-out farms; instead, strains of pigs used today are those with greater genetic diversity that are composites of multiple breeds in variable proportions. Examples are the combinations of Large White and Landrace for their superior size and mothering ability, and the Pietrain for its superior muscling traits.

Image 1: Meishan Pigs, Wrinkled Pork Factory

Meishan pig – The oldest known Chinese pig breed

Image 2: Large White Pigs, The Essential Guide

Large White pig – The most common European pig breed

Many mathematical functions have been used to describe the potential growth of the vast genetic diversity of the modern pig through their multiple phases of production; namely: Richards, Logistic, von Bertalanffy and Gompertz (Coyne *et al*., 2015). All functions consist of at least three parameters: a starting weight, a mature weight and a rate of maturing, and all should be used only to predict the potential growth of the pig in a non-limiting environment rather than actual growth.

The Richards function (Richards, 1959) enables the inflection point, where the rate of growth (g/d) is at its

maximum, to be adjusted, while in the Logistic function (Wellock *et al*., 2004) the maximum rate of growth is at the midpoint of the normal distribution. The Gompertz function (Knap, 2000b) has a fixed inflection point at approximately one-third (0.368) of the time taken to reach maturity, making it the most applicable descriptor of potential growth in pigs (Emmans, 1981). The potential protein growth rate may be used to determine the weights and rates of growth of the chemical components of the body; lipid, water and ash; using the allometric relationships between them (Emmans & Fisher, 1986; Moughan *et al.*, 1990). When using this approach to describe a genotype, the characteristics required include the rate of maturing, the body protein weight at birth and maturity, the inherent fatness or lipid to protein ratio at maturity and the allometric coefficients which describe the relationships between body protein and these components, which are said to be constant within breeds or strains of pig (Emmans & Kyriazakis, 1995). Ferguson and Kyriazis (2003) provided evidence that the rate of maturing is similar for all chemical components of the body, namely, protein, lipid, water and ash. Therefore, the differences in mature protein size, mature composition and rate of maturing will result in differences between potential growth curves of pig genotypes under non-limiting conditions.

The allometric relationships between water and protein, and between ash and protein are maintained throughout the life of the pig, with the relative proportion of ash in the body varying little between sexes and breeds as it is a constant proportion of protein growth of approximately 0.20 (Moughan *et al.*, 1990; Ferguson & Kyriazis, 2003). This is not the case with body lipids. Whereas each animal has a potential lipid growth rate which is allometrically related to body protein, the rate of lipid deposition is dependent on the feed consumed, sometimes being greater than desired in which case the pig deposits excess lipid which is labile and may be used as an energy source when circumstances permit (Emmans, 1981; Kyriazakis & Emmans, 1992a, 1992b; 1999; Ferguson & Theeruth, 2002). For example, feeding a diet with a low protein to energy ratio will result in an overconsumption of energy and hence a higher rate of lipid deposition as excess energy cannot be used for protein synthesis due to the lack of sufficient essential amino acids (Figure. 5). A consequence of the concept of maintaining a desired level of fatness is that the pig has the ability to utilise its lipid reserves to supplement feed energy content; therefore, it is possible to obtain considerable protein deposition rates at low lipid deposition rates (Moughan *et al.*, 1987; Pomar *et al.*, 1991).

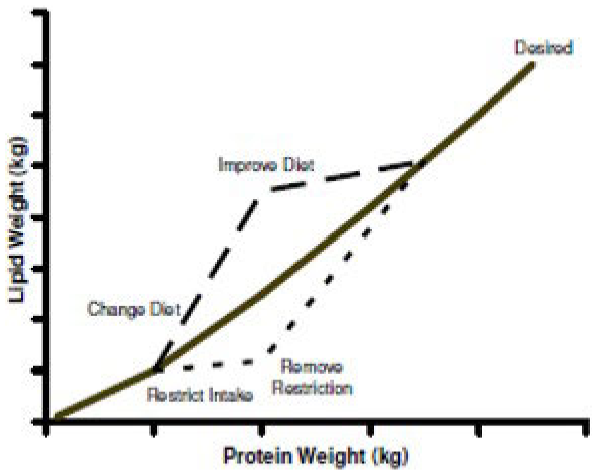

Figure 5. The compensatory responses in fat growth when animals are made either fatter or leaner than their preferred or desired level of fatness (from Emmans, 1987a)

In the absence of feed and environmental constraints, lean mass can be defined using the Gompertz function of time (Emmans, 1981). Pt = Pt' exp - exp - B(t - t') and dPt/dt = Pr* = B. Pt. *In* (Pt'/Pt) where Pt = weight of protein at time t; Pt' = weight of protein when t = infinity; t* = time at hich Pt/Pt' = 1/e; B = rate of decline of relative growth rate; Pr* = maximum protein growth rate at a given value of Pt. Lipid deposition is independent of protein deposition (Emmans, 1981).

Feed

The conventional theory that animals eat to satisfy an energy requirement (Schinckel & de Lange, 1996) has been disproved by many authors including Clark et al. (1982), Gous et al. (1987), Burnham et al. (1992) and Ferguson *et al.* (2000a, 2000b). An example of how pigs have greater rates of lipid deposition on some feeds compared to others is just one anomaly that disproves this popular theory. Emmans theory of feed intake describes desired feed intake as the quantity of feed needed to satisfy the requirement for the first limiting nutrient under non-limiting conditions, whether it be energy or an amino acid, or more specifically any essential nutrient. The theory of predicting voluntary feed intake supposes that a pig will eat for its potential growth requirements within the constraints of gut volume, health, environmental temperature (Emmans, 1981) and the pigs' ability to cope with the feed's anti-nutritional factors. Further evidence to support this theory is that animals increase their feed intake when the concentrations of essential amino acids are reduced in the feed (Clark et al., 1982; Gous et al., 1987; Burnham et al., 1992). As a result, it is necessary to identify the first limiting nutrient or energy in order to predict feed intake.

Energy is required for maintenance and growth (Emmans 1994, 1997), which can be expressed in units of metabolisable energy (ME), or more recently as net (NE) or effective energy (EE). Metabolisable energy is the potential energy available to the pig (Emmans, 1994) but does not account for the heat increment associated with the animal and feed. In order to predict feed intake, it is essential to quantify the heat increment of feed. The term NE is interchangeable with EE as NE is ME with the heat increment of feed accounted for (Armsby & Fries, 1915). EE is a concept of energy utilisation which can be applied across all species in which the heat increment of feed is linearly correlated to urinary, faecal organic matter, positive protein and lipid retention (Emmans, 1994). The energy lost from the synthesis and excretion of nitrogen in the urine during fasting as well as differences in maintenance requirements when the activity and health status of pigs change are used to calculate effective energy (Emmans, 1994 and Ferguson, 2015). According to Ferguson (2015), activity and disease can increase the energy required for maintenance by 0.15 and 0.20 respectively even though disease may reduce activity because a pigs immune response to the disease has a high protein requirement. The EE content of feed for pigs can be estimated from the constant relationship between ME and crude protein content. As a result, EE values can be tabulated for feed ingredients and are additive in complete feeds, therefore, they can be used to formulate diets using linear programming (Emmans, 1994).

The protein requirement of a pig is dependent on the amount of protein required for maintenance, on its potential protein growth rate and on the efficiency of utilization of the dietary protein (Green & Whittemore 2003, and de Lange, 2004) (Table 1).

Table 1. Profiles of the amino acid coefficients expressed as mg/g protein used for the various constituents of protein requirements (*Adapted from Green & Whittemore, 2003 and de Lange, 2004)*

	Lys	Met + Cys	Thr	Trp	Ile	Leu	P + T	His	Val
Protein Deposition	70	37	38	10	35	75	63	30	45
Maintenance Turnover	65	75	90	17	49	45	79	21	44

Protein is composed of amino acids, some of which are essential. If an amino acid is the first limiting nutrient in a feed, then desired feed intake will be based on the requirement for that amino acid as well as the concentration of that amino acid within the feed (Ferguson, 2015). Publications by Moughan (1999), Boisen *et al.* (2000), Whittemore e*t al.* (2001c), Green & Whittemore (2003) and De Lange (2004) justify the separation of protein required for maintenance into various components and include different amino acid profiles to account for protein loss as a result of protein turnover, endogenous and integument losses. The ideal protein requirement for maintenance is the sum of these components and the efficiency of protein utilization, which is estimated to be 0.95 (Ferguson, 2015).

De Lange *et al.* (2001; 2004) suggested that it is not appropriate to relate the requirements of amino acids to lysine, as maintenance losses are high in methionine, cysteine, threonine and tryptophan (Boisen e*t al.*, 2000) which must be increased as the maintenance requirements of a pig increases with age. The ideal protein requirement for growth is dependent on both potential protein deposition rate and the efficiency of protein utilization, which is estimated to be 0.85 (Ferguson and Gous, 1997; Green & Whittemore, 2003) and is constant across sexes, breeds and amino acids (Kyriazakis *et al.*, 1992b). Similarly, the desired feed intake to reach a desired level of fatness is dependent on, firstly, the amount of energy required for maintenance, then growth, and the available energy content of the feed.

The interaction between gut capacity of the pig and bulk density of the diet may result in constrained feed intake, which is more common in younger pigs due to their smaller size and resultant gut capacities. Tsaras *et al.* (1998) proposed the concept of a bulk constraint, which is a far more rational approach than imposing a fixed maximum intake limit based solely on the size of the pig. Attempts at measuring the bulkiness of a feed include the use of dry matter (Lehmann, 1941; Whittemore 1983), neutral detergent fibre (Van Soest, 1963) and indigestible organic matter (Roan, 1991 and Whittemore, 2001a; 2003) whilst in some cases bulkiness is ignored altogether (ARC, 1981). These attempts have been shown to be inaccurate because feeds differ in their 'filling effect' with undigested organic matter having different bulk equivalents (Kyriazakis & Emmans, 1995). For example, Brouns *et al.* (1991) found that voluntary feed intake by sows was lower with sugar-beet pulp-based feed compared to more indigestible raw materials such as straw or rice bran. Kyriazakis & Emmans (1995) set out to identify the property of bulky feeds responsible for limiting feed intake in pigs, describe how bulk capacity varies with live weight of pigs and verify if the capacity for bulky feed can be influenced by an adaptation period. They found that digestible energy content, organic matter digestibility and density were negatively correlated with feed bulkiness while the fibre content and water holding capacity (WHC) were positively correlated. They demonstrated that intake initially increased and then declined as the proportion of wheat bran in a feed was increased due to the ability of pigs to accommodate more bulky feed with an increase in body size with age until a critical point known as 'capacity' (Owen & Ridgman, 1967) was reached. Initially, feed intakes were directly proportional to live weight and so scaled intakes expressed as g/kg live weight/day could be used. Kyriazakis & Emmans (1995) showed that feed intake began to decrease with an increase in the inclusion rate of wheat bran and that feed intake was directly proportional to the reciprocal of the WHC of the feeds; as a result, both daily live weight gains and feed efficiency decreased significantly. The WHC of feed describes the ability of non-starch polysaccharides to trap water, swell and form gels (Eastwood, 1973). Kyriazakis & Emmans (1995) concluded that the WHC of a feed is an appropriate measurement of bulk and can be used to predict the maximum feed intake capacity of pigs as it does not consider differences in digestibility alone. However, the length of the adaptation period to bulky feeds needs to be considered when predicting feed intakes as intakes of the bulkiest feeds were greater when preceded with an intermediately bulky feed.

In order to determine desired feed intake in a thermo-neutral environment, one would need to determine the larger of the intakes to satisfy energy and ideal protein requirements. The actual daily feed intake would be the lesser of desired and constrained feed intakes. If the desired feed intake to satisfy both maintenance energy and protein requirements are equal, then the diet is balanced (Ferguson, 2000a; b).

There are multiple consequences of the amount of feed consumed on protein and lipid growth. When energy is the first limiting nutrient in a feed the pig will consume a sufficient quantity to meet its energy requirement which will satisfy both its potential protein deposition rate and desired lipid deposition rate, provided that the environment is not limiting. When an amino acid is the first limiting nutrient, the pig will consume sufficient to meet its protein requirement but the excess energy above that required for maintenance and production will result in a fatter pig than that defined by its potential (Ferguson & Theeruth, 2002). Kyriazakis & Emmans (1991), de Greef (1992), Tsaras *et al.* (1998) and Ferguson & Theeruth (2002) found that young pigs that were fatter than desired, due to being fed a low protein diet, deposited fat at a much slower rate when fed a high protein diet compared to pigs who were leaner. The implication is that pigs will adjust their feed intake to maintain their potential protein deposition rate at the expense of lipid deposition, with a minimum lipid:protein of 0.1 (Wellock *et al.*, 2003a). When gut capacity is limiting, as is common in younger pigs, or when feed nutrient density is low, then intake will be lower than desired. If dietary protein content is high but energy is limiting, the pig may be able to consume sufficient protein to sustain potential protein deposition but not desired lipid deposition rates. If protein is also limiting then potential protein deposition rates are not reached as dietary protein is prioritised for maintenance before growth. Energy that would otherwise be used for protein synthesis would be deposited as fat at a higher or lower rate than desired (Ferguson, 2002).

Environment

Physical Environment

The interaction between the pig, its feed and the environment in which it is kept must be understood in order to predict voluntary feed intake. When predicting feed intake, daily heat production by the pig must be compared with the maximum and minimum daily limits to heat loss which vary with environmental temperature and humidity. If desired heat loss remains within these bounds, feed intake and body composition will not be constrained (Ferguson, 2008) but if this is greater than is possible under the given conditions, feed intake will need to be reduced below the desired. In contrast, if desired heat loss is less than the minimum permissible, particularly in cold conditions, feed intake will need to be increased to account for the energy required for thermogenesis (Figure 6). Besides the ambient temperature there are multiple factors that influence the rate of heat loss; namely, ventilation rate, relative humidity, floor type and house insulation (Whittemore, 1983). Therefore, the ambient temperature needs to be adjusted to a more accurate measurement of the temperature actually felt by the pig, known as effective temperature (Emmans, 1990).

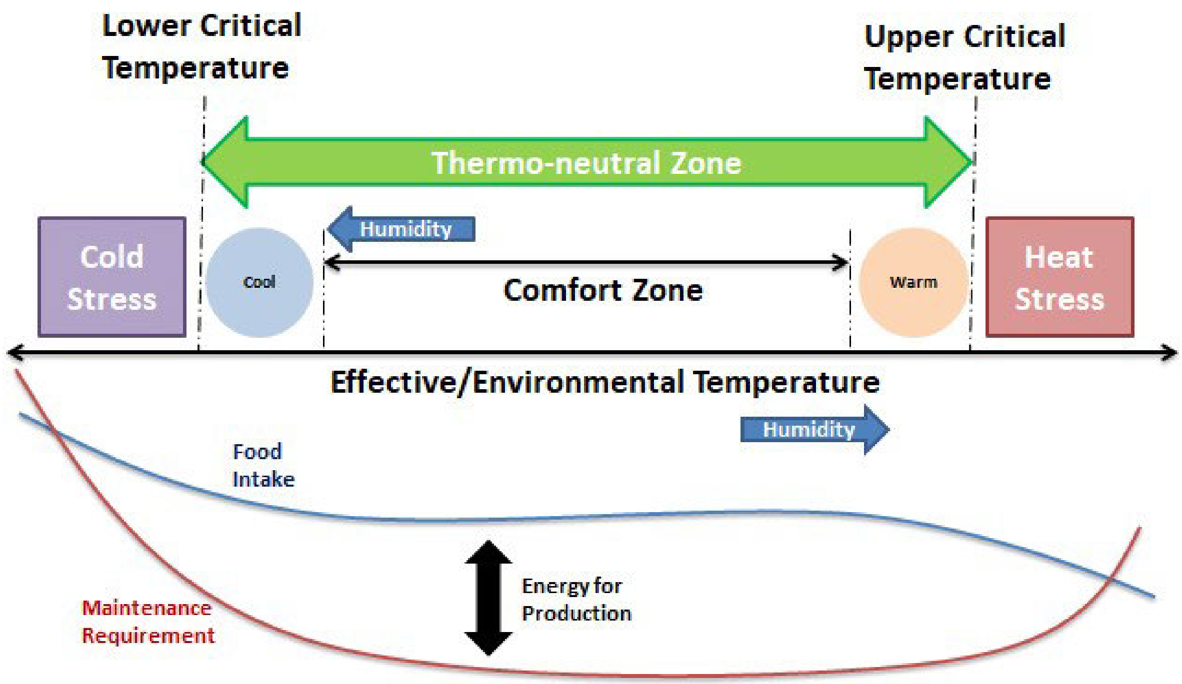

Figure 6. The relationship between desired feed intake, maintenance requirements, humidity, temperature and thermal stress (Adapted from Emmans, 1990 and NRC, 1981).

Total heat loss is the sum of evaporative and sensible heat loss. Minimum and maximum evaporative heat losses are constant for a given live weight at low temperatures, but maximum evaporative heat loss increases at higher temperatures due to the wetting of the pig's skin (Black *et al.*, 1986; 1999; Knap, 2000a).

The maximum and minimum sensible heat loss of a pig is altered by behavioural and physiological changes such as huddling, vasodilation and vasoconstriction. Sensible heat loss dominates under cold conditions and diminishes at a constant rate until it reaches zero at the body temperature of the animal. The amount of heat lost is dependent on the difference in temperature between the pig and its immediate surroundings as well as the surface area of the pig itself (Mount, 1975).

Social environment

The social environment under commercial conditions is significant as there are multiple contributing factors such as disease challenges, air quality, feeder space and stocking density which have an effect on pig performance (Kornegay & Notter, 1984; Hyun *et al.*, 1998; Black *et al.*, 1999;

Morgan e*t al.*, 1999; Knap, 2000a). Findings from Chapple (1993), Baker & Johnson (1999), Morgan *et al.* (1999), Matteri *et al.* (2000) and Ferguson *et al.* (2001) suggest that stress associated with high stocking density reduces protein growth irrespective of feed intake as protein deposition is reduced through a lower rate of maturing. Disease affects growth performance and feed intake (Baker & Johnson, 1999; Greiner *et al.*, 2000; Escobar *et al.*, 2002) even if pigs show no signs of clinical disease as subclinical disease increases maintenance protein and energy requirements, and reduces nutrient digestibility, activity, protein deposition and feed intake (Black *et al.*, 1999; Knap, 2000a). Black *et al.* (1999) and Knap (2000a) indicated that the possible effect of disease on growth under commercial conditions was an increase of 18 days to slaughter when pigs had poor health status. The EFG model accounts for this by increasing the time it takes to reach mature protein weight when disease challenge is increased. This is done using health coefficients which have effects on the rate of maturing and therefore protein and lipid deposition rates as well as feed intake. Although simplistic, this approach has improved the accuracy of predictions under commercial conditions (Ferguson, 2008).

Economics and Optimisation

According to Visser (2006), the agricultural product market has shifted from a producer dominated market to an educated consumer dominated market that demands higher quality, healthy, affordable, and ethically produced agricultural products. Pork consumption in South Africa is 5.0 kg per capita (Table 3), which is small in comparison to the EU or the USA where the per capita consumption is 32.5 kg and 23.6 kg respectively (USDA, 2017) making pork the most widely consumed meat product around the world (Dugan *et al*., 2015; OECD, 2018). Although the per capita consumption of pork in South Africa is small, it has increased by 13.6 % since 2010 (USDA, 2017). Pork production systems have undergone intensification (Robinson, 2014) and progressed from the field to specially designed buildings, allowing for an increase in pork production and efficiency in order to keep up with the increase in demand (McGlone, 2013). The increase in pork production can also be attributed to genetic improvement for better feed efficiency and growth parameters, artificial insemination and improved sustainable production practices, which are vital for world food security (FAO, 2009). There are variations in the demand for specific pork products which increase the total carcass value and further increase the importance of international trade. South Africa is vulnerable to changes in the global pork market as it contributes less than 0.2 % to the total pork produced worldwide and is a net importer of pork in order to match the increase in demand (BFAP, 2013; 2014). South Africa usually follows a farrow to finish system, allowing piglets to be acquired at cost price; furthermore, most farmers mix their own rations thereby reducing feed costs and allowing for farm-specific requirements to be met, both of which reduce production costs. This differs from the EU, where piglet production and the finishing operations are not undertaken by the same producer, allowing for specialization but increasing production costs (BFAP, 2014).

Advances in housing, genetics and feeding are essential for maintaining the competitiveness of modern-day pork production (Robinson, 2014). Housing has not only become intensified, but also more sophisticated through optimising space, temperature, ventilation, feed, health, hygiene and welfare. Genetic improvement has increased the potential of the modern-day pig, but not necessarily its performance, as a pig cannot perform to its potential unless it is housed, fed and managed optimally (Robinson, 2014). Feed makes up 70 % of the total costs of production (Gordjin, 2014) which makes feed most vulnerable to budget cuts. According to Robinson (2014), it is never favourable for a productive intensive piggery to reduce its feed budget as this leads to pigs failing to grow because they are not fed optimally and there are insufficient funds for better feed. Robinson (2014) recommends selling part of the herd in difficult times to purchase better feed for the remainder. Pig welfare is becoming an increasingly important aspect of pork production due to growing consumer awareness and the resultant increase in demand for it. The Five Freedoms (Webster, 2016) are used as a benchmark to measure the acceptability of the farming system which states that pigs should not be subjected to starvation, thirst, physical abuse, disease, overcrowding or pain and should have the ability to express natural and social behaviour (Robinson, 2014). A farmer should arrive at an acceptable system which will satisfy the needs of the pigs but also allow them the freedom to express natural and social behaviour as these aspects of production can often be opposing. For example, for pigs to be fed optimally in a clean and temperature-controlled environment, they need to be housed inside in smaller groups on concrete slatted floors. Modern pigs are vastly different from their wild counterparts in terms of size, dietary requirements and behaviour; as a result, they cannot be treated as equals (Robinson, 2014). It is important to note that no animal will perform to its potential if it is not treated optimally, making welfare one of the most important aspects of economic success on farms (Moberg, 2000).

Unlike poultry, revenue received is not only based on cold carcass weight, but also on carcass grading. Carcass classification systems are constantly being developed and updated together with the change in carcass compositions in order to ensure the fair trading of pork products as well as achieving efficient animal production and meat price determination (Myburgh, 2019). The PORCUS system is a standard system used throughout South Africa (Table 2) where six categories exist and are given to carcasses based on their lean meat contents and backfat thickness (Hugo & Roodt, 2015) using a calibrated Intrascope or Hennessy probe placed between the second and third-last rib of a warm carcass. According to Bruwer (1992), the Hennessy probe estimates carcass lean percentage by measuring backfat and eye muscle thickness, while the intrascope estimates carcass lean percentage using the formula: % Lean = 74.4367 – (0.4023 x fat thickness). New-age methods of analysis such as computerized tomography, nuclear magnetic resonance, electrical conductivity and ultrasound are more accurate and less invasive (Busk *et al.*, 1999); however, these are not widely utilized in South Africa and will not be discussed further. Additional classifications which influence revenue include carcass conformation, damage and sex.

Table 2. Carcass classification system used in South Africa *(Adapted from SAMIC, 2006)*

Classification Characteristics of Pork		
Class	% Lean meat	Fat thickness, mm
P	≥ 70.0	≤ 12.9
O	68.0 - 69.9	13.0 - 17.9
R	66.0 - 67.9	18.0 - 22.9
C	64.0 - 65.9	23.0 - 27.9
U	62.0 - 63.9	28.0 - 31.9
S	≤ 61.0	≥ 32.0

Although the classification system is standardized across the country, the payment method between the processor and producer is not; instead, it is based on a contractual agreement between them. As a result, the desired cold carcass weight and lean meat content may differ for producers in different areas, thus it is not simply based on consumer preference. The general trend currently is that producers receive the highest revenue for leaner carcasses. Larger and older pigs tend to have lower lean percentages but higher lean mass; therefore, a balance between carcass leanness and weight must be achieved in order to maximise profit per pig. There is a contrast between the quality of the fat preferred by the processor and that desired by the consumer due to perceived health reasons (Myburgh, 2019). Genetic selection for leaner carcasses has resulted in an increase in the proportion of unsaturated fatty acids which has a negative effect on fat texture and taste as well as meat processing and storage (Affentranger *et al*., 1996). These negative effects can be efficiently and effectively omitted by feeding the type of fatty acid that is desired in the end product (Sosnicki *et al.,* 2010) as pigs are monogastric; therefore, their body fat composition will match that of their feed.

The profitability of a pig enterprise is dependent on many factors including the feed price, meat price and management. Comprehensive financial and production records are required in order to determine the financial status and progress of the enterprise, trends in the market for raw ingredient prices, consumer demand and pig performance as well as identify new objectives – vital for optimisation (Gordjin, 2014). According to Gordjin (2014), variable costs are among the most crucial factors influencing the cost of pork production, with feed cost making up 70-80 % of these costs. As a result, farmers can improve cost effectiveness by mixing their own feed using high quality raw materials to improve feed efficiency. Feed efficiency can be estimated from the cost per kg feed, cost of gain, time taken to reach slaughter weight and carcass quality (Gordjin, 2014).

Table 3. Meat Consumption in South Africa, kg/capita *(Adapted from USDA, 2017)*

Year	Beef	Poultry	Pork	Mutton
2010	17.8	38.4	4.4	3.5
2011	17.6	39.9	4.6	3.1
2012	16.7	39.4	4.6	3.0
2013	17.4	39.4	4.7	3.3
2014	18.5	38.6	4.5	3.6
2015	19.5	39.6	4.7	3.5
2016	20.9	40.0	4.8	3.6
2017	21.3	41.2	5.0	3.7
% Increase	19.7	7.3	13.6	5.7

Factors which reduce feed efficiency include feed wastage and mortality, especially during the finishing phase of production, as feed intake is greatest during this phase. The profitability of the entire unit is dependent on the growing and finishing phase as this is the endpoint of production where income is derived (Gordjin, 2014). The success of these two phases of production is determined by feed efficiency, growth rate, carcass quality and market demand. However, an attempt to improve one may result in the deterioration of one or more of the others. For example, an increase in growth rate reduces the cost of housing, labour and other fixed costs as economics is time and space dependent. But an increase in growth rate may, but not necessarily, lead to excessive fat deposition which is expensive in terms of energy and feed as well as leads to poor carcass classification (Gordjin, 2014).

It is thought that pork prices are cyclical, but the peaks and troughs may be a few months to years apart (Gordjin, 2014) as many external factors such as disease outbreaks and consumers influence the supply and demand. It is therefore vital to analyse all aspects of pork production in order to make informative decisions, which can be done through optimization.

Optimization is a process that maximizes or minimizes an objective function. Such functions may be measures of productivity, for example, average daily gain (ADG), carcass lean yield, P2 measurement, feed conversion ratio (FCR), nitrogen excretion, amongst others, where no account is taken of economic factors. Alternatively, the objectives of the business should be considered by taking account of costs and returns; maximizing margin over feed cost or margin per m^2 per annum would be more appropriate objectives (Gous, 2014). By combining a feed formulation program, a model that simulates pig performance and an optimization routine, it is possible to achieve such an objective. The optimization process involves starting with a given feed composition which is then passed to the simulation model where the objective is evaluated, passed to the optimizer, which alters the feed composition appropriately, before repeating the process. This process continues until the combination of circumstances which maximize or minimize the objective function is achieved. The feeds are formulated on a least cost basis to allow for a practical approach to be undertaken.

To be economically relevant, objective functions should include costs, revenue, space and time, making margin/m^2 per annum or margin over feed cost the most applicable objectives in commercial pork production systems. These objectives account for fixed and variable costs as well as the income derived from the sale of product, giving an indication of the overall success of the pig enterprise. Fixed costs have increased significantly due to rising electricity and labour costs (Gordjin, 2014) as well as the considerably improved housing systems that have been constructed in piggeries in South Africa recently, therefore a greater throughput is particularly important and can be achieved by reducing the age at slaughter. Such objective functions are more sensible than attempting to minimize FCR, for example, which would be achieved with the use of highly digestible and nutrient dense feed, resulting in higher feed costs, despite the reduction in feed intakes, and hence lower margins.

Three practical and commercially applicable optimization routines are incorporated into the EFG Pig Optimizer, based on the premise that the optimum ratios between the essential amino acids and energy change during the growing period (Emmans, 1999). These routines are to determine the optimum amino acid to energy ratio in each feed in a given feeding programme; to optimize the nutrient density of the feeds; and to optimize the length of time or amount that each given feed should be fed (Gous, 2014). Both nutritional and economic decisions need to be made when optimizing feeds and feeding programmes. The information required for optimization consists of feed costs, a description of the pig's genotype as discussed above, both fixed and variable costs affecting the production system, and details of revenue such as price per kilogram of pork and carcass grading. It is important to note that the performance on one feed impacts ~~on~~ the performance on subsequent feeds; as a result, the optimum feed composition cannot be determined independently for each phase (Gous, 2014) but must be based on the entire growing period.

Optimising the feeding schedule (Table 7) is valuable to pig producers who do not mix their own feeds or wish to reduce the number of feeds that they are currently mixing. There are a multitude of options when designing a feeding schedule, as the length of each period may be based on an amount to be fed in each period, a desired starting and finishing live weight, or on fixed ages for each feed. The optimum feeding schedule is dependent on the composition of the feeds, their respective prices, the amount of feed each pig will consume during the period and the revenue to be derived from the sale of the product (Gous, 2014).

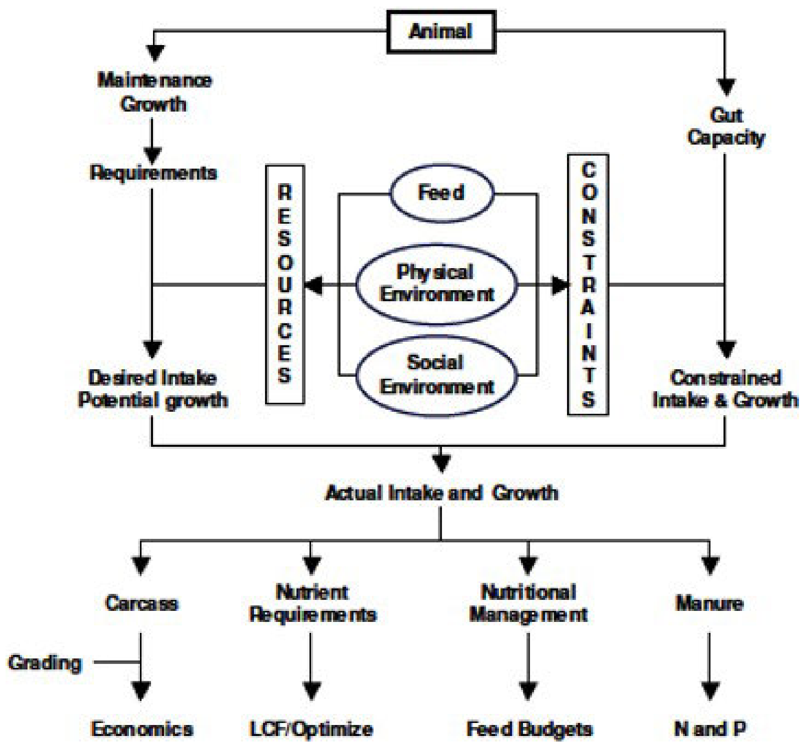

Figure 7. Framework of the processes involved in modelling growth and feed intake and the subsequent commercial application (after Emmans & Oldham, 1988)

Chapter 1: Determining the optimum economic amino acid contents in feeds for growing pigs[1]

Introduction

The theory used to predict feed intake (Emmans, 1981; 1987a) accounts for the effect of changes in dietary amino acid and energy content, environmental temperature, social stress and more. It has led to feed intake being an output rather than an input function of models, which has enabled the EFG model to be used to optimise feeds and feeding programs, a process that would otherwise not be possible if feed intake were not accurately predicted.

Economic optimum nutrition is a term used to describe the balance between the biological optimum of the growing pig and the economic optimum of the farmer. This requires an adaptive and dynamic feeding strategy that continuously changes with genetic improvement and current economic conditions. Factors which determine the most profitable feeding strategy include farm- specific objectives, raw ingredient prices and their availability, price of pork and payment grid, the growth potential of the genotype, and grading, as well as the social and physical environment on the farm experienced by the pigs.

In order to attain the objectives of improved performance, productivity and profitability, one can use the EFG Pig Model and Optimiser to assess whether the current feeding strategies on farm could be improved. An important factor contributing to the success of model predictions is model evaluation through field trials. This formed the basis of one the trials – being able to accurately describe the pigs genotype by its ability to grow, desire to consume feed and to do this in the physical and social environment experienced by the pig. One of the most beneficial economic objectives of a farming enterprise is to maximise margin over feed cost (MOFC), which is the difference between the revenue and cost of feeding. Margin over feed cost takes account of the pig, the feed and market effects by including carcass weight and grading, feed intake and cost of raw materials, as well as the price of pork and payment grid.

It is important to note that optimum is not synonymous with maximum, as maximum growth may be costly in terms of nutrient density and its effect on feed price as well as feed intake. A more nutrient dense feed may improve feed efficiency, but the cost of this efficient feed may not be offset by the improvement in growth. This vital point, which has been reiterated by multiple authors (Emmans and Fisher, 1986; Gous, 2014), is due to the fact that pigs do not consume all feeds at a constant rate; instead, the amount of feed consumed depends on the level of the first limiting nutrient or energy in the feed. As a result, pigs will consume more of a low density or low protein feed which may be less-expensive per kilogram, but the cost of feeding may be higher than that on a high nutrient-dense feed; or the performance may be substantially less thereby reducing revenue.

The significance of simulation models that predict feed intake, growth and body composition, is that they are capable of accurately and rapidly determining the optimum economic level of amino acids and energy to be used in each of the feeds in a phase-feeding program, as well as the optimum length of time to feed each of the feeds during the growing period. The alternative is to conduct experiments, but these are time-consuming and would need to be repeated for different genotypes and environments. Furthermore, models can identify factors that constrain growth, which may be environmental (heat, space, disease) or feed specific (a limiting essential amino acid or bulk density). The optimisation process can then be used to mitigate these constraining factors by altering the feed or feeding schedule. These are time-sensitive factors which contribute to overall farm profitability and allow farmers to remain competitive in a dynamic market by allowing them to be proactive in their decision-making process, which is not possible with tables of nutrient requirements alone.

Feeding to meet a fixed requirement is quite different from feeding to meet a desired objective, such as maximising margin over feed cost or minimising feed conversion ratio. Feeding to reach a desired objective requires adaptive feeding strategies that usually change with economic circumstances making objectives dynamic and farm specific. Simulation modelling accounts for these differences, thereby improving the farm and pig industry's adaptability and profitability. Opportunities arising from changing economics, good or bad, need to be grasped immediately in order to gain the largest benefit and this can only be achieved by predicting performance.

In the trial reported here, the EFG Pig Growth Model was used as the basis for making decisions about the biological and economic levels of amino acids and energy to use when feeding growing pigs. The commercial feeds and feeding program used on the farm were the basis for comparisons; a treatment was designed to evaluate the biological levels of amino acids in these feeds. Two further treatments addressed hypothetical scenarios with a view to improving the profitability of the enterprise were such economic circumstances to arise in the future.

Materials and Methods

The study was performed in accordance with the Animal Research Ethics Committee of the University of KwaZulu-Natal, School of Agricultural, Earth and Environmental Sciences (Protocol reference number: AREC/001/020M, approved 13 October 2020).

Pigs and management

Two-hundred-and- forty Topigs TN60 boars and 240 Topigs TN60 gilts aged 10 weeks were placed in an open-sided house consisting of 48 pens, with 10 pigs in each pen. The pens were 11 m^2 in size, with two water nipples and a manual feeder in each, arranged in three blocks (rows) with 16 pens per block (row). Boars and gilts were housed in alternate pens. Each pig was ear tagged and weighed on exiting the delivery vehicle and then randomly allocated to a pen. Pen weights were then balanced within the same sex to be within 0.05 SD of each other. A desired temperature range of 20-24°C was maintained using manual blinds, and ventilation was controlled similarly. Natural lighting was used throughout the trial.

All pigs were weighed individually on a weekly basis. The daily amount of feed allocated to each pen was recorded automatically (see below) and feed remaining in each feeder was weighed back at the end of each week. Each pen had a recording sheet for any sick or injured pigs, as well as their respective medical treatments. The trial period lasted for 12 weeks when the pigs were 22 weeks of age, after which they were transported to a commercial abattoir where carcasses were evaluated.

Treatments and feeds

When using the EFG Pig Growth Model for designing the feed treatments used in this trial, the following description of the genotypes for boars and gilts was used, assuming that these values reflected the Topigs TN60 genotype:

	Boars	Gilts
Mature body protein weight (kg)	45.0	37.5
Rate of maturing (/d)	0.0125	0.0136
Lipid : protein ratio at maturity	1.3	1.7

Four feed treatments were used in the trial, with each treatment consisting of four phases lasting three, two, three and four weeks, respectively. The final phase in all treatments contained Paylean®. The treatments are described as follows:

Feed treatment 1, the control, was the commercial grower feeding schedule used on Baynesfield Estate in 2020.

The four phases for feed treatment 2 were formulated at least cost to achieve an ideal amino acid to energy ratio within each phase, but without taking account of anticipated revenue.

Feed treatment 3 was formulated to achieve the greatest margin over feed cost when the cost of all protein-containing ingredients was 25 % above the current protein prices.

Feed treatment 4 was formulated to achieve the greatest margin over feed cost assuming the price of pork would increase by 25 % above the current price.

The composition of the feeds used, together with their respective specifications, are given in Tables 1.1 to 1.5. All feeds were mixed in the Baynesfield Estate feed mill.

Feeding

After mixing, each phase of feed was stored in one of four bulk tanks outside the research facility. An auger enabled the feed from each bulk tank to be accessed inside the facility, the feed being manually weighed into respective colour-coded 25 kg bags, with the weight being recorded automatically and printed on a label. Each pen was colour-coded to minimise the risk of errors being made when allocating feed to pens.

Feeders in all pens were kept filled with feed by adding feed either once or twice daily. The label on the bag used, which recorded the weight of the bag, was removed and pinned to a secure fastener on the pen, and these additions were subsequently recorded daily on feed sheets. Feed allocated during the week, and that remaining at the end of each week, was used to calculate feed intake.

Calculations

Average daily gain (g/pig d) was calculated as the difference between the mean pen weight at the beginning and end of each week divided by the mean number of pigs in each respective pen and the number of days between weighing. Feed intake (g/pig d) was calculated by subtracting the weight of feed remaining in the feeder at the end of the week from the amount fed during that week, divided by the mean number of pigs in the pen and the number of days between weighing. Feed conversion efficiency (FCE, g gain/kg feed) was calculated by dividing average daily gain (including mortalities and culls) by mean feed intake for each pen.

Carcass processing and analyses

All pigs aged 22 weeks and averaging 120 kg live weight were transported 34 km in the Baynesfield pig truck to Frey's Cato Ridge abattoir where they were routinely slaughtered. Individual warm carcass weights were recorded together with their lean percentage using the calibrated Hennessey probe and standardised PORCUS classification system. Individual cold carcass weights were calculated by subtracting a standard 3 % from the warm carcass weights. The abattoir recording system calculated the lean meat percentage from the Hennessy probe using the following regression model, developed by Bruwer in 1992:

Lean meat % = 72.5114 – 0.46118 $X1$ + 0.0547 $X2$

Where: X_1 *= fat thickness between the* 2^{nd} *and* 3^{rd} *last rib, 45 mm from the carcass midline and* X_2 *= muscle thickness at the same position.*

Bruwer's equation can be used for pigs with carcasses from 20 to 100 kg, above which a penalty fee is added. Once the lean meat percentage is calculated, a defined class can be assigned to the carcass using the standardised carcass classification system, developed by The Society for Automation, Instrumentation, Mechatronics and Control – SAMIC (2006). This classification system, described in Table 2 of the Literature Review above, is used to determine the payment method between the producer and the abattoir.

Statistical analyses

All data were initially entered into an Excel spreadsheet and then imported into Genstat (VSN International, 2017) for statistical analysis. Because the objective of this experiment was to compare three alternative feeding strategies with the current system, two-way comparisons were made between treatments, but for general interest the main effects (feed treatment and sex) and two-way interactions over all four treatments were identified by means of factorial analysis using ANOVA, and treatment means were calculated.

Two-way comparisons, using F-probability, between treatments 1 and 2, 1 and 3 and 1 and 4 were made by restricting the results of each of the pairs of treatments in Genstat and then analysing these by ANOVA, as above.

Table 1.1. Ingredient composition (g/kg) of the feeds used in the four phases within each treatment

Ingredient	Control				Treatment 2				Treatment 3				Treatment 4			
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 1	Phase 2	Phase 3	Phase 4	Phase 1	Phase 2	Phase 3	Phase 4	Phase 1	Phase 2	Phase 3	Phase 4
Maize	700	688	683	708	626	680	697	672	551	595	591	567	580	665	704	676
Wheat bran	67.1	95.4	117	60.6	104	97.1	112	111	188	194	233	233	20.0	20.0	20.0	20.0
Soybean 46	142	122	111	142	200	185	158	183	194	140	105	129	161	92.4	77.3	105
Soybean full fat					29.8								200	185	163	164
Sunflower 37	51.6	62.0	62.0	51.7					30.0	35.0	40.0	40.0				
L-lysine	6.55	5.05	3.41	5.12	6.57	5.77	5.27	5.77	6.14	5.85	5.38	5.85	5.19	5.58	5.10	5.60
DL methionine	2.89	2.00	1.14	2.27	1.95	1.58	1.37	1.57	1.82	1.57	1.35	1.57	1.91	2.01	1.70	2.00
L-threonine	2.01	1.28	0.63	1.39	2.10	1.96	1.85	1.96	1.80	1.88	1.76	1.86	1.62	1.97	1.85	2.00
Valine					0.21	0.24		0.23	0.01	0.13	0.07	0.09	0.05	0.29	0.22	0.30
Tryptophan	0.76	0.49	0.21	0.38	0.46	0.14	0.21	0.13						0.27	0.23	0.30
Premix	1.62	1.60	1.60	1.60	1.50	1.50	1.50	1.50	1.43	1.43	1.42	1.42	1.50	1.50	1.50	1.50
Limestone	12.8	11.9	11.0	9.30	15.4	14.8	13.3	12.7	15.6	15.5	14.1	13.6	13.7	13.8	12.2	11.6
Salt	4.62	4.23	4.06	3.77	5.28	4.82	4.68	4.33	5.30	4.68	4.50	4.15	5.69	4.88	4.75	4.40
MDCP	4.56	3.36	2.73	2.96	6.49	6.68	6.00	5.17	5.47	4.60	3.40	2.56	8.87	8.17	7.81	7.00
Total	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

Table 1.2. Calculated nutrient composition of feeds (%) used in four phases of Treatment 1 (Control)

Nutrient	Phase 1			Phase 2			Phase 3			Phase 4		
	Total	Digestible	AA/Lys	Total	Digestible	AA/Lys	Total	Digestible	AA/Lys	Total	Digestible	AA/Lys
ME (pig) (MJ/kg)	13.002			12.924			12.917			13.188		
DE (pig) (MJ/kg)	13.595			13.479			13.471			13.726		
EE (pig) (MJ/kg)	11.587			11.475			11.446			11.644		
Crude protein	16.000			15.500			15.000			16.000		
Lysine	1.229	1.100	1.000	1.083	0.950	1.000	0.933	0.800	1.000	1.142	1.000	1.000
Methionine	0.610	0.526	0.478	0.493	0.436	0.459	0.470	0.348	0.435	0.503	0.467	0.467
Methionine + Cystine	0.858	0.660	0.600	0.840	0.570	0.600	0.820	0.480	0.600	0.853	0.600	0.600
Threonine	0.727	0.680	0.618	0.735	0.589	0.620	0.768	0.520	0.650	0.750	0.630	0.630
Tryptophan	0.229	0.220	0.200	0.231	0.190	0.200	0.232	0.160	0.200	0.219	0.185	0.185
Arginine	1.201	0.897	0.815	1.194	0.880	0.926	1.212	0.861	1.076	1.234	0.912	0.912
Isoleucine	0.779	0.549	0.499	0.762	0.530	0.558	0.770	0.515	0.644	0.803	0.560	0.560
Phe. + Tyrosine	1.489	1.339	1.218	1.455	1.295	1.363	1.473	1.309	1.636	1.557	1.377	1.377
Valine	0.931	0.618	0.562	0.915	0.603	0.635	0.924	0.590	0.737	0.940	0.628	0.628
Crude fibre	3.516			3.937			4.105			3.492		
Crude fat	3.575	3.396		3.584	3.405		3.604	3.424		3.716	3.530	
WHC	2.883			2.961			3.004			3.104		
Calcium	0.750			0.700			0.660			0.600		
Avail. phosphorous	0.300			0.326			0.312			0.322		
Sodium	0.222			0.207			0.201			0.188		
Chloride	0.468			0.419			0.379			0.389		

Table 1.3. Nutrient composition of feeds (%) used in four phases of Treatment 2 (Ideal AA : Energy)

	Phase 1			Phase 2			Phase 3			Phase 4		
Nutrient	Total	Digestible	AA/Lys	Total	Digestible	AA/Lys	Total	Digestible	AA/Lys	Total	Digestible	AA/Lys
ME (pig) (MJ/kg)	13.200			13.200			13.200			13.200		
DE (pig) (MJ/kg)	13.747			13.709			13.674			13.704		
EE (pig) (MJ/kg)	11.748			11.843			11.898			11.828		
Crude protein	18.152	15.500		16.590	14.237		15.596	13.327		16.654	14.260	
Lysine	1.386	1.250	1.000	1.219	1.100	1.000	1.113	1.000	1.000	1.221	1.100	1.000
Methionine	0.469	0.436	0.349	0.417	0.387	0.352	0.384	0.356	0.356	0.416	0.387	0.387
Methionine + Cystine	0.803	0.710	0.568	0.735	0.650	0.591	0.693	0.610	0.610	0.736	0.650	0.650
Threonine	0.864	0.750	0.600	0.792	0.690	0.627	0.743	0.645	0.645	0.793	0.690	0.690
Tryptophan	0.215	0.185	0.148	0.197	0.170	0.155	0.180	0.155	0.155	0.197	0.170	0.170
Arginine	1.133	1.035	0.828	1.014	0.931	0.846	0.941	0.861	0.861	1.020	0.935	0.935
Isoleucine	0.745	0.640	0.512	0.670	0.580	0.527	0.619	0.535	0.535	0.671	0.580	0.580
Phe. + Tyrosine	1.456	1.291	1.033	1.332	1.188	1.080	1.244	1.108	1.108	1.334	1.189	1.189
Valine	0.923	0.795	0.636	0.824	0.710	0.645	0.763	0.655	0.655	0.825	0.710	0.710
Crude fibre	3.580			3.394			3.437			3.508		
Crude fat	3.647	3.111		3.251	2.804		3.330	2.884		3.274	2.816	
WHC	3.025			3.042			3.062			3.071		
Calcium	0.750			0.720			0.650			0.620		
Avail. phosphorous	0.300			0.300			0.290			0.270		
Sodium	0.226			0.207			0.201			0.188		
Chloride	0.468			0.431			0.415			0.401		

Table 1.4. Nutrient composition of feeds (%) used in four phases of Treatment 3 (Low nutrient dense)

Nutrient	Phase 1			Phase 2			Phase 3			Phase 4		
	Total	Digestible	AA/Lys	Total	Digestible	AA/Lys	Total	Digestible	AA/Lys	Total	Digestible	AA/Lys
ME (pig) (MJ/kg)	12.625			12.625			12.500			12.500		
DE (pig) (MJ/kg)	13.134			13.082			12.910			12.938		
EE (pig) (MJ/kg)	11.021			11.147			11.045			10.978		
Crude protein	18.398	15.554		16.558	13.923		15.608	12.989		16.604	13.865	
Lysine	1.335	1.196	1.000	1.179	1.052	1.000	1.069	0.947	1.000	1.172	1.042	1.000
Methionine	0.466	0.432	0.361	0.421	0.389	0.370	0.390	0.358	0.378	0.422	0.389	0.373
Methionine + Cystine	0.808	0.710	0.594	0.742	0.650	0.618	0.702	0.610	0.644	0.745	0.650	0.624
Threonine	0.836	0.717	0.600	0.769	0.660	0.627	0.718	0.611	0.645	0.766	0.653	0.627
Tryptophan	0.209	0.177	0.148	0.192	0.163	0.155	0.176	0.147	0.155	0.191	0.161	0.155
Arginine	1.176	1.078	0.901	1.031	0.941	0.895	0.963	0.876	0.925	1.038	0.946	0.908
Isoleucine	0.747	0.641	0.536	0.649	0.555	0.528	0.595	0.507	0.535	0.644	0.549	0.527
Phe. + Tyrosine	1.452	1.288	1.078	1.280	1.135	1.079	1.186	1.047	1.106	1.271	1.123	1.078
Valine	0.894	0.760	0.636	0.802	0.679	0.645	0.753	0.633	0.669	0.800	0.674	0.647
Crude fibre	4.600			4.580			4.868			4.941		
Crude fat	3.181	2.656		3.301	2.794		3.392	2.870		3.339	2.806	
WHC	3.144			3.142			3.189			3.198		
Calcium	0.750			0.720			0.650			0.620		
Avail. phosphorous	0.320			0.300			0.290			0.270		
Sodium	0.233			0.207			0.201			0.188		
Chloride	0.468			0.424			0.408			0.393		

Table 1.5. Nutrient composition of feeds (%) used in four phases of Treatment 4 (High nutrient density)

Nutrient	Phase 1			Phase 2			Phase 3			Phase 4		
	Total	Digestible	AA/Lys	Total	Digestible	AA/Lys	Total	Digestible	AA/Lys	Total	Digestible	AA/Lys
ME (pig) (MJ/kg)	14.000			14.000			14.000			14.000		
DE (pig) (MJ/kg)	14.664			14.584			14.550			14.583		
EE (pig) (MJ/kg)	12.611			12.805			12.876			12.798		
Crude protein	20.767	17.384		17.861	14.913		16.623	13.895		17.802	14.928	
Lysine	1.508	1.330	1.000	1.324	1.170	1.000	1.201	1.060	1.000	1.320	1.170	1.000
Methionine	0.500	0.457	0.344	0.473	0.434	0.371	0.430	0.394	0.372	0.471	0.433	0.370
Methionine + Cystine	0.863	0.750	0.564	0.802	0.700	0.598	0.747	0.650	0.613	0.801	0.700	0.598
Threonine	0.940	0.800	0.602	0.853	0.730	0.624	0.794	0.680	0.642	0.851	0.730	0.624
Tryptophan	0.239	0.200	0.150	0.214	0.180	0.154	0.191	0.160	0.151	0.213	0.180	0.154
Arginine	1.361	1.221	0.918	1.115	0.995	0.850	1.020	0.910	0.858	1.108	0.992	0.848
Isoleucine	0.906	0.756	0.569	0.746	0.620	0.530	0.684	0.570	0.538	0.742	0.620	0.530
Phe. + Tyrosine	1.705	1.479	1.112	1.431	1.237	1.057	1.328	1.151	1.086	1.428	1.240	1.060
Valine	1.023	0.856	0.643	0.895	0.750	0.641	0.834	0.700	0.660	0.892	0.750	0.641
Crude fibre	3.382			3.139			3.033			3.117		
Crude fat	6.227	5.317		6.159	5.320		5.889	5.114		5.847	5.056	
WHC	2.782			2.779			2.800			2.808		
Calcium	0.750			0.720			0.650			0.620		
Avail. phosphorous	0.320			0.300			0.290			0.270		
Sodium	0.241			0.207			0.201			0.188		
Chloride	0.468			0.421			0.408			0.393		

Results & Discussion

A total of 13 pigs either died or were culled during the trial, the numbers per treatment being 0, 3, 6 and 4, respectively. The Chi-square test indicated that there were no treatment effects.

Mean body weight gain, feed intake, FCE, cold carcass weight, dressing percentage and lean meat content for the 4 treatments over the 12-week trial period are given in Table 1.6a for boars and gilts, respectively. Levels of significance between the three pairs of treatments to be compared (1 vs. 2; 1 vs. 3; and 1 vs 4) are given in Table 1.6b.

Because the experiment was designed to compare three alternative feeding strategies, the comparisons of importance are those between Treatments 1 and 2, 1 and 3, and 1 and 4. Consequently, attention should be directed at the levels of significance in Table 1.6b. This shows that the only significant differences of interest are those for feed intake, FCE and percent lean between treatments 1 and 3. Although other significant differences do occur between treatments these are not part of the trial design and should therefore be ignored.

In spite of the lack of significant differences between treatments in the biological traits measured, the main purpose of the trial was to compare the financial implications of implementing alternative feeding strategies, and these comparisons are described further.

This trial had two objectives, the first being to demonstrate the advantage of moving away from fixed amino acid specifications in response to changes in genotype and economic conditions, while the second was to evaluate the EFG Pig Growth Model and Optimiser by comparing the predictions made by the model with the actual outcomes of the trial. Three comparisons were envisaged as a means of achieving these objectives: to make use of the Growth Model to evaluate the existing feeds and feeding program being used on the Baynesfield Estate; and to make use of the Optimiser to determine the changes needed in feed composition when protein ingredient prices increase by 25 % and (2) to evaluate a feeding strategy to be used to shorten the growth cycle to take account of a temporary increase in the price of pork. These comparisons would determine whether the model could improve performance if shortcomings in the basal feeds were evident, and they would evaluate the opportunity cost of failing to take advantage of changes in the feed ingredient and pork markets.

Treatment 2 boars had the greatest gains of all treatments; additionally, they had a greater lean meat percentage when compared to the control, indicating that there may be an imbalance in the ideal amino acid ratios currently used on the farm. Treatment 4 boars also had greater gains when compared to the control, indicating that energy may be a limiting factor for growth during the grower and finisher phases. This is backed up by the higher lean meat percentage of pigs on treatment 4 which indicates that the additional energy was used to assist protein deposition. Treatment 3 boars had the lowest gains of all treatments but the leanest carcasses. This suggests that feed bulk may be a limiting factor during the grower and finisher phases when boars are fed high fibre diets. A similar trend can be seen for weight gain among the gilts. However, treatment 4 gilts had an equally low lean meat percentage as the control, indicating that energy and amino acid requirements differ between gilts and boars. Boars benefit from both higher energy and amino acid levels, while gilts require a lower level of each. As expected, both boars and gilts on the higher nutrient density feeds had lower feed intakes when compared to the lower nutrient dense feeds of treatment 3. Gilts feed intakes are greater than boars across all treatments due to their lower feed efficiencies. Feed efficiency represented as FCE differed as expected for the respective treatments. A greater FCE indicates more efficient feed conversion, with boars being more efficient than gilts across all feed treatments. The feed efficiency on the lower nutrient dense feed (treatment 3) is lower when compared to the higher nutrient dense feed of the control. This is attributed to the greater feed intakes and lower gains of treatment 3. The starting weights were balanced across all treatments and sexes; therefore, treatments with greater total gains also had greater carcass weights. Cold carcass weight is calculated using the warm carcass weights minus a standard of 3 % due to drip loss. Both treatment 2 and 4 boars had higher dressing percentages than the control. This may be due to a higher nutrient density in the feed, amino acids and energy per treatment, respectively, as well as the greater total gains. The lower dressing percentage of treatment 3 can be attributed to the higher fibre diet resulting in a more developed gastrointestinal tract and consequently weight of those organs. Generally, boars were leaner than gilts, which is expected, as gilts mature at a faster rate and have a greater rate of fat deposition at an equal age. Treatment 3 boars were the leanest due to feed bulk limiting their energy intake. Treatment 2 and 4 also had higher lean meat percentages when compared to the control, indicating that the control feed could be balanced better for both amino acids and energy respectively.

Table 1.6 a. Mean body weight gain, feed intake, FCE[1] and carcass characteristics of boars and gilts on each treatment, together with the standard error of the mean for treatment (Trt), sex and the interaction

	Treatment 1		Treatment 2		Treatment 3		Treatment 4		Standard error of means (23 d.f.)		
	Boars	Gilts*	Boars	Gilts*	Boars	Gilts*	Boars	Gilts*	Trt	Sex	Trt x sex
Total Gain, kg	85.8 ^{b}	83.1 ^{c}	88.8 ^{a}	83.4 ^{b}	84.9 ^{b}	82.7 ^{c}	87.3 ^{b}	87.5 ^{a}	15.8	11.2	22.4
Total Feed intake, kg	207 ^{b}	212 ^{ab}	210 ^{ab}	212 ^{ab}	212 ^{ab}	220 ^{a}	203 ^{b}	208 ^{b}	2.61	1.85	3.70
FCE[1], g gain/kg feed	412 ^{ab}	390 ^{b}	420 ^{a}	399 ^{b}	402 ^{b}	373 ^{c}	427 ^{a}	415 ^{a}	7.76	5.49	10.98
Cold Carcass Weight, kg	90.5 ^{ab}	90.6 ^{b}	92.7 ^{a}	90.5 ^{b}	87.7 ^{b}	89.7 ^{b}	92.4 ^{ab}	94.5 ^{a}	0.88	0.72	1.25
Cold Dressed, %	77.1	78.3	81.4	77.5	74.7	77.7	77.9	79.6	1.31	1.07	1.85
Lean, %	69.2 ^{b}	69.2 ^{b}	69.7 ^{a}	69.6 ^{ab}	70.2 ^{a}	69.9 ^{a}	69.8 ^{a}	69.2 ^{b}	0.11	0.09	0.15

[1] Feed conversion efficiency, g gain/kg feed
* Gilts fed boar diets
[a, b, c] Means with the same superscript do not differ significantly (P<0.05)

Table 1.6 b. F-Probability comparisons of mean body weight gain, feed intake, FCE[1] and carcass characteristics between pairs of treatments for both boars and gilts

Variable	P value		
	Treatment 1 vs. 2	Treatment 1 vs. 3	Treatment 1 vs. 4
Total Gain, kg	0.976	0.273	0.527
Total Feed intake, kg	0.575	0.075	0.254
FCE[1], g gain/kg feed	0.641	0.046*	0.871
Cold Carcass Weight, kg	0.453	0.238	0.057
Cold Dressed, %	0.403	0.528	0.627
Lean, %	0.054	<0.001**	0.146

[1] Feed conversion efficiency, g gain/kg feed

Table 1.7 shows the cost of feed per phase for the four treatments. Feed prices were based on the cost of the raw ingredients at the time of starting the trial, and their inclusion levels. The increase in feed price of 25 % was calculated by applying a 25 % increase to all the raw ingredients that are considered to be the main protein sources in each feed, such as soya oilcake and synthetic amino acids. The higher the nutrient density, whether amino acids or energy, the greater the feed price - across treatments and phases; for example, Phase 1 is always more nutrient dense than phase 2; Treatment 2 and 4 are more nutrient dense than the control; and treatment 3 is less nutrient dense than the control due to a higher fibre inclusion level.

Table 1.7. Cost of feed per phase (ZAR/t) for the four feeding treatments

	Treatment 1		Treatment 2	Treatment 3[1]	Treatment 4
	Current price	Price + 25 %[1]			
Phase 1	3961	4392	4120	4282	4855
Phase 2	3752	4132	3844	3961	4544
Phase 3	3562	3900	3672	3687	4314
Phase 4	3907	4313	3812	3863	4476

[1] Cost of all protein-containing ingredients increased by 25 %

Tables 1.8a to 1.8d summarise the predicted and actual performance and economic parameters for each treatment compared to treatment 1, respectively. The EFG Pig Model was used to predict both the growth and carcass parameters of each treatment before the trial was conducted.

As shown in Table 1.8a, the predicted gains were slightly higher than the actual, although the predicted and actual gains for boars were similar (only differing by 0.5 kg). The total feed intake of boars was similar for phase 1 to 3 but differed for phase 4 where the actual feed intake was greater than predicted. The gilts' feed intakes were similar across all phases. The predicted FCE for boars was greater than that for gilts, the same trend occurring in the actual values. The predicted and actual FCE was similar for gilts, but differed slightly more for boars, although only by 38 g/kg feed. The EFG Pig Model predicted that the dressing percentage of boars would be less than that of gilts, which was also seen in the actual outcome. The boars were leaner than predicted, while the leanness of gilts was predicted accurately.

The actual MOFC was less than predicted for all treatments when compared to treatment 1 for each independent economic scenario. This can be attributed either to lower gains or greater feed intake, or a combination across the phases. In addition, differences may arise due to environmental effects such as effective temperature which cannot be accurately predicted, feed wastage, human error and lack of updated and accurate genetic descriptions.

As shown in Table 1.8b, the predicted gains were less than the actual for boars, whilst the opposite was seen for gilts. The total feed intake of gilts was similar across all phases, while that for boars was greater than predicted due to a higher intake during phase 4. The predicted FCE for boars was greater than that for gilts, the same trend being seen in the actual results. The predicted and actual FCE was very similar for gilts but differed slightly more for boars. The EFG Pig Model predicted that the dressing percentage of boars and gilts would be similar and was true for gilts. However, the dressing percentage for boars was higher than predicted, indicating that some essential amino acids may have been limiting in the feed, as predicted. Both boars and gilts were leaner than expected, but the gilts leanness was predicted more accurately. The actual MOFC was less than predicted as cold carcass weights were greater than the actual for both sexes, and feed intake for boars was higher.

As shown in Table 1.8c, the predicted gains were greater for both boars and gilts. The total feed intake of gilts was similar across all phases, while that for boars was greater than predicted due to a higher intake during phase 4. The predicted FCE for boars was greater than that for gilts, the same trend being seen in the actual results. The predicted and actual FCE was distinctly similar for gilts but differed more for boars. The EFG Pig Model predicted that the dressing percentage of boars and gilts would be similar, but these were lower, specifically for boars. This can be attributed to the high fibre feed promoting gut development, allowing these organs to grow faster than predicted. Both boars and gilts were far leaner than expected. The actual MOFC was less than predicted as cold carcass weights were greater than the actual for both sexes.

Table 1.8 a. Summary of predicted and actual performance and economic parameters for Treatment 1

	Treatment 1 – Control			
	Boars		Gilts*	
	Predicted	Actual	Predicted	Actual
Total Gain, kg	86.3	85.8	85.7	83.1
Feed intake, kg				
Phase 1	33.6	34.5	33.7	38.3
Phase 2	29.0	29.8	31.9	28.8
Phase 3	54.1	51.7	57.7	52.3
Phase 4	74.1	91.2	90.7	92.8
Total	191	207	214	212
FCE[1], g gain/kg feed	452	414	400	392
Cold Carcass Weight, kg	93.9	90.5	94.2	90.6
Cold Dressed, %	77.7	77.1	77.9	78.3
Lean, %	68.8	69.2	69.2	69.2
Cost of Feeding, ZAR	724	789	813	809
Revenue, ZAR	2432	2344	2440	2347
Margin Over Feed Cost, ZAR	1708	1555	1627	1538
For comparison with Treatment 3 when the cost of protein was increased by 25 %				
Cost of Feeding, ZAR	798	870	896	891
Revenue, ZAR	2432	2344	2440	2347
Margin Over Feed Cost, ZAR	1634	1474	1544	1455
For comparison with Treatment 4 when revenue was increased by 25 %				
Revenue, ZAR	3040	2930	3050	2934
Margin Over Feed Cost, ZAR	2316	2141	2237	2125

[1] Feed conversion efficiency
* Gilts fed boar diets

Table 1.8 b. Summary of predicted and actual performance and economic parameters for Treatment 2

	Boars		Gilts*	
	Predicted	Actual	Predicted	Actual
Total Gain, kg	86.2	88.8	85.7	83.4
Feed intake, kg				
Phase 1	30.5	35.2	31.6	36.8
Phase 2	27.4	31.5	31.3	32.5
Phase 3	47.4	51.3	56.6	50.3
Phase 4	74.6	92.4	90.5	92.6
Total	180	210	210	212
FCE[1], g gain/kg feed	479	422	408	393
Cold Carcass Weight, kg	94.6	92.7	94.1	90.5
Cold Dressed, %	77.7	81.4	77.9	77.5
Lean, %	68.8	69.7	69.2	69.6
Cost of Feeding, ZAR	689	807	803	814
Revenue, ZAR	2450	2401	2437	2344
Margin Over Feed Cost, ZAR	1761	1594	1634	1530

[1] Feed conversion efficiency
* Gilts fed boar diets

Table 1.8 c. Summary of predicted and actual performance and economic parameters for Treatment 3

	Boars		Gilts*	
	Predicted	Actual	Predicted	Actual
Total Gain, kg	93.1	84.9	92.5	82.7
Feed intake, kg				
Phase 1	30.4	34.8	32.2	38.6
Phase 2	27.6	30.9	32.7	33.5
Phase 3	51.6	52.1	61.8	51.9
Phase 4	83.9	94.0	102	96.0
Total	194	212	229	220
FCE[1], g gain/kg feed	481	401	405	376
Cold Carcass Weight, kg	93.8	87.7	94.5	89.7
Cold Dressed, %	78.4	74.7	78.5	77.7
Lean, %	69.0	70.2	66.2	69.9
Cost of Feeding, ZAR	754	827	888	860
Revenue, ZAR	2429	2271	2448	2323
Margin Over Feed Cost, ZAR	1676	1445	1559	1463

[1] Feed conversion efficiency
* Gilts fed boar diets

Table 1.8 d. Summary of predicted and actual performance and economic parameters for Treatment 4

	Boars		Gilts*	
	Predicted	Actual	Predicted	Actual
Total Gain, kg	85.9	87.3	85.4	87.5
Feed intake, kg				
Phase 1	27.5	32.5	29.2	36.7
Phase 2	25.8	30.2	29.6	28.8
Phase 3	45.5	51.9	53.3	51.5
Phase 4	70.4	88.4	85.3	91.4
Total	169	203	197	208
FCE[1], g gain/kg feed	508	430	433	420
Cold Carcass Weight, kg	94.4	92.4	95.0	94.5
Cold Dressed, %	77.7	77.9	78.2	79.6
Lean, %	68.9	69.8	69.2	69.2
Cost of Feeding, ZAR	762	915	888	940
Revenue, ZAR	3057	2992	3076	3060
Margin Over Feed Cost, ZAR	2295	2077	2188	2120

[1] Feed conversion efficiency
* Gilts fed boar diets

As shown in Table 1.8d, the actual gains were greater for both boars and gilts as were the total feed intakes, resulting in the actual FCE values for both sexes being lower than predicted. The predicted and actual FCE was more similar for gilts than for boars. The Model accurately predicted the dressing percentage of boars, whereas that for gilts was marginally greater than predicted. Boars were leaner than predicted while the predicted leanness for gilts was accurate. Cold carcass weights were lower than predicted, resulting in lower MOFC for each sex.

Table 1.9 presents the comparison between the predicted and actual MOFC for each treatment compared to treatment 1 under different economic scenarios. In summary, boars performed better across all treatments when compared to gilts. Both boars and gilts achieved an improvement in MOFC on treatment 2. This suggests that some essential amino acids were limiting protein deposition rates in the basal feed, more significantly for boars than gilts. Boars achieved the greatest MOFC in treatment 3, as they managed to maintain reasonable feed efficiency, while the gilts did not. Treatment 4 feed was too expensive to warrant the slight increase in gains. The gains were not sufficient to offset the increased cost of feeding as feed intake was not as low as predicted. Table 1.9 reinforces that the potential benefit of changing the feed largely depends on the quality and performance of the basal feed, which was satisfactory in this case.

Table 1.9. Comparison of predicted and actual margin over feed cost (MOFC, ZAR) for Treatment 1 (Control) and three treatments designed to maximise margin over feed cost under different scenarios

Comparison	Predicted or actual	Sex	MOFC Treatment 1	To maximise MOFC	Difference (ZAR)
T1 vs. T2	Predicted	Boars	1708	1761	+53
		Gilts	1627	1634	+7
	Actual	Boars	1403	1475	+72
		Gilts	1350	1369	+19
T1 vs. T3	Predicted	Boars	1634	1676	+42
		Gilts	1544	1559	+15
	Actual	Boars	1322	1399	+77
		Gilts	1268	1232	-36
T1 vs. T4	Predicted	Boars	2306	2316	+10
		Gilts	2232	2237	+5
	Actual	Boars	1950	1941	-9
		Gilts	1908	1861	-47

Conclusions

The purpose of the trial reported here was to assess the biological and economic implications of using feeds differing in protein and energy content on the growth and feed intake of pigs grown in a commercial facility; and to evaluate the results in relation to those simulated by the EFG Pig Growth Model and Optimiser. The Growth Model proved to be an accurate means of assessing the shortcomings in the base feeds used, and in providing economically beneficial feeds to be used under different economic circumstances.

Pigs on the control feed performed well, yielding 86 and 83 kg of gain over the 12 weeks, for boars and gilts, respectively. Nevertheless, changes to the amino acid balance suggested by the Growth Model, and applied in Treatment 2, resulted in a higher growth rate and MOFC in both boars and gilts. In addition, the dressing percentage and lean meat percentage of the boars was improved, from 77 to 81 % and from 69 to 70 %, respectively. The extent to which these improvements would increase profitability of the enterprise would depend on the prevailing pork price and payment grid.

Treatment 3 was designed to address a scenario where the cost of protein-containing ingredients is considerably increased, which resulted in feeds being formulated at lower nutrient densities than the control. Pigs on this treatment performed well on these high fibre feeds, and overall gains were not significantly different to the control. The cost of these feeds was lower (R 43/pig) than those of the controls, but income per pig differed from the control, resulting in a small negative difference in margin over feed cost. The simulated results suggested a greater margin for Treatment 3 than for the controls, the difference between the simulated and actual results being due to feed intake being greater than predicted. It would be of interest to evaluate the benefits of a higher fibre adaptation period before 10 weeks of age, as this should improve performance by promoting gut health and development.

The question was raised whether it was worth feeding a high nutrient density feed to speed up the growth process as a means of benefiting from a greater demand for pork meat, for example just before Christmas. Treatment 4 was designed to address this issue, using margin over feed cost (MOFC) as the objective function and a higher revenue to encourage faster growth. This treatment resulted in the greatest cold carcass weights (87 kg for boars and gilts) and hence the greatest revenue, but did not yield the highest MOFC, as the improved feed efficiency was not sufficient to offset the higher feed costs. It is essential to account for both income and costs, as the greatest revenue generated from the largest carcass does not necessarily result in the greatest profit as cost of feeding plays a significant role in profitability due to feed being the biggest cost in an intensive pig farming operation. One needs to find the optimal point where pig performance is either sacrificed or gained as the cost of feeding is reduced or increased.

An explanation for the differences between the predicted and actual MOFC for treatment 4 can be attributed to the fact that the control feed was already of good quality and produced fast growing pigs. Therefore, the small improvement in growth was not sufficient to improve MOFC. However, the concept should not be discarded: where demand is increased and pigs can be marketed at an earlier age because of a faster growth rate, as demonstrated in this treatment, feed intake to that age would be lower, hence MOFC would be greater, and in addition to meeting the increased demand, more time would be available for cleaning and drying the pig facilities thereby possibly improving the health status of the next batch of pigs to occupy the facility, and increasing the number of production cycles/year.

The genetic description used in the EFG Pig Growth Model and Optimiser for the TN60 pigs was sufficiently accurate in predicting growth rate and carcass composition to enable the simulated results to predict realistically the performance of the pigs on the various treatments. In general, the TN60 pigs consumed larger quantities of feed than predicted, which may partly be due to feed spillage. The model predictions were in line with the trends seen in the trial, suggesting that the theory of the model is sound. However, the model simulations were more accurate for gilts, which emphasises the need for more regular trials and genetic descriptions to be conducted by breeding companies to describe more accurately these modern and rapidly changing genotypes.

With these points in mind, when does one make feed changes to match economic scenarios? Usually, both feed ingredient and pork prices can be predicted, as they both follow annual patterns and are farm or area specific. The swine nutritionist may make feed changes in the grower and finisher phases to match the current economic scenario; however, the outcome of these feed changes will only be seen at slaughter 12 weeks later when the economic situation may be vastly different. Whether the farmer benefits from the change or not depends on which part of the economic situation is changing; the feed ingredient price or the pork price. For example, if it is only the pork price that is changing then one should make the change to the feed 12 weeks prior to slaughter so that the pigs are marketed at the time of the change and the benefit is gained. However, if it is only the feed ingredient prices that are changing then one should not make any changes until the time that the actual change has occurred. It is important to note that if pork price increases or ingredient prices decrease the nutritional changes required for maximising MOFC are the same. The EFG Pig Simulation Model can predict the outcome of a given feed or it can predict the optimum feed under a given future economic scenario using the EFG Pig Optimiser, allowing the farmer to benefit from having a dynamic feeding system.

One of the most important conclusions is that even though differences in feed intake and growth were in most cases not statistically significant, differences in the cost of feeding due to the composition of the optimised feeds resulted in economically significant improvements in profitability. When these improvements in MOFC are extrapolated to large-scale enterprises the improvement in profitability is considerable and warrants the use of this new approach to feed formulation. As proven in this trial, MOFC is most affected by the cost of feeding as feed costs account for 75 % of production costs in an intensive pig farming system. Therefore, one should not focus solely on maximising growth or feed efficiency; rather, compromise those in order to reduce feed costs which will contribute to achieving the economic optimum for the farm.

In order to apply growth models successfully in a commercial operation, it is imperative to have an accurate biological description of the animal and a well-defined commercialization process that involves all stakeholders (technical advisors, managers, business owners and the various beneficiaries of the technology) in the design and development stages of the model. A 'modelling culture' must exist within the organization as well as a biological framework that is sufficiently robust to allow for easy and rapid changes and inclusion of new technologies. One of the most important is the strategic utilization of the models to drive dynamic decision-making processes through all levels of production, particularly when it comes to profit optimisation (Ferguson, 2015).

In other words, a good model cannot be successful alone. It needs people that understand, support and know how to apply the model effectively.

In conclusion, pigs adapt their feed intake and growth to multiple feed types. In this trial they demonstrated their ability to produce good quality carcasses of respectable size across all feed treatments imposed; however, large differences in profitability were evident between the various treatments, and it should be the objective of pig producers to ensure that the feeds offered during the growing period will always result in maximum profit for the enterprise. We, as nutritionists, researchers and farmers, should use this to our advantage by using dynamic feeding strategies which change with and ahead of market economics. This will ensure that the pork industry will remain competitive in spite of increasing feed ingredient costs that are expected in the foreseeable future.

Chapter 2: The response of growing pigs to dietary protein[1]

Introduction

Dietary protein content influences feed intake, growth and carcass composition of growing animals (Emmans, 1981; 1987); as a consequence, the cost of feeding and the revenue derived from the sale of product are also affected. Therefore, the protein content that maximises margin over feed cost is expected to vary with the cost of the protein-containing ingredients in a feed and/or when revenue changes. As a result, it is of benefit to a producer to have information available on the response of growing animals to dietary protein so that changes can be made to the protein content of the feed being offered to the animals such that margin over feed cost may be maximised for all economic scenarios. The trial described here was designed to produce the necessary responses of gilts and boars to a wide range of dietary protein contents.

Feed intake is not controlled solely by the energy content of the feed, as suggested by many authors (Leeson, 1996a; 1996b; Wu et al., 2007), but by the content of the first-limiting nutrient in the feed (Emmans, 1987; 1989) which would often be an essential amino acid but could in some cases be energy. The animal attempts to consume sufficient quantities of the limiting nutrient to attain its potential rate of growth, and in so doing would over-consume other nutrients that were supplied in excess of requirement (Emmans, 1987). Excess energy would also be consumed in this process and the animal would become fatter than desired: the extent to which the animal becomes fat is related to the balance between the first limiting nutrient and the dietary energy content. This was demonstrated by Gous et al. (1990) with broiler chickens.

The effect of changes in amino acid content on feed intake, growth rate and carcass composition have been published on broiler chickens. Burnham et al. (1992) showed that feed intake increased at marginal deficiencies of dietary isoleucine content but then decreased at more severe deficiencies of this amino acid. Body lipid content increased curvilinearly as the amino acid content was reduced whilst feed conversion efficiency (FCE) decreased curvilinearly over the same range (Figures 2.1 and 2.2).

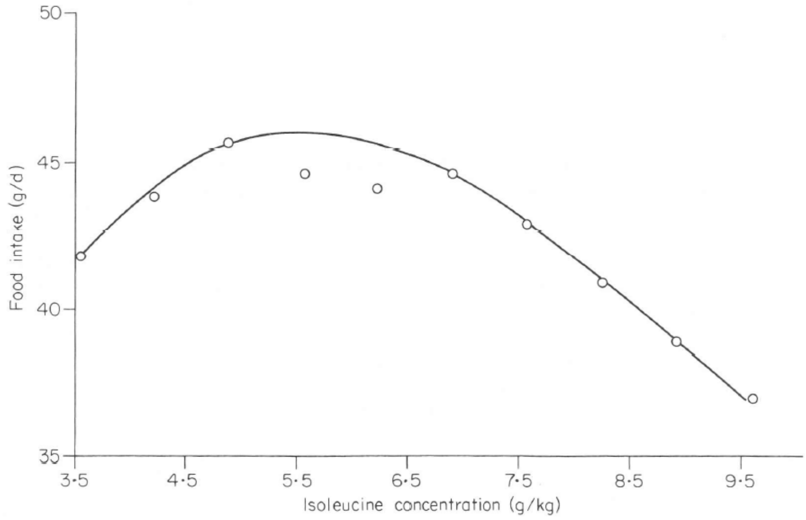

Figure 2.1. Effect of dietary isoleucine content on feed intake in broiler chickens (after Burnham et al., 1992)

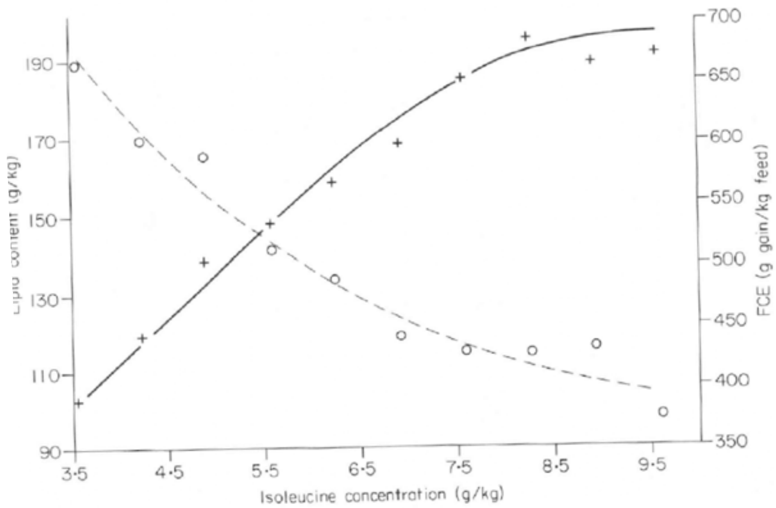

Figure 2.2. Response in lipid content (dashed) and feed conversion efficiency (solid) to a range of dietary isoleucine concentrations in broiler chickens (after Burnham et al., 1992)

Other evidence from broilers that demonstrates that feed intake increases as the dietary protein content is reduced was presented by Clark et al. (1982), Gous & Morris (1985) and by Lemme *et al.* (2006).

Genotypes differ in their ability to fatten. Both Kemp *et al.* (2005) and Berhe & Gous (2008) demonstrated that Cobb broilers had a greater propensity to fatten on low protein feeds than Ross broilers, but were unable to benefit from higher protein feeds, unlike Ross broilers which consumed more feed, grew faster, and had increased breast weights on the higher protein feeds. Similarly, Leeson & Caston (1991) showed that Nicholas turkey hens did not respond to an increase in dietary protein content whereas males consumed more of the high protein feed and consequently grew at a faster rate. If this is the case with gilts and boars then the optimum dietary protein level would be expected to differ between the sexes, so separate response curves should be derived for each sex. It is important to note that feed intake would not increase indefinitely with a reduction in dietary protein levels due to the feed effect known as bulk. Bulk is proportional to the amount of fibre in the feed, which has a filling effect and is higher in lower nutrient dense diets; as a result, desired feed intake would not be attainable, and feed intake would become constrained. As illustrated in the previous chapter, actual feed intake is the lesser of the desired and constrained feed intakes.

Uniformity in a population of growing pigs is of considerable importance at both the production and consumer level. The extent of variation in body weight when pigs are marketed is a serious consideration, as is variation in all commodities. Ideally, all pigs should be alike in body weight throughout the growing period as this makes husbandry more efficient when handling, medicating or housing pigs such as stocking rate and environmental temperature regulation. There is less competition at the feeder and waterer, resulting in less stress and the product being sold is more attractive when the uniformity is high. Batch uniformity is also vital when formulating feed and feeding, as more uniform pigs can be fed more closely to their requirements. This contributes to more efficient growth and less nutrient waste in the manure. This is significant in South African commercial systems as changes in the feeding schedule are based on age rather than weight. Furthermore, there are economic implications at the abattoir when carcasses are underweight (less than 60 kg) or overweight (more than 105 kg) resulting in a penalty which would negatively affect revenue. Carcass grading has a significant effect on revenue as leaner carcasses acquire higher prices per kg of pork, the significance of which depends on the payment grid between the producer and abattoir. In general, a greater number of leaner carcasses is desired. It is likely, because of the variation in size and resultant differences in potential growth rate in a population, that differences in gain would become more pronounced as the dietary protein content of the feed was reduced. Larger animals would have the ability to consume more feed thereby having a better chance of meeting the requirement for a limiting nutrient and allowing them to grow at their potential; whereas smaller animals would be unable to do so. Furthermore, differences in feed intake in response to the level of nutrients in the feed would alter the pigs' ability to store sufficient or insufficient amounts of body lipid. Thus, variation in body composition between individuals would also increase as the dietary protein content is reduced, resulting in a wider range of carcass grades at the abattoir. These differences in final body weight and carcass composition would need to be accounted for when calculating the optimum economic level of dietary protein to be fed to the pigs.

The most important implication from this theory is that feed intake is not constant over a range of dietary protein contents, and that the composition of the animal will differ depending on the protein level fed, which has implications when determining the economic optimum dietary protein content to feed to growing pigs.

Once the responses in feed intake, weight gain and carcass composition have been derived for boars and gilts, appropriate costing may be applied to determine the cost of feeding and the revenue derived from the sale of the carcass, taking account of the carcass grade expected at each level of dietary protein. If uniformity is shown to be influenced by the protein content of the feed, then this aspect should also be incorporated into the calculation of optimum economic level of dietary protein. As dietary protein costs escalate, or as the revenue for pork declines, the optimum economic level of dietary protein to be fed to the animals might be expected to decrease, and *vice versa*. Because boars and gilts are expected to respond differently to dietary protein the optimum economic level of protein for each sex is also likely to differ, suggesting that different feeds should be fed to the two sexes if margin over feed cost is to be maximised.

The research reported below consists of two elements: the simulation of the response to balanced dietary protein in boars and gilts, and the actual measurement of those responses. The composition of the feeds used was the same in both approaches, and the outputs were used in the same way to calculate the optimum economic level of dietary protein under different economic circumstances. Conducting both a simulation and a real exercise offers the advantage of being able to assess the theory incorporated into the simulation model and to explain any anomalies that might appear in the results of the trial itself.

Materials and Methods

The study was performed in accordance with the Animal Research Ethics Committee of the University of KwaZulu-Natal, School of Agricultural, Earth and Environmental Sciences (Protocol reference number: AREC/029/020M, approved 5 November 2020).

Simulation

Use was made of the EFG Pig Growth Model to simulate the results of the protein response trial to be conducted on the Baynesfield Estate. The description of the boars and gilts used was the same as that used in the simulations conducted in Chapter 1, as was the management description. Six feed treatments were simulated, with each treatment consisting of three grower phases and one finisher phase lasting three, two, three and four weeks, respectively. The treatments contained 0.7, 0.8, 0.9, 1.0, 1.1 and 1.2 of the Topigs recommended lysine levels, respectively (Topigs Norsvin TN70, n.d.) with all other amino acids being balanced according to the lysine content, using the amino acid balance suggested by Topigs in each phase. The 24 feeds making up the four phases in each of the six protein treatments were formulated at least cost. The composition of the basal feeds used in the simulation are given in Table 2.1 below, from which the 24 feeds used in the exercise were derived. When protein-containing ingredient prices were changed (see below) the ingredient composition of all 24 feeds changed accordingly, but the lower bounds for nutrient content remained the same. The performance of gilts and boars on each of the six dietary treatments was simulated, from which the required information was transferred to tables displayed in the Results section below.

Pigs and management

264 Topigs TN60 boars and 264 Topigs TN60 gilts aged 74 days were placed in an open-sided house consisting of 48 pens, with 11 pigs in each pen. The pens were 11 m^2 in size, with two water nipples and a TR60 manual feeder in each, arranged in four blocks with 12 pens per block. Boars and gilts were housed in alternate pens. Each pig was ear tagged and weighed on exiting the delivery vehicle and then randomly allocated to a pen. Pen weights were then balanced within sexes to be within 0.05 SD of each other. Temperature was maintained automatically between 20-24 °C using blinds, and ventilation was controlled similarly with a minimum of 5% air flow. Natural lighting was used throughout the trial.

All pigs were weighed individually on a weekly basis. The daily amount of feed allocated to each pen was recorded automatically (see below) and feed remaining in each feeder was weighed back at the end of each week. Each pen had a recording sheet for any sick or injured pigs, as well as their respective medical treatments. The trial period lasted for 12 weeks when the pigs were 22 weeks of age, after which they were transported to a commercial abattoir where carcasses were evaluated.

Treatments and feeds

Six feed treatments were used in the trial, with each treatment consisting of three grower phases and one finisher phase lasting three, two, three and four weeks, respectively. The treatments 1 through 6 contained 0.7, 0.8, 0.9, 1.0, 1.1 and 1.2 times the Topigs recommended lysine levels, respectively (Topigs Norsvin TN70, n.d.). Boars and gilts within treatments were fed the same diet but were in separate pens, allowing for their responses to be analysed separately. The composition of the feeds used, together with their respective specifications, are given in Table 2.1 below. Two basal feeds were used per phase, one with high and the other low crude protein content. These basal feeds were blended in appropriate proportions (Table 2.2) to produce the six treatments per phase, each phase having the same net energy content between treatments and defined ratio between the essential amino acids. All feeds were mixed at the Baynesfield Estate feed mill.

Table 2.1. Composition (g/kg) of the low and high protein basal feeds used in phases 1 to 4 of the trial

	Phase 1		**Phase 2**		**Phase 3**		**Phase 4**	
	Low	High	Low	High	Low	High	Low	High
Maize	795	630	781	698	790	718	800	735
Wheat bran	47.0		92.0	7.0	115.0	40.0	133.0	67.0
Soya full fat	-	83.0	-	-	-	-	-	-
Soya oilcake	114	238	86.0	250	58.0	201	33.0	161
Limestone	16.3	15.8	15.6	15.2	14.2	13.8	13.0	12.7
Monocalcium phosphate	13.0	11.5	10.8	9.9	9.2	8.5	8.2	7.5
Salt	5.6	5.6	5.3	5.3	5.0	5.0	4.7	4.7
Lysine HCl	4.2	5.7	3.9	5.5	3.6	5.0	3.4	4.6
DL Methionine	2.0	4.0	1.8	3.4	1.6	3.0	1.3	2.6
Threonine	1.5	2.8	1.4	2.6	1.2	2.3	1.0	2.0
Tryptophan	0.5	0.8	0.4	0.7	0.4	0.6	0.3	0.6
Valine	0.3	1.2	0.1	0.9	-	0.7	-	0.5
Vitamin/mineral premix	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Crude Protein	127	201	119	179	109	162	101	148
Fat	37.0	46.9	37.0	35.6	37.3	36.1	37.6	36.5
Fibre	21.0	20.0	25.0	20.7	26.5	22.7	27.7	24.4
Calcium	8.50	8.50	7.90	7.90	7.10	7.10	6.50	6.50
Sodium	2.30	2.30	2.20	2.20	2.10	2.10	2.00	2.00
Dig P	3.30	3.30	2.90	2.90	2.60	2.60	2.40	2.40
NE	9.80	9.80	9.70	9.70	9.70	9.70	9.70	9.70
SID Lys	7.70	13.2	6.93	11.9	6.09	10.4	5.39	9.24
SID Lys:NE	0.79	1.35	0.71	1.22	0.63	1.08	0.56	0.95

Table 2.2. Mixing proportions used in producing the six levels of balanced protein used in the trial

Dietary protein level	Low protein basal	High protein basal
0.7	100	0
0.8	83	33
0.9	67	50
1.0	50	67
1.1	33	83
1.2	0	100

Feeding

After mixing, each feed was stored in one of six bulk tanks outside the research facility. An auger enabled the feed from each bulk tank to be accessed inside the facility, the feed being manually weighed into respective colour-coded 25 kg bags, with the receiving pen being recorded manually. Each pen was colour-coded to minimise the risk of errors being made when allocating feed to pens. Feeders in all pens were kept full by adding feed either once or twice daily. Feed allocated during the week, and that remaining at the end of each week, was used to calculate feed intake by adding the start weight of the feed for the week to the amount added throughout the week and subtracting this value from the amount remaining at the end of each week.

Calculations

Average daily gain (g/pig d) was calculated as the difference between the mean pen weight at the beginning and end of each week divided by the mean number of pigs in each respective pen and the number of days between weighing. Feed intake (g/pig d) was calculated by subtracting the weight of feed remaining in the feeder at the end of the week from the amount fed during that week, divided by the mean number of pigs in the pen and the number of days between weighing. Feed conversion ratio (g feed/g gain) was calculated by dividing average daily gain by mean feed intake for each pen.

Carcass processing and analyses

All pigs aged 22 weeks were transported 34 km in the Baynesfield pig truck to Frey's Cato Ridge abattoir where they were routinely slaughtered. Individual warm carcass weights were recorded together with their lean percentage using the calibrated Hennessey probe and standardised PORCUS classification system (see Table 2 in Introduction). Individual cold carcass weights were calculated by subtracting a standard 3 % from the warm carcass weights. This classification system, along with the carcass mass, is used to determine the payment method between the producer and the abattoir.

Statistical analyses

All data were initially entered into an Excel spread sheet and then imported into Genstat for statistical analysis. Main effects and two-way interactions were identified by means of factorial analysis. Variation in body weights within treatments and between sexes at the end of the trial were determined using coefficients of variation (%) within each pen, calculated as the standard error x 100 / mean of all individuals within each pen.

Regression equations were chosen that best fitted feed intakes within each phase of the trial, the final body weights, and the final carcass characteristics of boars and gilts, so that the fitted values could be used to calculate revenue and the cost of feeding over all four phases. Predicted feed intakes within each phase were multiplied by the cost of the respective feeds (R/ton) to obtain the cost of feeding within each phase, and these were then summed to calculate the total feeding cost per treatment. The predicted final cold carcass weights were multiplied by the revenue (R/kg) and the feeding cost per pig was subtracted from this to obtain the margin over feed cost for each sex and treatment. The protein level yielding the highest margin is regarded as being the optimum economic protein level to use under the specific economic and environmental circumstances.

To demonstrate the effect of changing dietary protein prices on this optimum level, the cost of all protein ingredients (soybean oilcake, full-fat soya, sunflower oilcake and the five synthetic amino acids, Met, Lys, Thr, Trp and Val) were increased by 25 % above the base level, and reduced by 25 % below the base level, before repeating the above calculation of margin over feed cost.

Results

Simulation

The growth model simulated the amount of feed consumed by boars and gilts on each of the six dietary protein treatments as well as the body weight gain and feed conversion efficiency (FCE, g gain/kg feed) and these simulated results are given in Table 2.3.

Table 2.3. Simulated feed intake/d, gain/d and feed conversion efficiency (FCE) of gilts and boars fed six dietary protein levels

Dietary	Feed intake, kg/d		Weight gain, kg/d		FCE, g gain/kg feed	
protein[1]	Gilts	Boars	Gilts	Boars	Gilts	Boars
0.7	2.54	2.54	1.00	1.04	396	398
0.8	2.37	2.37	1.01	1.00	427	427
0.9	2.35	2.21	1.01	1.00	431	457
1.0	2.35	2.20	1.01	1.01	431	459
1.1	2.33	2.19	1.01	1.01	433	463
1.2	2.33	2.19	1.01	1.01	433	463

[1] Balanced amino acid mixture relative to recommendations by Topigs

In Table 2.4, the simulated body protein and lipid weights, and P2 measurement, are given for the two sexes at the end of the 12-week trial period for the six protein levels used.

The growth model simulated the amount of feed that was consumed in each phase on each of the six dietary protein treatments and these intakes were multiplied by the cost of the respective feeds to calculate the cost of feeding. To determine the effect on the optimum economic level of protein of a change in the cost of feeding, the price of protein-containing ingredients was either increased or decreased by 25 %, and the respective costs of feeding compared with the base price are given in Table 2.5.

Table 2.4. Simulated final body protein, lipid and P2 measurement for gilts and boars on six dietary protein levels

Dietary protein[1]	Body protein weight, kg		Body lipid weight, kg		P2, mm	
	Gilts	Boars	Gilts	Boars	Gilts	Boars
0.7	18.1	18.3	19.4	17.4	16.9	16.2
0.8	18.1	18.9	19.4	15.0	16.9	15.4
0.9	18.1	18.9	19.4	15.0	16.9	15.4
1.0	18.1	18.9	19.4	15.0	16.9	15.4
1.1	18.1	18.9	19.4	15.0	16.9	15.4
1.2	18.1	18.9	19.4	15.0	16.9	15.4

[1] Balanced amino acid mixture relative to recommendations by Topigs

Table 2.5. Simulated cost of feeding gilts and boars on a range of dietary protein levels from 10 to 22 weeks of age compared when the base price of protein-containing ingredients is either increased or decreased by 25 %

Dietary protein[1]	Base price		+ 25 %		- 25 %	
	Gilts	Boars	Gilts	Boars	Gilts	Boars
0.7	739	734	789	784	685	699
0.8	719	719	777	778	658	654
0.9	749	710	820	777	676	639
1.0	781	734	865	814	694	652
1.1	817	767	914	858	717	673
1.2	850	798	959	901	738	692

[1] Balanced amino acid mixture relative to recommendations by Topigs

Having simulated the feed intake and body weight gain, the feeding cost and revenue may be calculated from which the margin over feed cost can be determined. Using the above information and calculating the revenue as the product of the carcass weight and revenue of R20/kg, the margin over feed cost for gilts and boars for the six protein levels used were calculated, and these are presented in Table 2.6. The effect of increasing or decreasing the cost of the protein-containing ingredients on margin over feed cost is demonstrated in the table.

Table 2.6. Simulated margin over feed cost (MOFC) for gilts and boars fed six levels of dietary protein over a 12-week period, and demonstrating the effect on margin of increasing or decreasing the price of protein-containing ingredients by 25 %

Dietary protein[1]	Base price		+ 25 %		- 25 %	
	Gilts	Boars	Gilts	Boars	Gilts	Boars
0.7	1036	1041	987	993	1090	1087
0.8	**1056**[1]	1060	**998**	**1002**	**1117**	1125
0.9	1028	**1070**	955	**1002**	1099	**1141**
1.0	994	1045	910	966	1081	1127
1.1	959	1013	862	922	1059	1107
1.2	927	963	817	880	1038	1087

[1] Maximum MOFC in each column shown in bold.

Response trial

A total of 12 pigs either died or were culled during the trial, the numbers per treatment being 4, 3, 1, 0, 1 and 3, respectively. The Chi-square test indicated that there were no treatment effects (P=0.306).

Mean body weight gain, feed intake and FCE for the six dietary protein treatments over the 12-week trial period are given in Table 2.7 for boars and gilts, respectively, and for the mean of the two sexes. Both body weight gain and FCE increased with dietary protein content, the best-fitting equation describing the response being an exponential of the form $Y = A + B (R^X)$ (Table 2.8). These equations differed significantly ($P<0.05$) between sexes so separate equations were needed to describe the responses for each sex.

An exponential equation best fitted the final body weights measured in the trial (Table 2.9). These predicted values may be used to calculate the revenue derived from the sale of the pigs, but in this case, cold carcass weight was used.

The response in daily feed intake (kg/d) to dietary protein (DP) (Table 2.5) was not well described by any equation, the best being a linear regression in which feed intake among the gilts decreased as dietary protein content increased, the equation being 2.520 (± 0.009) – 0.046 (± 0.089) x DP, while intake increased with protein content among the boars, the linear equation being 2.247 (± 0.095) + 0.207 (± 0.098) x DP. The variance accounted for by these equations was only 8.2 %.

Table 2.7. Mean body weight gain (kg/d), feed intake (kg/d) and feed conversion efficiency (FCE, g gain/kg feed) in gilts (G) and boars (B) fed a range of dietary protein levels for the grower-finisher period of 12 weeks

Dietary protein level[1]	Body weight gain, kg/d			Feed intake, kg/d			Feed conversion efficiency, g gain/kg feed		
	G	B	Mean	G	B	Mean	G	B	Mean
0.7	0.94	0.86	0.90	2.46	2.36	2.41	377	365	371
0.8	1.01	0.96	0.98	2.52	2.45	2.49	400	391	395
0.9	1.01	1.05	1.03	2.47	2.48	2.48	407	425	416
1.0	1.02	1.02	1.02	2.49	2.40	2.45	409	425	417
1.1	1.04	1.07	1.06	2.49	2.44	2.46	418	440	429
1.2	1.04	1.08	1.06	2.44	2.52	2.48	425	427	426
Mean	1.01	1.01		2.48	2.48		406	412	
SEM (33 d.f.)	0.017		0.012	0.039		0.027	5.40		3.82

[1] These dietary protein levels represent the proportion of the recommended amino acid (and hence dietary protein) levels being used commercially on Baynesfield Estate.

Table 2.8. Coefficients of exponential equations[1] that describe the response in body weight gain (g/d) and feed conversion efficiency (FCE, g gain/kg feed) by boars and gilts fed six levels of dietary protein from weaning for a period of 12 weeks

Coefficient of response	Body weight gain, g/d		FCE, g gain/kg feed consumed	
	Gilts	Boars	Gilts	Boars
R	0.4768 ± 0.0667		0.0023 ± 0.0025	
B	-1642	-3309	-2901	-5360
A	87.2	90.5	422	439
Variance accounted for (%) 47 d.f.	71.7		72.7	

[1] Equation of the form A + B (R^X)

Table 2.9. Exponential regression coefficients describing the final body weight of gilts and boars

Coefficients	Gilts	Boars
R	0.4636 ± 0.0708	
B	-17.1	-39.8
A	114	117
R^2 = 69.3		

The respective best-fitting equations describing feed intakes for each phase and sex are given in Table 2.10. Curvilinear equations fitted the data in phases 1 and 2 better than linear equations, and the constant terms differed significantly between sexes ($P<0.05$). In the third and fourth phases the response in feed intake was linear and did not differ between the sexes. The variance accounted for by the respective regressions decreased with each phase of the feeding schedule.

Table 2.10. Regression coefficients describing changes in feed intake/d over the range of dietary protein levels used, for each phase of the trial

	Phase 1		Phase 2		Phase 3		Phase 4	
	Gilts	Boars	Gilts	Boars	Gilts	Boars	Gilts	Boars
constant term	1.176 ± 0.337	1.048	1.131 ± 0.489	1.071	2.4729 ± 0.0871		2.781 ± 0.126	
linear coefficient	0.0144 ± 0.0073		0.025 ± 0.0105		0.00215 ± 0.00009		0.00206 ± 0.0013	
quadratic coefficient	-0.000083 ± 0.000038		-0.000133 ± 0.0000055					
R^2	53.6		14.2		9.1		3.1	

Measurements taken of the pigs at the abattoir are summarised in Table 2.11. Results for mean cold carcass weight (CCW), cold dressing percentage (CD) and percentage lean meat content are given for boars and gilts for the six protein levels used. Cold carcass weight increased in both sexes in an exponential manner, with a wider range being evident in boars (Figure. 2.3) than in gilts.

Table 2.11. Mean cold carcass weight (CCW), cold dressing percentage (CD) and percentage lean in boars and gilts fed a range of dietary protein levels from weaning for a period of 12 weeks

Dietary protein level[1]	CCW, kg			CD, %			Lean, %		
	F	M	Mean	F	M	Mean	F	M	Mean
0.7	76.3	68.4	72.4	75.6	73.7	74.7	69.4	69.7	69.5
0.8	83.1	75.6	79.8	75.6	75.7	75.7	69.2	69.5	69.4
0.9	79.2	86.4	82.8	77.0	74.7	75.9	69.4	69.5	69.4
1.0	85.9	85.0	85.4	76.8	75.8	76.3	69.9	70.0	70.0
1.1	86.1	85.5	85.8	76.2	75.2	75.7	69.4	69.7	69.5
1.2	87.9	83.2	85.5	77.1	75.5	76.3	69.9	69.8	69.9
Mean	83.1	80.8		76.4	75.1		69.6	69.7	
SEM (33 d.f.)	1.66		0.96	0.522		0.369	0.185		0.131

[1] These dietary protein levels represent the proportion of the recommended amino acid (and hence dietary protein) levels being used commercially on Baynesfield Estate.

The coefficients for the exponential equation are given in Table 2.12. Cold dressing percentage also increased exponentially but differences between the sexes were not as evident as with CCW, here both the R and B coefficients were common to both sexes. Percent lean showed a linear increase with dietary protein (DP) content (68.9 ± 0.34 + 0.0783 ± 0.0347 x DP), but the variance accounted for was low (8.0 %).

Table 2.12. Coefficients of exponential and linear equations describing the response in cold carcass weight (CCW), cold dressing percentage (CD) and percentage lean in boars and gilts fed six levels of dietary protein from weaning for a period of 12 weeks

Coefficient of response	Cold carcass weight, kg		Cold dressing percentage	
	Gilts	Boars	Gilts	Boars
R	0.466 ± 0.105		0.0000116 ± 0.0000828	
B	-29.83		-4120	
A	87.4	85.1	76.7	75.5
Variance accounted for (%) 47 d.f.	47.6		27.9	

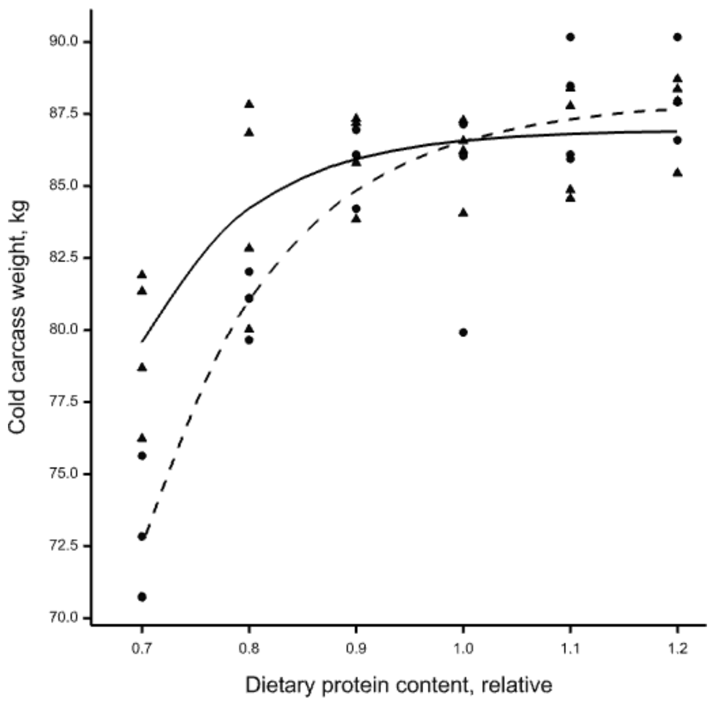

Figure 2.3. Cold carcass weight (kg) of gilts (solid line, ▲) and boars (dashed line, ●) in response to increasing dietary protein content (relative to the recommended amino acid (and hence dietary protein) levels being used commercially on Baynesfield Estate

The coefficients of the exponential equations in Table 2.12 were used to calculate the expected CCW of gilts and boars on the six protein levels, and these are given in Table 2.13 together with the income from the sale of the pigs on each treatment, using a price of R20/kg CCW.

Table 2.13. Cold carcass weight (CCW) predicted using the coefficients in Table 2.12 and income derived from the sale of gilts and boars on the six protein levels used in the trial

Protein content[2]	Cold carcass weight, kg		Revenue, R/pig[1]	
	Gilts	Boars	Gilts	Boars
0.7	78.9	72.4	1579	1448
0.8	83.7	81.3	1675	1625
0.9	85.8	85.0	1715	1700
1.0	86.6	86.6	1732	1731
1.1	87.0	87.2	1739	1744
1.2	87.1	87.5	1742	1750

[1] Revenue calculated at R20/kg CCW

[2] Balanced amino acid mixture relative to recommendations by Topigs.

The cost of feeding the pigs over the 12-week period was calculated as sum of the product of feed consumed in each of the four feeding phases, using the linear and quadratic coefficients in Table 2.10, and the cost of the respective feed. These costs are given in Table 2.14 for gilts and boars on the six dietary protein levels. To ascertain the effect of higher and lower dietary protein-containing ingredients on the cost of feeding, and hence the margin over feed cost, the calculations were done with protein-containing ingredient prices 25 % above and below the base price.

Income was calculated at R20/kg CCW. The margin over feed cost (Table 2.13) and the cost of feeding, for the three protein-containing ingredient prices (Table 2.14). The protein level generating the highest margin is shown in bold, although the true maximum, when a polynomial regression is fitted to the data, is illustrated in Figure. 2.5. The dietary protein level that maximises margin over feed cost differs for gilts and boars and is influenced by the cost of protein-containing ingredients, being lower when the cost of protein increases, and *vice versa*.

Table 2.14. Cost of feeding and margin over feed cost for gilts and boars given a range of dietary protein levels over a 12-week period, with protein-containing ingredients being considered at 25 % above and below the base price

Protein content[1]	Base		+25 %		-25 %	
	Gilts	Boars	Gilts	Boars	Gilts	Boars
Cost of feeding, R/pig						
0.7	694	680	722	708	665	652
0.8	730	715	771	755	689	675
0.9	762	747	815	798	709	695
1.0	793	776	857	839	728	713
1.1	823	806	900	881	746	731
1.2	846	828	934	913	757	742
Margin over feed cost, R/pig[2]						
0.7	885	768	856	740	913	795
0.8	945	910	**904**	870	986	950
0.9	**953**	953	900	**902**	**1006**	1005
1.0	940	**955**	875	892	1005	**1018**
1.1	916	939	839	864	994	1014
1.2	896	922	809	837	985	1008

[1] Balanced amino acid mixture relative to recommendations by Topigs.

[2] Revenue calculated at R20/kg body weight

Uniformity

The amount of variation in final body weight at the end of the trial, calculated as the coefficient of variation (%) decreased linearly as the dietary protein content increased, the rates for boars and gilts being the same (-0.631 ± 0.233) but with the constant terms differing significantly ($P<0.05$), being 10.0 ± 0.91 % for gilts and 13.6 for boars. These relationships are illustrated in Figure. 2.4.

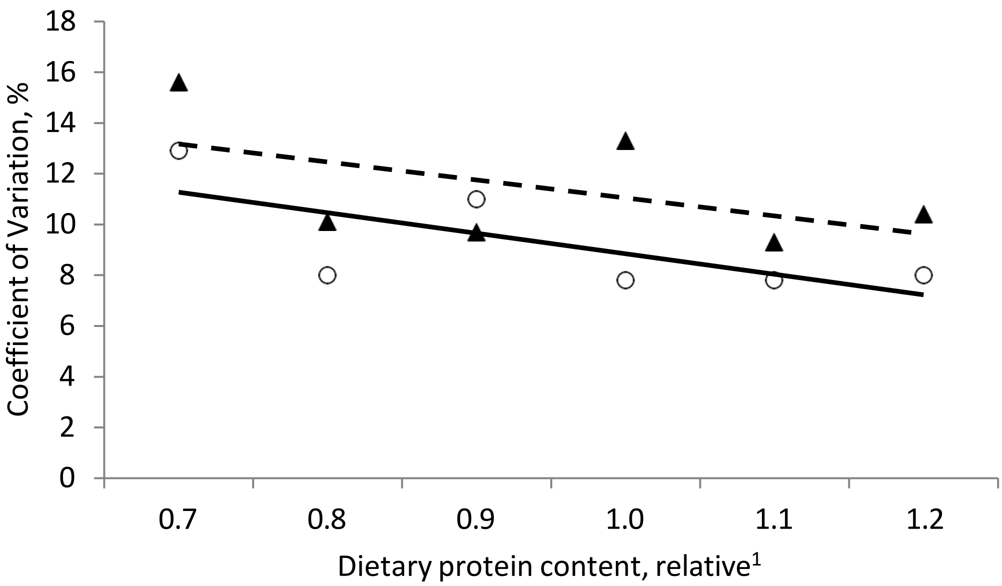

Figure 2.4. Uniformity in body weight, as measured by the coefficient of variation, %, of boars (▲, dashed line) and gilts (○, solid line) fed a range of dietary protein contents over a 12-week growing period. [1] Dietary protein contents represent the proportion of the recommended amino acid (and hence dietary protein) levels being used commercially on Baynesfield Estate

Discussion

One of the main objectives of this trial was to develop equations that would describe the response of boars and gilts of this modern strain of growing pig to a range of dietary protein contents such that these equations could be used in the future to calculate the optimum economic level of dietary protein under different circumstances. For example, when the cost of dietary protein increases, or the demand for pork diminishes, it is unlikely that the level of dietary protein that maximises profit for the enterprise will remain constant. Pig producers would do better by considering the consequences of such changes on the optimum economic level of dietary protein than blindly following fixed tables of nutrient requirements.

The approach used here, first to simulate, and then to measure the response to a range of dietary protein contents, has the advantage of being able to compare the shape and size of the responses generated by each method: if these coincide, the results of the trial may be explained by the theory, thereby making the discussion of the results simple and straightforward; if not, a more comprehensive explanation would be required.

Body weight gain in the trial (Table 2.7) showed a greater difference between treatments than did the simulated results. The range among gilts was 100 g/d and between boars, 220 g/d, whereas the equivalent simulated range was only 10 and 40 g/d. The wide difference in weight gains in the trial translated into significant differences in CCW, the basis on which revenue is calculated.

The simulated response in feed intake increased in both sexes as the dietary protein content was decreased, but in the trial itself the variation both between and within treatments was such that no obvious trend was apparent. It is unlikely that feed intake would have remained the same over all protein treatments given the many cases in the literature where broiler chickens have shown definite trends in feed intake over a range of dietary protein levels (Clark et al., 1982; Gous and Morris, 1985; Burnham et al., 1992; Lemme *et al.,* 2006; Azevedo et al., 2021). The biggest difference between the simulated and actual feed intakes was among boars on the highest protein treatments, where the simulated intakes were about 250 g/d lower. In all other cases the intakes between the simulated and actual were similar, resulting in similar FCE's on most treatments other than with boars on the highest protein levels. The research facility was designed to measure feed intake accurately, and many interventions were employed to ensure that errors were minimised in the measurement of this important variable but measuring feed intake accurately is difficult because spillage and wastage cannot be totally avoided. Where no obvious response is apparent, fitting equations to the data (Table 2.10) is a means of smoothing the response prior to calculating the cost of feeding. In this case it was necessary to have an equation for each of the four feeding phases as the cost of the feed used in each phase differed. There was no alternative but to make use of the weak relationships measured in this trial when predicting feed intake in boars and gilts over the range of protein levels used.

The lack of change in lean % (Table 2.11) was surprising given the extensive changes in body lipid content in the broiler trials mentioned above, in which the response to dietary protein was measured. However, the simulated results corroborated these findings, showing no change in body lipid content except in boars on the lowest protein level used. This characteristic is more important in pigs than in broilers as the price paid for pork is related to the carcass grade, whereas there is no penalty for high carcass fatness when selling broiler carcasses. More research could be directed at determining whether the lack of change in fatness is a characteristic of the breed used in the trial, or whether this is a more general phenomenon in growing pigs.

Both the cost of feeding the gilts and boars and the revenue generated by selling the carcasses were calculated for each level of dietary protein (Tables 2.5 and 2.14) which were then used to calculate the corresponding margin over feed cost (Tables 2.6 and 2.14). In both the simulated and trial results the margin was maximised at a higher protein content for boars than for gilts irrespective of the cost of protein-containing ingredients. However, an increase in the cost of protein-containing ingredients decreased the optimum economic protein level when using the trial results, whereas in the simulated results the maximum margin did not change for gilts and was the same for two levels of protein in boars: the same level as for the other protein prices, and a lower level, as with the trial results (Table 2.6). The latter demonstrates the lower sensitivity of the effect of dietary protein on the economic variables when using the simulation model. The trial results, which demonstrated that the optimum economic level of protein should be higher for boars than for gilts, and that this should be reduced in both sexes when protein ingredient prices increase, corroborate with the tested hypothesis.

The change in optimum economic level of protein for gilts and boars due to changing feed economics can be seen in Figure 2.5 which illustrates the fitted responses for the six scenarios investigated and highlights the maximum margin in each case. It is clear from this graph that when dietary protein prices are low, the optimum economic level of dietary protein for gilts and boars is similar, but as protein prices increase so does the difference in the optimum protein level. This demonstrates the value of separating the sexes and treating them differently, especially when costs are high or profits are low.

Uniformity

The extent of variation in body weight when pigs are marketed is a serious consideration, as is variation in all commodities. Ideally, all pigs should be alike in body weight throughout the growing period as this makes husbandry more efficient, there is less competition at the feeder and waterer resulting in less stress and the product being sold is more attractive when the uniformity is high. The results of this study showed clearly that uniformity increased with dietary protein content, but also by separating the sexes, this latter having a greater effect than dietary protein content (Figure. 2.4). This provides another argument for separating the sexes during the rearing period and treating them differently.

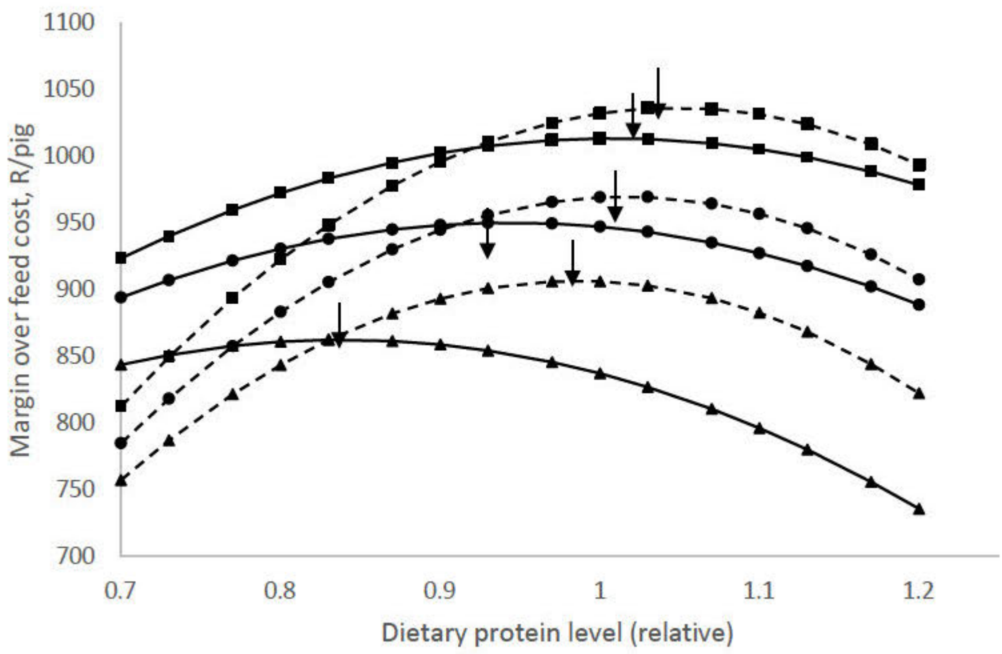

Figure 2.5. Fitted polynomial regressions illustrating the change in margin over feed cost in gilts (solid line) and boars (dashed line) at three prices of protein-containing ingredients (base ●, +25 % ■, -25 % ▲). Arrows denote the maximum margin

Conclusions

Although some differences were evident when comparing the simulated results and those from the trial itself, the important trends were similar in both cases, and the results themselves were comparable in most instances. The simulated results could corroborate the small change in carcass fatness observed at the end of the trial, and the lack of any obvious trend in feed intake with protein level in the trial was corroborated again by the small difference in feed intake in the simulated results.

The results of both the simulation exercise and the trial provide strong evidence that the optimum economic level of dietary protein differs for gilts and boars, and that this difference widens as profitability in the enterprise is reduced, either through an increase in the cost of feed ingredients, or at lower pork prices. With an increase of 25 % in protein-containing ingredient prices the level of dietary protein should be reduced if maximum profit is to be maintained on the farm.

The improvement in uniformity of body and carcass weight as the dietary protein content is increased, and the difference in this measure between gilts and boars, adds weight to the above argument that gilts and boars should be reared separately.

General Discussion

The objective of this study had a dual purpose: to demonstrate how performance, productivity and profitability of the grower-finisher units on the Joseph Baynes Estate could be improved with the use of separate-sex feeding and dynamic feeding strategies in response to changing economic scenarios, and to evaluate the EFG Pig Growth Model and Optimiser as a means of achieving these objectives. The Joseph Baynes Trust is committed to agricultural research and development, with the goal of improving on-farm productivity, so it was fitting to conduct the study in the research facilities on this Estate.

The economic scenario on a farm can be predicted through annual cycles of consumer demand and raw material supply, which influence the pork and feed prices, respectively. Tables of nutrient requirements are inappropriate when making nutritional decisions aimed at maximising profit for the enterprise under different economic circumstances. Opportunities arise when economic conditions change, and these need to be grasped immediately if maximum benefit is to be obtained. This can best be achieved by predicting performance, but use can also be made of responses to dietary protein such as those generated in the exercise reported in Chapter 2 of this thesis. The results of this study demonstrated that it is worth changing the nutrient specifications in response to changes in raw material prices, and that the EFG Pig Growth Model is sufficiently accurate in predicting feed intake, growth rate and carcass composition to make it a suitable means of predicting performance and hence optimising the way in which pigs should be fed under different economic circumstances.

Because the pork market is dynamic, the feeding strategies applied on the farm should be dynamic too. The research conducted in this study clearly demonstrates that a dynamic approach to feed formulation can be applied on the farm, allowing the nutritionist to be proactive when making decisions, thereby improving performance, productivity and profitability.

Tables and Figures

Figure 1. Weekly average abattoir purchase price in South Africa (SAPPO, 2022a).

Figure 2. Monthly average SAFEX price, R/ton (SAPPO, 2022b).

Figure 3. Relative meat prices in South Africa (BFAP, 2020).

Figure 4. Pork producer price versus feed price (BFAP, 2013).

Figure 5. The compensatory responses in fat growth when animals are made either fatter or leaner than their preferred or desired level of fatness (from Emmans, 1987a).

Figure 6. The relationship between desired feed intake, maintenance requirements, humidity, temperature and thermal stress (Adapted from Emmans, 1990 and NRC, 1981).

Figure 7. Framework of the processes involved in modelling growth and feed intake and the subsequent commercial application (after Emmans & Oldham, 1988).

Figure 2.1. Effect of dietary isoleucine content on feed intake in broiler chickens (after Burnham et al., 1992).

Figure 2.2. Response in lipid content and feed conversion efficiency to a range of dietary isoleucine concentrations in broiler chickens (after Burnham et al., 1992).

Figure 2.3. Cold carcass weight (kg) of gilts (solid line, ▲) and boars (dashed line, ●) in response to increasing dietary protein content (relative to the recommended amino acid (and hence dietary protein) levels being used commercially on Baynesfield Estate.

Figure 2.4. Uniformity in body weight, as measured by the coefficient of variation, %, of boars (▲, dashed line) and gilts (○, solid line) fed a range of dietary protein contents over a 12-week growing period. [1] Dietary protein contents represent the proportion of the recommended amino acid (and hence dietary protein) levels being used commercially on Baynesfield Estate.

Figure 2.5. Fitted polynomial regressions illustrating the change in margin over feed cost in gilts (solid line) and boars (dashed line) at three prices of protein-containing ingredients (base ●, +25 % ■, -25 % ▲). Arrows denote the maximum margin.

References

Affentranger, P., Gerwig, C., Seewer, G.J.F., Schwörer, D. and Künzi, N., 1996. Growth and carcass characteristics as well as meat and fat quality of three types of pigs under different feeding regimens. *Livestock Production Science*, *45*(2-3), pp.187-196.

Agricultural Research Council (Great Britain and Commonwealth Agricultural Bureaux, 1981. *The nutrient requirements of pigs: technical report*. Farnham Royal: Commonwealth Agricultural Bureaux.

Amills, M., Clop, A., Ramírez, O. and Pérez-Enciso, M., 2010. Origin and genetic diversity of pig breeds. *eLS*.

Armsby, H. P. & Fries, J. A., 1915. Net energy values of feeding-stuffs for cattle. *Journal of Agricultural Research* 3, 435491.

Azevedo, J.M., de Paula Reis, M., Gous, R.M., de Paula Dorigam, J.C., Leme, B.B. and Sakomura, N.K., 2021. Response of broilers to dietary balanced protein. 1. Feed intake and growth. *Animal Production Science*, *61*(14), pp.1425-1434.

Baker, D.H. and Johnson, R.W., 1999. Disease stress, cytokines and amino acid needs of pigs. *Pig news and information*, *20*(4), p.123N.

Berhe, E.T. and Gous R.M. (2008) Effect of dietary protein content on growth, uniformity and mortality of two commercial broiler strains. *South African Journal of Animal Science* 38: 293 - 302.

BFAP. 2013. Evaluating the South African pork value chain. Bureau for Food and Agricultural Policy. [Available on the internet:] www.bfap.co.za, 28 June 2021.

BFAP. 2014. Evaluating the competitiveness of South African pork production within the global context. Bureau for Food and Agricultural Policy. [Available on the internet:] www.bfap.co.za, 28 June 2021.

BFAP. (2020). Baseline – Agricultural Outlook. [Available on the internet:] www.bfap.co.za, 28 June 2021.

Black, J.L., Campbell, R.G., Williams, I.H., James, K.J. and Davies, G.T., 1986. Simulation of energy and amino acid utilisation in the pig. Research and Development in Agriculture. 3(3):121-145. http://hdl.handle.net/102.100.100/271908?index=1

Black, J.L., Mullan, B.P., Lorschy, M.L. and Giles, L.R., 1993. Lactation in the sow during heat stress. *Livestock Production Science*, *35*(1-2), pp.153-170.

Black, J.L., Bray, H.J. and Giles, L.R., 1999. The thermal and infectious environment. In: Kyriazakis, I. (ed.) *A Quantitative Biology of the Pig*. CABI Publishing, Oxon. pp.71-97.

Boisen, S., Hvelplund, T. and Weisbjerg, M.R., 2000. Ideal amino acid profiles as a basis for feed protein evaluation. *Livestock Production Science*, *64*(2-3), pp.239-251.

Brouns, F., Edwards, S.A. and English, P.R., 1991. Fibrous raw materials in sow diets: effects on voluntary food intake, digestibility and diurnal activity patterns. *Proceedings of the British Society of Animal Production (1972)*, *1991*, pp.127-127.

Bruwer, G. G. (1992). The evaluation of pig carcasses for the development of a classification system. Ph.D.

Dissertation, University of Pretoria, Pretoria, South Africa.

Busk, H., Olsen, E.V. and Brøndum, J., 1999. Determination of lean meat in pig carcasses with the AutoFom classification system. *Meat Science*, *52*(3), pp.307-314.

Burnham, D., Emmans, G.C. and Gous, R.M., 1992. Isoleucine requirements of the chicken: the effect of excess leucine and valine on the response to isoleucine. *British Poultry Science*, *33*(1), pp.71-87.

Chapple, R.P., 1993. Effect of stocking arrangement on pig performance. *Manipulating pig production IV*, *87*. E. S Batterham, ed. Australian Pig Science Association, Victoria.

Clark, F.A., Gous, R.M. and Morris, T.R., 1982. Response of broiler chickens to well-balanced protein mixtures. *British Poultry Science*, *23*(5), pp.433-446.

Coyne, J.M., Berry, D.P., Mäntysaari, E.A., Juga, J. and McHugh, N., 2015. Comparison of fixed effects and mixed model growth functions in modelling and predicting live weight in pigs. *Livestock Science*, *177*, pp.8-14.

De Greef, K.H., 1992. *Prediction of production: Nutrition induced tissue partitioning in growing pigs*. Ph D Thesis, Wageningen University and Research.

De Lange, C.F.M., Gillis, A.M. and Simpson, G.J., 2001. Influence of threonine intake on whole-body protein deposition and threonine utilization in growing pigs fed purified diets. *Journal of Animal Science*, *79*(12), pp.3087-3095.

De Lange, C.F.M., 2004. A systems approach to optimizing phosphorus and nitrogen utilization in the growing pig. *Proceedings of 25th Western Nutrition Conference*, Saskatoon, pp. 226-246.

Dugan, M.E., Vahmani, P., Turner, T.D., Mapiye, C., Juárez, M., Prieto, N., Beaulieu, A.D., Zijlstra, R.T., Patience, J.F. and Aalhus, J.L., 2015. Pork as a source of omega-3 (n-3) fatty acids. *Journal of Clinical Medicine*, *4*(12), pp.1999-2011.

Eastwood, M.A., 1973. Vegetable fibre: its physical properties. *Proceedings of the Nutrition Society*, *32*(3), pp.137-143.

EFG Software. 2019. Pig Growth Model (version 2) and Pig Nutrition Optimiser (version 1). Accessed January 2019 from www.efgsoftware.net

Emmans, G., 1981. 3.3 A model of the Growth and Feed Intake of Ad Libitum Fed Animals, Particularly Poultry. *BSAP Occasional Publication*, *5*, pp.103-110.

Emmans, G.C. and Fisher, C., 1986. Problems in nutritional theory*, in: Fisher, C. & Boorman, K.N. (Eds) Nutrient Requirements of Poultry and Nutritional Research, pp 9-39 (London, Butterworths).*

Emmans, G.C., 1987a. Growth, body composition and feed intake. *World's Poultry Science Journal*, *43*(3), pp.208-227.

Emmans, G.C., 1987b. The genetic variables and efficiency constants [for poultry]. In *Third International Poultry Breeders' Conference. Ayr (UK). 24-25 Mar 1987.*

Emmans, G.C. and Oldham, J.D., 1988. Modelling of growth and nutrition in different species. *Modelling of livestock production systems*, pp.13-21.

Emmans, G., 1989. The growth of turkeys. in: Nixey, C., Grey, T.C. (Eds) *Recent Advances in Turkey Science*, pp. 135-166 (Butterworths, London).

Emmans, G.C., 1995. Problems in modelling the growth of poultry. *World's Poultry Science Journal*, *51*(1), pp.77-89.

Emmans, G.C., 1994. Effective energy: a concept of energy utilization applied across species. *British Journal of Nutrition*, *71*(6), pp.801-821.

Emmans, G.C. and Kyriazakis, I., 1995. A general method for predicting the weight of water in the empty bodies of pigs. *Animal Science*, *61*(1), pp.103-108.

Emmans, G.C., 1997. A method to predict the food intake of domestic animals from birth to maturity as a function of time. *Journal of Theoretical Biology*, *186*(2), pp.189-199.

Escobar, J., Van Alstine, W.G., Baker, D.H. and Johnson, R.W., 2002. Growth performance and whole-body composition of pigs experimentally infected with Mycoplasma hyopneumoniae. *Journal of Animal Science*, *80*(2), pp.384-391.

FAO. (2009). How to feed the world in 2050. Food and Agriculture Organization. [Available on the internet:] www.fao.org, 28 June 2021.

Ferguson, N.S. & Gous, R.M., 1993. Evaluation of pig genotypes: (1) Theoretical aspects of measuring genetic parameters. *Animal Production* 56, 233-243.

Ferguson, N.S. and Gous, R.M., 1997. The influence of heat production on voluntary food intake in growing pigs given protein-deficient diets. *Animal Science*, *64*(2), pp.365-378.

Ferguson, N.S., Arnold, G.A., Lavers, G. and Gous, R.M., 2000a. The response of growing pigs to amino acids as influenced by environmental temperature. 1. Threonine. *Animal Science*, *70*(2), pp.287-297.

Ferguson, N.S., Arnold, G.A., Lavers, G. and Gous, R.M., 2000b. The response of growing pigs to amino acids as influenced by environmental temperature. 2. Lysine. *Animal Science*, *70*(2), pp.299-306.

Ferguson, N.S., Lavers, G. and Gous, R.M., 2001. The effect of stocking density on the responses of growing pigs to dietary lysine. *Animal Science*, *73*(3), pp.459-469.

Ferguson, N.S. and Theeruth, B.K., 2002. Protein and lipid deposition rates in growing pigs following a period of excess fattening. *South African Journal of Animal Science*, *32*(2), pp.97-105.

Ferguson, N.S. and Kyriazis, S.T., 2003a. Evaluation of growth parameters of six commercial crossbred pig genotypes 1. Under commercial housing conditions in individual pens. *South African Journal of Animal Science* 33, 11-20.

Ferguson, N.S. and Kyriazis, S.T, 2003b. Evaluation of growth parameters of six commercial crossbred pig genotypes 1. Under ideal temperature conditions in chambers. *South African Journal of Animal Science*

33, 21 - 26.

Ferguson, N.S., 2006. Basic concepts describing animal growth and feed intake. *Mechanistic modelling in pig and poultry production*, eds RM Gous, TR Morris and C Fisher, pp. 22-53. CABI, Wallingford, UK.

Ferguson, N.S., 2008. Application of an integrated management system to improve performance and profitability in finishing pigs. *Advances in Pork Production*, *19*, pp.85-91.

Ferguson, N., Sakmoura, N.K., Gous, R., Kyriazakis, L. and Hauschild, L., 2015. Commercial application of integrated models to improve performance and profitability in finishing pigs. *Nutritional modelling for pigs and poultry (ed. Sakomura, NK, Gous, RM, Kyriazakis, I and Hauschild, L)*, pp.141-156.

Ferguson, N.S., 2015. Commercial Application of Integrated Models to Improve Performance and Profitability in Finishing Pigs. CAB International 2015. Nutritional Modelling for Pigs and Poultry (eds N.K. Sakomura, R.M. Gous, I. Kyriazakis & L. Hauschild)

Gordjin, R., 2014. Economics of pig production. *Modern Pig Production 17(1)*, pp. 465-498.

Gous, R.M. and Morris, T.R., 1985. Evaluation of a diet dilution technique for measuring the response of broiler chickens to increasing concentrations of lysine. *British Poultry Science*, *26*(2), pp.147-161.

Gous, R.M., Griessel, M. and Morris, T.R., 1987. Effect of dietary energy concentration on the response of laying hens to amino acids. *British Poultry Science*, *28*(3), pp.427-436

Gous, R.M., Emmans, G.C., Broadbent, L.A. and Fisher, C., 1990. Nutritional effects on the growth and fatness of broilers. *British Poultry Science*, *31*(3), pp.495-505.

Gous, R.M., 2014. The role of simulation modelling in optimizing pig production. *Modern Pig Production 19*(1), pp. 511-521.

Green, D.M. and Whittemore, C.T., 2003. Architecture of a harmonized model of the growing pig for the determination of dietary net energy and protein requirements and of excretions into the environment (IMS Pig). *Animal Science*, *77*(1), pp.113-126.

Greiner, L.L., Stahly, T.S. and Stabel, T.J., 2000. Quantitative relationship of systemic virus concentration on growth and immune response in pigs. *Journal of animal science*, *78*(10), pp.2690-2695.

Hugo, A. and Roodt, E., 2015. Fat quality of South African pigs with different carcass classification characteristics. *South African Journal of Animal Science*, *45*(3), pp.302-312.

Hyun, Y., Ellis, M., Riskowski, G. and Johnson, R.W., 1998. Growth performance of pigs subjected to multiple concurrent environmental stressors. *Journal of animal science*, *76*(3), pp.721-727.

Kemp, C., Fisher, C. and Kenny, M., 2005. Genotype-nutrition interactions in broilers; response to balanced protein in two commercial strains. In *Proceedings of the 15th European Symposium on poultry nutrition, Balatonfüred, Hungary, 25-29 September, 2005* (pp. 54-56). World's Poultry Science Association (WPSA).

Knap, P.W., 2000a. *Variation in maintenance requirements of growing pigs in relation to body composition: a simulation study*. Wageningen University and Research.

Knap, P.W., 2000b. Time trends of Gompertz growth parameters in 'meat-type' pigs. *Animal Science*, *70*(1), pp.39-49.

Kornegay, E.T. and Notter, D.R., 1984. Effects of floor space and number of pigs per pen on performance. *Pig News and Information*.

Kyriazakis, I. and Emmans, G.C., 1991. Diet selection in pigs: dietary choices made by growing pigs following a period of underfeeding with protein. *Animal Science*, *52*(2), pp.337-346.

Kyriazakis, I. and Emmans, G.C., 1992a. The effects of varying protein and energy intakes on the growth and body composition of pigs: 1. The effects of energy intake at constant, high protein intake. *British journal of Nutrition*, *68*(3), pp.603-613.

Kyriazakis, I. and Emmans, G.C., 1992b. The effects of varying protein and energy intakes on the growth and body composition of pigs: 2. The effects of varying both energy and protein intake. *British Journal of Nutrition*, *68*(3), pp.615-625.

Kyriazakis, I. and Emmans, G.C., 1995. The voluntary feed intake of pigs given feeds based on wheat bran, dried citrus pulp and grass meal, in relation to measurements of feed bulk. *Genetics and Behavioural Sciences Department,* Scottish Agricultural College. Edinburgh.

Leeson, S. and Caston, L.J., 1991. Response of two strains of turkey hens to various protein and energy feeding programs. *Poultry Science*, *70*(8), pp.1739-1747.

Leeson, S., Caston, L. and Summers, J.D., 1996a. Broiler response to diet energy. *Poultry science*, *75*(4), pp.529-535.

Leeson, S., Caston, L. and Summers, J.D., 1996b. Broiler response to energy or energy and protein dilution in the finisher diet. *Poultry Science*, *75*(4), pp.522-528.

Lemme, A., Wijtten, P.J.A., Van Wichen, J., Petri, A. and Langhout, D.J., 2006. Responses of male growing broilers to increasing levels of balanced protein offered as coarse mash or pellets of varying quality. *Poultry Science*, *85*(4), pp.721-730.

Matteri, R.L., Carroll, J.A. and Dyer, C.J., 2000. Neuroendocrine responses to stress. *The biology of animal stress: basic principles and implications for animal welfare*, *43*. CABI Digital Library.

Moberg, G.P., 2000. Implications for Animal Welfare. *The biology of animal stress: basic principles and implications for animal welfare*, p.1.

McGlone, J.J., 2013. The future of pork production in the world: towards sustainable, welfare-positive systems. *Animals*, *3*(2), pp.401-415.

Morgan, C.A., Nielsen, B.L., Lawrence, A.B. and Mendl, M.T., 1999. Describing the social environment and its effects on food intake and growth.

Moughan, P.J., Smith, W.C. and Stevens, E.V.J., 1990. Allometric growth of chemical body components and several organs in the pig (20–90 kg liveweight). *New Zealand Journal of Agricultural Research*, *33*(1), pp.77-84.

Moughan, P.J. (1999) Protein metabolism in the growing pig. In: Kyriazakis, I. (ed.) *A Quantitative Biology of the Pig*. CABI Publishing, Oxon, pp. 299-331.

Mount, L.E. (1975) The assessment of thermal environment in relation to pig production. *Livestock Production Science* 2, 381-392.

Myburgh, R., 2019. *Verification of the South African pork classification system* (Doctoral dissertation, University of the Free State).

NRC. (1981). Shematic partition of energy in the animal. [Available on the internet:] www.researchgate.net/figure/Schematic-partition-of-energy-in-the-animal-NRC-1981_fig1, 28 June 2021.

OECD. (2018). Meat consumption (indicator). Organisation for Economic Cooperation and Development. [Available on internet:] www.data.oecd.org, 28 June 2021.

Owen, J.B. and Ridgman, W.J., 1967. The effect of dietary energy content on the voluntary intake of pigs. *Animal Science*, *9*(1), pp.107-113.

Pomar, C., Harris, D.L. and Minvielle, F., 1991. Computer simulation model of swine production systems: I. Modelling the growth of young pigs. *Journal of Animal Science*, *69*(4), pp.1468-1488.

Richards, F.J., 1959. A flexible growth function for empirical use. *Journal of experimental Botany*, *10*(2), pp.290-301.

Roan, S.W., 1991. *Bio-economic Models for the Simulation of the Production and Management of the Growing Pigs and Sows* (Doctoral dissertation, University of Edinburgh).

Roberts, R.C., 1979. Side effects of selection for growth in laboratory animals. *Livestock Production Science*, *6*(1), pp.93-104.

Robinson, J. (2014). The golden and proven guidelines in pig production. *Modern Pig Production* 18A, 501-505.

SAMIC. (2006). South African Meat Industry Company. [Available on internet:] www.samic.co.za, 28 June 2021.

SAPPO. (2022a). Domestic Carcass Price Statistics. [Available on the internet:] www.sappo.org, 1 February 2022.

SAPPO. (2022b) Raw Material Statistics. [Available on the internet:] www.sappo.org, 1 February 2022.

Schinckel, A.P. and De Lange, C.F.M., 1996. Characterization of growth parameters needed as inputs for pig growth models. *Journal of Animal Science*, *74*(8), pp.2021-2036.

Soest, P.V., 1963. Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fibre and lignin. *Journal of the Association of official Agricultural Chemists*, *46*(5), pp.829-835.

Sosnicki, A.A., Mathews, N., Fields, B., & Jungst, S. (2010). Pork Fat Quality. [Available on internet:]

www.engormix.com, 28 June 2021.

Topigs Norsvin TN70. (n.d.). *Home*. [Available on the internet:] www.tn70.topigsnorsvin.com, 7 December 2021.

Tsaras, L.N., Kyriazakis, I. and Emmans, G.C., 1998. The prediction of the voluntary food intake of pigs on poor quality foods. *Animal Science*, *66*(3), pp.713-723.

USDA. (2017). The South African pork market. United States Department of Agriculture. [Available on internet:] www.fas.usda.gov, 28 June 2021.

Visser, D.P., 2006. *Structuring of breeding objectives in the pork supply chain in South Africa* (Doctoral dissertation, University of Pretoria).

Webster, J., 2016. Animal welfare: Freedoms, dominions and “a life worth living”. *Animals*, *6*(6), p.35.

Wellock, I.J., Emmans, G.C. and Kyriazakis, I., 2003a. Modelling the effects of thermal environment and dietary composition on pig performance: model logic and concepts. *Animal Science*, *77*(2), pp.255-266.

Wellock, I.J., Emmans, G.C. and Kyriazakis, I., 2004. Describing and predicting potential growth in the pig. *Animal Science*, *78*(3), pp.379-388.

White, S., 2011. From globalized pig breeds to capitalist pigs: a study in animal cultures and evolutionary history. *Environmental History*, *16*(1), pp.94-120.

Whittemore, C.T. and Fawcett, R.H., 1976. Theoretical aspects of a flexible model to stimulate protein and lipid growth in pigs. *Animal Science*, *22*(1), pp.87-96.

Whittemore, C.T., 1983. Development of recommended energy and protein allowances for growing pigs. *Agricultural systems*, *11*(3), pp.159-186.

Whittemore, C.T., Green, D.M. and Knap, P.W., 2001a. Technical review of the energy and protein requirements of growing pigs: food intake. *Animal Science*, *73*(1), pp.3-17.

Whittemore, C.T., Green, D.M. and Knap, P.W., 2001c. Technical review of the energy and protein requirements of growing pigs: protein. *Animal Science*, *73*(3), pp.363-373.

Whittemore, E.C., Emmans, G.C. and Kyriazakis, I., 2003. The relationship between live weight and the intake of bulky foods in pigs. *Animal Science*, *76*(1), pp.89-100.

Wu, G., M.M. Bryant, P. Gunawardana and D.A. Roland Sr**.** 2007. Effect of nutrient density on performance, egg components, egg solids, egg quality and profits in eight commercial Leghorn strains during phase one. Poultry Science 86:691-697.

Appendix 1: Ethics Approval 1

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

13 October 2020

Ms Chantel Gwen Pennicott (220110846)
School of Agricultural, Earth & Environ Sciences
Pietermaritzburg

Dear Ms Pennicott,

Protocol reference number: AREC/001/020M
Project title: Economic optimum nutrition of growing pigs at Baynesfield.

Full Approval

This letter serves to notify you that your updated abattoir certificate was received. The Animal Research Ethics Committee has accepted the documents submitted, and **FULL APPROVAL** for the protocol has been granted.

This approval is valid for one year from 13 October 2020.

To ensure uninterrupted approval of this study beyond the approval expiry date, a progress report must be submitted to the Research Office on the appropriate form 2 - 3 months before the expiry date.

Please note: There must be adherence to national and institutional regulations and guidelines at all times. Researchers will be personally responsible and liable for non-adherence to national regulations. If in doubt, please contact the Research Ethics Chair and/or the University Dean of Research for advice.

Please note: Any Veterinary and Para-Veterinary procedures must be conducted by a SAVC registered VET or SAVC authorized person.

Any alteration/s to the approved research protocol, i.e Title of Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number.

Please note: Research data should be securely stored in the discipline/department for a period of 5 years.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

[redacted]

Dr Sanil D Singh, PhD
Chair: Animal Research Ethics Committee

/kr

cc Supervisor: Prof RM Gous

Animal Research Ethics Committee (AREC)
Ms Karen Reinertsen (Administrator)
Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000
Telephone: +27 (0) 31 260 8350 Facsimile: +27 (0) 31 260 4609 Email: animalethics@ukzn.ac.za
Website: http://research.ukzn.ac.za/Research-Ethics/Animal-Ethics.aspx

1910 - 2010
100 YEARS OF ACADEMIC EXCELLENCE

Founding Campuses: Edgewood Howard College Medical School Pietermaritzburg Westville

Appendix 2: Ethics Approval 2

UNIVERSITY OF KWAZULU-NATAL ™
INYUVESI YAKWAZULU-NATALI

05 November 2020

Ms Chantel Gwen Pennicott (220110846)
School of Agricultural, Earth & Environmental Sciences
Pietermaritzburg

Dear Ms Pennicott,

Protocol reference number: AREC/029/020M
Project title: Measuring the response to dietary balanced protein in growing pigs.

Full Approval – Research Application

With regard to your revised application received on 28 October 2020, the Animal Research Ethics Committee has accepted the documents submitted and FULL APPROVAL for the protocol has been granted.

Please note: There must be adherence to national and institutional COVID-19 regulations and guidelines at all times. Researchers will be personally responsible and liable for non-adherence to national regulations. If in doubt, please contact the Research Ethics Chair and/or the University Dean of Research for advice.

Please note: Any Veterinary and Para-Veterinary procedures must be conducted by a SAVC registered VET or SAVC authorized person.

Any alteration/s to the approved research protocol, i.e Title of Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number.

Please note: Research data should be securely stored in the discipline/department for a period of 5 years.

The ethical clearance certificate is only valid for a period of one year from the date of issue. Renewal for the study must be applied for before 03 August 2021.

Attached to the Approval letter is a template of the Progress Report that is required at the end of the study, or when applying for Renewal (whichever comes first). An Adverse Event Reporting form has also been attached in the event of any unanticipated event involving the animals' health / wellbeing.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

[redacted]

Dr Sanil D Singh, PhD
Chair: Animal Research Ethics Committee

/kr
cc Supervisor: Prof RM Gous

Animal Research Ethics Committee (AREC)
Ms Karen Reinertsen (Administrator)
Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000
Telephone: +27 (0) 31 260 8350 **Facsimile:** +27 (0) 31 260 4609 **Email:** animalethics@ukzn.ac.za
Website: http://research.ukzn.ac.za/Research-Ethics/Animal-Ethics.aspx

1910 - 2010
100 YEARS OF ACADEMIC EXCELLENCE

Founding Campuses: Edgewood | Howard College | Medical School | Pietermaritzburg | Westville

Appendix 3: Turnitin Report

Economic Optimum Nutrition of Growing Pigs

ORIGINALITY REPORT

8%	6%	6%	1%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to University of Stellenbosch, South Africa Student Paper	<1%
2	www.publish.csiro.au Internet Source	<1%
3	scholar.ufs.ac.za Internet Source	<1%
4	www.cambridge.org Internet Source	<1%
5	lib.bioinfo.pl Internet Source	<1%
6	orbit.dtu.dk Internet Source	<1%
7	Ferguson, N.S., M.M.V. Bradford, and R.M. Gous. "Diet selection priorities in growing pigs offered a choice of feeds", South African Journal of Animal Science, 2002. Publication	<1%
8	ulspace.ul.ac.za Internet Source	<1%