SIMULATION OF PRODUCTIVITY IN PIGS: EFFECTS OF GENOTYPE, DIET AND ENVIRONMENT

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Summary

Many of the factors that affect growth and productivity of pigs in Australia have been incorporated into a computer program that simulates energy and amino acid utilization in animals from birth to maturity. The structure and scope of the model are briefly outlined, its accuracy assessed and its current limitations noted.

The model is used to show how the amino acid requirements of pigs are affected by the strain, sex, feed intake and reproductive state of the animal. The effect on productivity of altering both the energy and protein contents of the diet is demonstrated and the consequences on profitability of feeding pigs for maximum rate of lean growth is assessed.

I. INTRODUCTION

Productivity of pigs is affected by many factors including strain and sex, amount and composition of feed eaten, environmental conditions within a shed and the penning arrangement of pigs. Although much is known about how each of these factors affects animal performance, the interactions between them often make it difficult to assess the likely profitability of different management strategies. Thus, a computer program that integrates this information has been developed to assist decision making in piggeries. This program simulates energy and amino acid utilization in pigs from birth to maturity. It differs from others (Whittemore and Fawcett 1976; Phillips and MacHardy 1982; Tess et al. 1983; Moughan and Smith 1984) because it contains information derived from genotypes used in Australia, it considers the effects of both hot and cold conditions, it predicts the performance of growing as well as reproducing animals and it deals more comprehensively with the interactions between genotype, diet and body composition. In this paper, the components of the model are briefly outlined, its accuracy is assessed and several examples of its uses are illustrated. Finally, current limitations to the model are discussed and areas requiring additional research are noted.

II. SCOPE OF SIMULATION MODEL

A full description of the computer simulation model is given by Black et al. (1986). It predicts on a daily basis, energy and amino acid utilization, body weight change, body composition, dressing percentage of the carcass and backfat thickness for entire or castrated male pigs and for female pigs of any age or reproductive state. Two strains of pig are represented: those resembling animals from the large commercial piggeries where considerable progress has been made in selecting pigs with fast growth rates and lean carcasses, and those from smaller piggeries with less intense selection. Weaning-to-conception interval is calculated for breeding sows from liveweight at the end of lactation and the duration of lactation. Litter size is estimated from the genotype and parity of the sow, and

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potential milk yield is affected by both parity and number of piglets. The model also accounts for the effects on productivity of increased energy expenditure associated with cold exposure. Voluntary feed intake is reduced in hot conditions when the animals are unable to dissipate sufficient heat to maintain body temperature. Finally, the profit per pig, per pig per day or per pig place per year, is calculated from cumulative feed intake, the cost of feed, the likely proportion of pigs in each carcass grade and the price paid per kg of carcass.

The major steps in the calculations are as follows. Feed intake is first determined from one of four options: daily intake can be specified and the amount or composition of the feed changed at intervals; the quantity of feed needed to produce either a specified rate of growth or to obtain the maximum rate of lean growth can be determined; or voluntary feed intake predicted. Voluntary intake is calculated from the maximum capacity of the animal to utilize energy for all body functions. It varies with the body weight, genotype and reproductive state of the animal, it is reduced when the animals consume protein-inadequate diets or when they are exposed to hot conditions, and it is increased when they are cold. Feed intake can also be limited by gut capacity which is predicted from body weight and the digestible energy content of the diet. Feed intakes of the magnitude recorded under experimental conditions are not always achievable in the environment of commercial piggeries. Thus, a factor has been introduced into the model to scale voluntary intake for a particular enterprise on the basis of observations in that piggery.

The intake of metabolizable energy and the quantity of individual amino acids absorbed are then calculated from the intake and composition of the diet. The available nutrients are partitioned between competing body functions with priority being given in order to maintenance, conceptus, milk and body growth. Differences between genotypes in growth and body composition are accommodated by defining for each type of animal simulated the parameters required, first, to predict the potential rates of energy and protein deposition in relation to body weight and second, those that predict the rate of change in protein deposition with changes in the intake of metabolizable energy. The order of potential limitation of each essential amino acid and of cystine plus methionine, and of tyrosine plus phenylalanine is determined and the amount of additional amino acid required each day or in each kg of feed is predicted and printed out at specified intervals.

Daily rates of gain of body protein and body fat are calculated from the retention of amino acids and energy. Liveweight gain is then determined from these parameters, conceptus growth and gut fill. Total birthweight of piglets born is assumed to be 60% of conceptus weight at parturition and the mean birth weight of each piglet is calculated from litter size.

Carcass weight is calculated from liveweight on the basis of a relationship established for pigs from the Animal Research Institute, Werribee. Maximum dressing percentage is constrained to 83 with values for females and castrates being 2 units higher than those for boars of the same weight. Dressing percentage is also reduced in animals weighing more than 70 kg when the digestible energy content of the diet is less than 14 MJ/kg to allow for the increased gut fill. Because the dressing percentage obtained for commercially reared pigs varies greatly depending upon the time of weighing in relation to slaughter, the tissues removed from the carcass during dressing and the constants used by the abattoir to adjust hot carcass weight to cold carcass weight, a factor is introduced to allow individual enterprises to scale dressing percentage to that commonly obtained. Backfat thickness, measured as P_2 (that is, 6.5 cm from the midline opposite the head of the last rib), is predicted from the fat content of the empty body using a relationship established mainly from pigs at the Animal Research Institute, Werribee.

III. OPERATION OF MODEL

(a) Information required to operate model

Information about the animal, its diet and the environment is required to operate the model. The strain, sex and initial liveweight of the animal must be stipulated as well as the number of pigs in each pen. If a sow is to reproduce, information must be provided on its age at mating as a gilt, the parity numbers at which it does not conceive at first mating, the age of piglets at weaning and the expected number of piglets born alive at the sixth pregnancy. The diet is described in terms of its crude protein, amino acid, neutral detergent fibre and digestible energy content. The availability of dietary lysine is also needed and the method required to determine feed intake must be stipulated. The environment at pig level is described in terms of floor type, maximum and minimum temperatures in mid-summer and mid-winter, relative humidity and the rate of air movement in mid-summer, mid-autumn, mid-winter and mid-spring. The number of carcass weight and P_2 classes in the grading system must be specified as well as the values for each that mark the class boundaries. Information is also required on the initial value of the pig, the cost per tonne of feed and the price per kg of carcasses in each P_2 class within each carcass weight class.

(b) Operation procedures

Currently the simulation model is on a CSIRO computer and it can be accessed by registered CSIRONET users. The procedures for becoming a registered user and for operating the model have been described by the Standing Committee on Agriculture (SCA, 1986); this information is also available from the authors.

IV. MODEL BEHAVIOUR

(a) Comparison of predictions and experimental observations

(i) The growing pig Several comparisons between predictions from the model and experimental observations for growing pigs of different genotype show close agreement (Black et al. 1986). For example, R.G. Campbell (personal communication) grew entire male pigs at the Animal Research Institute, Werribee, from 25 kg with feed intakes ranging from 0.55 of ad libitum to ad libitum. The diet contained 14.6 MJ/kg of digestible energy, 207 g/kg crude protein and 12.3 g/kg lysine. The experimental observations and predictions for pigs slaughtered at 45 and 105 kg are shown in Figs. 1 and 2, respectively. The predicted and observed (± s.e.) ad libitum feed intakes for pigs slaughtered at 45 and 105 kg were, respectively, 1.89 and 1.99(±0.03), and 2.50 and 2.45(±0.04) kg/d. Predicted liveweight gain and P_2 backfat thickness were both within two standard deviations of those observed for all levels of feed intake.

(ii) The lactating pig The results of King and Dunkin (1986) are used for comparison with the model predictions for a breeding sow. Gilts weighing about 120 kg at mating were fed 2 kg/d of a diet containing 12.6 MJ/kg of digestible energy and 146 g/kg crude protein throughout pregnancy and after lactation. During the 28 day lactation, feed intake ranged from 1.5 to 4.8 kg/d. Predictions and experimental results for four of the six treatments are given in Table 1. The predicted changes in liveweight, backfat thickness, nitrogen utilization and weaning-to-mating interval all show fair agreement with the observations at each level of intake. Although milk yield was not measured in the experiment, growth rate of piglets was unaffected by feed intake in the early part of lactation, but it was significantly less during the last week for sows given the lowest intake. This observation agrees well with the predictions which showed that the effect of feed intake on milk yield became progressively larger as lactation proceeded.

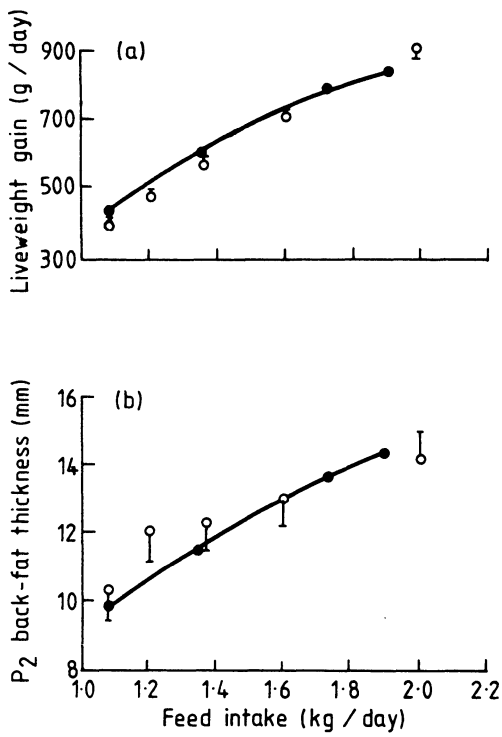

Fig. 1. Predicted relationship (●—●) and experimental observations (o, with standard error) between feed intake and (a) mean liveweight gain and (b) P_2 backfat thickness at 45 kg for entire male pigs bred at Animal Research Institute, Werribee, and grown from 25 to 45 kg.

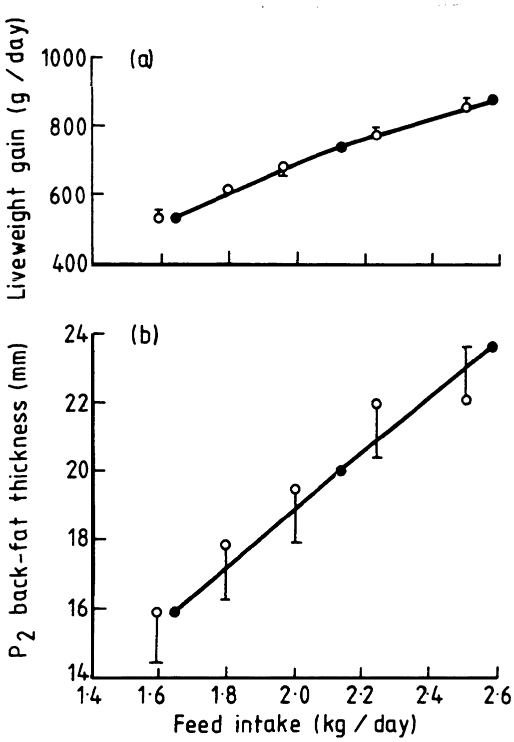

Fig. 2. Predicted relationship (●—●) and experimental observations (o, with standard error) between feed intake and (a) mean liveweight gain and (b) P_2 backfat thickness at 105 kg for entire male pigs bred at the Animal Research Institute, Werribee, and grown from 25 to 105 kg.

Table 1. Experimental observations (O) and predictions (P) of the effects of feed intake during lactation on animal performance. Results from King and Dunkin (1986)

Characteristic	Feed intake during lactation (kg/d)							
	1.5		2.9		3.6		4.8	
	O	P	O	P	O	P	O	P
Liveweight (kg)								
at mating	124	121	116	121	117	121	122	121
after farrowing	157	152	152	152	151	152	153	152
end of lactation	112	109	123	120	131	127	144	141
42 days later	137	131	141	136	144	142	156	153
P_2 backfat (mm)								
after farrowing	25.9	26.2	26.3	26.2	26.4	26.2	26.7	26.2
end of lactation	17.0	16.9	19.9	19.7	20.7	21.5	22.7	23.7
42 days later	16.9	18.1	19.7	20.4	20.5	22.1	23.0	24.1
Weaning to mating (days)	29.8	25.3	21.2	20.1	14.6	16.5	7.8	9.7
Milk yield (kg/d)								
day of lactation 4	-	4.36	-	4.36	-	4.36	-	4.36
" " " 14	-	5.94	-	6.49	-	6.49	-	6.49
" " " 24	-	6.30	-	7.14	-	7.17	-	7.17
Nitrogen balance (g/d)	-45.4*	-42.1†	-29.6*	-25.8†	-27.8*	-19.2†	-15.2*	-6.5†
Milk nitrogen (g/d)	56.3§	47.8§	53.1§	55.5§	57.4§	56.9§	54.7§	56.9§

* For entire lactation; † At day 14 of lactation; § Estimated from piglet growth and milk composition.

Table 2. Amino acid composition of the diet used in the simulation for assessing the amino acid requirements of pigs

Amino acid	g/kg diet	Amino acid	g/kg diet
Alanine	8.3	Valine	10.7
Aspartic acid	11.4	Isoleucine	8.3
Glutamic acid	73.0	Leucine	16.1
Proline	15.0	Threonine	9.1
Serine	10.3	Histidine	4.9
Glycine	9.6	Lysine	14.8
Arginine	10.7	Tryptophan	3.0
Tyrosine	6.4	Phenylalanine	10.8
Cystine	5.0	Methionine	3.8

(b) Prediction of amino acid requirements

The model can be used to illustrate how amino acid requirements of pigs vary with genotype, body weight, reproductive state and feed intake. In the examples given, the diet used in the simulations contained 14.6 MJ/kg of digestible energy, 250 g/kg crude protein and the amino acid composition shown in Table 2.

An output of the program for an entire male pig of the fast growing genotype fed ad libitum and weighing 16 kg is given in Table 3. When the amino acid pattern required for metabolism is compared with that available from the diet, the model shows that the highest efficiency with which the dietary proteins can be used is 0.58. The first three limiting amino acids were methionine, isoleucine and lysine, and the supply of each was predicted to be less than that required by the animal as indicated by the ratio of moles of amino acids available to moles required being less than 1.0. Only 83% of the animal's requirement for methionine was predicted to be satisfied, but the diet supplied 181% of the total nitrogen needed. The model predicted that the pig required 0.62 g/d more methionine, 0.34 g/d more isoleucine and 0.41 g/d more lysine to meet its needs. Negative values in columns 1 and 2 of Table 3 for the other amino acids indicate the amount by which each was available in excess of its requirements. The diet was predicted to supply insufficient methionine until the animal weighed about 30 kg.

Table 3. Model output in relation to amino acid calculations for an entire male pig of the fast-growing genotype weighing 16 kg. (Efficiency of utilization of dietary protein = 0.58)

Limiting amino acid (from most deficient)	Available amino acid required (g/d)	(g/kg diet)	Moles available: moles required
Methionine	0.62	0.64	0.83
Isoleucine	0.34	0.35	0.95
Lysine	0.41	0.42	0.97
Valine	-0.94	-0.96	1.13
Leucine	-1.00	-1.03	1.16
Threonine	-1.80	-1.86	1.17
Histidine	-0.60	-0.61	1.18
Tryptophan	-0.55	-0.57	1.31
Tyrosine + phenylalanine	-0.21	-0.22	1.32
Cystine + methionine	-2.23	-2.30	1.37
Phenylalanine	-2.93	-3.03	1.53
Total nitrogen	-14.37	-14.78	1.81

A similar analysis for the lactating gilt (Table 1) on day 14 of lactation when fed 1.5 kg of a diet containing amino acids in the same proportion as indicated in Table 2, indicates that the dietary protein was used with a much higher efficiency of 0.75, and that tryptophan, methionine and histidine were the first three limiting amino acids.

The model also predicts the amount of available amino acids that are required per MJ of digestible energy or per kg diet and how these are affected by genotype, body weight or feed intake. Shown in Fig. 3 is the predicted requirement for available lysine of a slow growing, entire male pig ranging in weight from 5 to 100 kg and fed either ad libitum or 0.6 ad libitum. Lysine requirement was predicted to be unaffected by feed intake for weights less than about 30 kg, but, above this weight, the requirement was considerably higher when feed intake was restricted. The predicted effect of feed intake on the lysine requirement of an entire male pig of the fast growing genotype weighing 50 kg is also shown in Fig. 4. Lysine requirement rose slightly as intake increased from 400 g/d (0.4 ad libitum) to 690 g/d (0.6 ad libitum) but fell quite steeply as intake was raised further to 1230 g/d (ad libitum). The change in lysine requirement with feed intake occurs because of the linear/plateau relationship between protein deposition and energy intake when protein absorption is not limiting (Dunkin et al. 1985). The maximum amino acid requirement per unit of digestible energy occurs when energy intake is just sufficient to stimulate the potential rate of protein deposition (that is, at the beginning of the plateau in protein deposition with increasing energy). At lower energy intakes, protein deposition is reduced to a greater extent than energy intake because energy is still required for maintenance when body protein deposition ceases and the requirement for amino acids per unit of digestible energy falls. At higher energy intakes, protein deposition remains constant with increasing energy and the requirement also falls. Thus, maximum amino acid requirements coincide with the intake that stimulates the fastest rate of lean growth. The predicted maximum lysine requirements for entire males, females and castrates of both the fast and slow growing genotypes over the range from 5 to 120 kg are given in Fig. 5. Experimental estimates of lysine requirements cover a similar range and confirm that both sex and energy intake have an effect (Campbell et al. 1985; SCA 1986).

The predicted maximum requirement for all the essential amino acids in an entire male of the fast growing genotype weighing 20, 50 or 90 kg is given in Table 4. These estimates are consistent with those suggested from experimental findings by the SCA Working Party on feeding standards for pigs (SCA 1986).

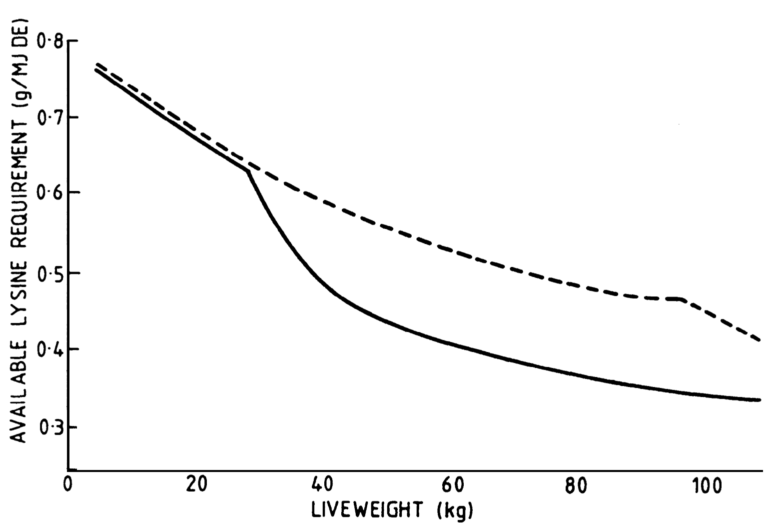

Fig. 3. Predicted relationship between the requirement for available lysine and liveweight for entire male pigs of the slow growing genotype fed either ad libitum (——) or at 0.6 of ad libitum (---).

Table 4. Predicted maximum requirement (g/MJ of digestible energy) for all essential amino acids by an entire male pig of the fast-growing genotype weighing 20, 50 or 90 kg

Amino acid	Live weight (kg)		
	20	50	90
Phenylalanine + tyrosine	0.60	0.42	0.38
Cystine + methionine	0.31	0.21	0.19
Valine	0.44	0.30	0.27
Isoleucine	0.40	0.28	0.25
Leucine	0.63	0.44	0.40
Threonine	0.36	0.25	0.22
Histidine	0.19	0.13	0.12
Lysine	0.70	0.49	0.44
Tryptophan	0.11	0.07	0.07
Phenylalanine	0.32	0.22	0.20
Methionine	0.21	0.14	0.13

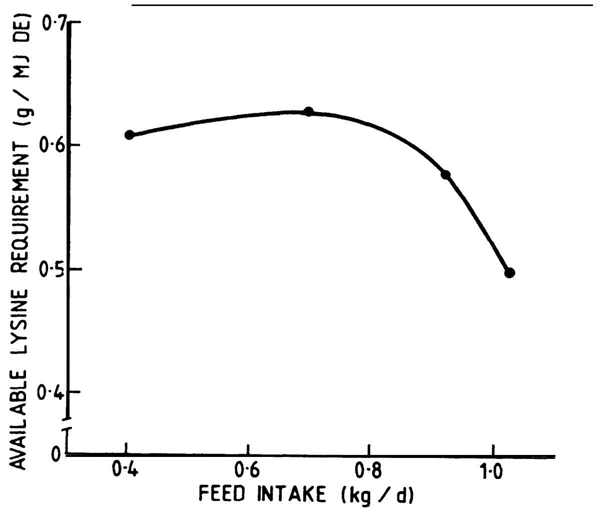

Fig. 4. Predicted relationship between the requirement for available lysine and feed intake for entire male pigs of the fast growing genotype weighing 50 kg.

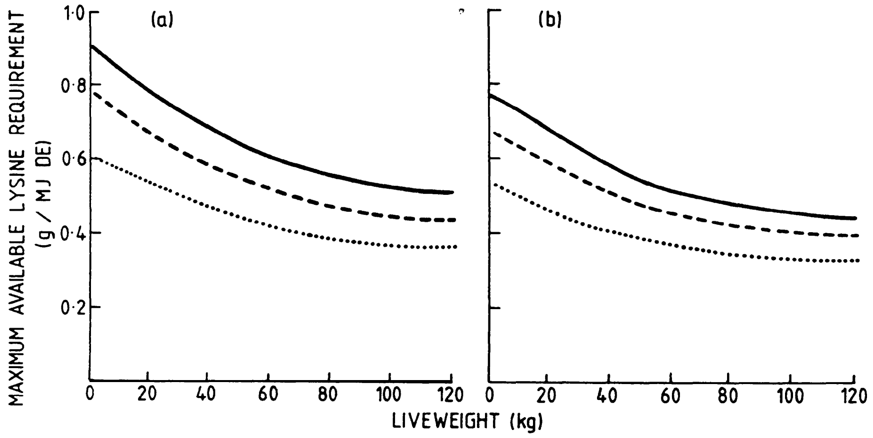

Fig. 5. Predicted maximum lysine requirements that coincide with feed intake that stimulates the fastest rate of lean growth. (a) fast growing genotype; (b) slow growing genotype; (-) entire males; (---) females; (···) castrates.

(c) Effects of diet composition on the performance of growing pigs

(i) Energy content of the diet The predicted effects of reducing the digestible energy content of a diet from 16 to 10 MJ/kg on feed intake and performance of entire male pigs of the slow growing genotype weighing 50 kg are shown in Table 5. An initial reduction from 16 to 14 MJ/kg did not affect the growth rate because feed intake increased to compensate for the reduced energy density of the diet. This was reflected by an increase in the ratio of feed to gain. With a further reduction in energy density to 12 MJ/kg, growth was predicted to decline because the animal was unable to increase feed intake sufficiently to maintain the input of digestible energy. With a continuing reduction to 10 MJ/kg, intake remained constant at 2.53 kg/d because it was limited by gut fill, and growth rate declined still further. A major consequence of the reduced growth rate when diets of low energy density were offered was the marked decline in backfat thickness when pigs were grown from 4 to 50 kg. This response is typical of a slower growing animal receiving a balanced diet (Black 1974).

Table 5. Predicted effect of digestible energy content of the diet on the performance of entire male pigs of the slow growing genotype weighing 50 kg

Characteristic		Digestible energy content of diet (MJ/kg)			
		10	12	14	16
Voluntary feed intake	(kg/d)	2.53	2.53	2.44	2.08
Growth rate	(g/d)	663	824	909	909
Feed : gain	(g/g)	3.82	3.07	2.68	2.29
P_2 backfat at 50 kg (when grown from 4 kg)	(mm)	12.9	14.5	16.4	17.7
Available lysine requirement	(g/kg)	5.1	5.8	6.0	7.1

(ii) Protein content of diet The predicted effect of reducing the protein content of a diet with the amino acid pattern given in Table 2 from 21% to 8% of the dry matter is given in Table 6 for entire male pigs of the fast growing genotype that were grown from 20 to 65 kg. The amino acid requirement of the animals at 65 kg was predicted to be satisfied with a diet containing about 13% protein. The most efficient use of feed occurred when the diet contained this amount of protein. Although animal growth rate was not affected by feeding excess protein, the efficiency of feed use declined. However, when dietary protein was insufficient to meet the animal's requirements, feed intake was substantially reduced and growth rate declined. Associated with the decrease in body protein synthesis was an increase in fat deposition which was reflected in the higher P_2 values and lower proportion of pigs in the better carcass grades.

(d) Effects of feed intake on the performance of growing pigs

It was shown in Figs. 1 and 2 that both growth rate and P_2 values decline as the intake of a balanced diet is reduced. Because of the linear/plateau relationship between the rate of body protein deposition and energy intake, the highest efficiency of feed use and the fastest rate of lean growth occur when animals are given sufficient energy to reach the beginning of the plateau in protein deposition. For many of the genotypes used in Australia, maximum lean growth occurs at intakes well below ad libitum. The consequences on productivity of feeding either ad libitum or at the level that provides for maximum lean growth is illustrated in Table 7 for entire male pigs of the slow growing genotype that are reared from 4 to 90 kg. Mean feed intake was about 0.35 kg/d less in pigs fed for maximum lean growth and they grew on average 100 g/d slower. They used feed more efficiently, had less backfat and a higher proportion of carcasses in the premium grade. However, they took 109 days to reach 90 kg compared with 96 days for the animals fed ad libitum. Because the pigs fed for maximum lean growth deposited less fat, it was predicted that their carcasses were more valuable with a higher profit per animal. Despite being held in the piggery for 13 days longer, these animals were predicted also to yield a better financial return per pig place per year.

Table 6. Predicted effect of protein content of the diet on the performance of entire male pigs of the fast growing genotype weighing 65 kg

Characteristic		Protein content of diet (g/g)			
		0.21	0.14	0.11	0.08
Voluntary feed intake	(kg/d)	2.94	2.78	2.45	1.62
Growth rate	(g/d)	1100	1107	901	443
Feed : gain	(g/g)	2.64	2.50	2.71	3.66
Time from 20 kg	(d)	45	46	58	103
Feed from 20 kg	(kg)	97	96	111	143
Protein supply : requirement	(g/g)	1.8	1.1	0.8	0.6
P_2 backfat at 65 kg when grown from 20 kg	(mm)	16.6	17.8	21.5	26.6
% of animals in P_2 grades*					
Premium		2	1	0	0
A		12	7	2	0
B		34	25	7	2
C		35	36	21	5
D		17	34	70	93

* Carcass weight and P_2 grades given in SCA (1986)

V. LIMITATIONS TO CURRENT MODEL

Preliminary evaluation of the model indicates that the predictions follow observed patterns of response for several situations, but more extensive evaluation is required. Limitations to the current model are most likely to be associated with parameters describing different pig genotypes and with predicting the effects of climate. There has not yet been a systematic study into how pig genotypes in Australia vary in their capacity to deposit body protein and body fat, in their fecundity and in their potential milk yields. Studies are required particularly to define these factors for the most important genotypes in Australia.

Limitations in predicting the effects of climate are associated with determining the micro-environment at pig level and particularly, how this is affected by the building materials used, the ventilation system and the density of pigs within a shed.

Despite these known limitations, the pattern of responses predicted by the model appear to be of the right order of magnitude for many situations. Hence, the model should prove to be a useful aid to the decision making process in Australian piggeries.

Table 7. Comparison between the predicted performance of entire male pigs of the slow growing genotype that were reared from 4 to 90 kg when fed either ad libitum or at a level that produced the maximum rate of lean growth

Characteristic		Feeding level	
		ad libitum	For maximum lean growth
Mean feed intake	(kg/d)	1.85	1.51
Mean growth rate	(g/d)	896	789
Time to 90 kg	(d)	96	109
Mean feed : gain	(g/g)	2.07	1.92
Total intake to 90 kg	(kg)	178	165
P_2 backfat at 90 kg	(mm)	19.3	13.4
Carcasses in premium grade*	(%)	22	94
Carcass value	($/kg)**	1.56	1.70
Profit/pig†	($)	62.30	74.60
Profit/pig.day	($)	0.62	0.68
Profit/pig place.year	($)	226	248

* Carcass grading system given in SCA (1986)
** November 1984 prices
† Initial value of pig assumed to be $12.00 and feed cost to be $200/tonne

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