# Optimisation of Nutrient Use to Maximise Profitability and Minimise Nitrogen Excretion in Pig Meat Production Systems

P.C.H. Morel, Institute of Food Nutrition and Human Health, Massey University, Palmerston North, New Zealand
G.R. Wood, Department of Statistics, Division of Economic and Financial Studies, Macquarie University, New South Wales, 2109, Australia

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**Abstract**
**Reduction of environmental mineral pollution, while maintaining profitability, is one of the major challenges faced by the pig industry today. This paper describes a computer-based growth simulation study undertaken to demonstrate how economic profitability can be maintained whilst the environmental effects associated with nitrogen wastes are minimised. For this purpose, a computer program linking a linear program, a stochastic pig growth model and a genetic algorithm (GA) was developed. The objective function to be maximised by the GA is the weighted difference of gross margin and nitrogen excretion cost. Simulations were conducted to investigate how different pig genotypes (fat, normal, lean) and different relative economic weighting of gross margin (1) and nitrogen excretion (0, 1, 5, 10, 20, 40, 80 or 120) affect the nitrogen excretion and profitability under practical or GA optimised feeding strategies in Switzerland. In all the cases investigated, nitrogen excretion is reduced and profitability increased when the pigs are from a leaner genotype. Across all genotypes a 45% reduction in nitrogen excretion can be achieved with only a 3.5% drop in profitability when diets designed to maximise profitability and minimise nitrogen excretion are fed. The maximal nitrogen retentions observed were 44.9%, 52.6% and 57% for the fat, normal and lean genotypes respectively. It is concluded that a more sustainable pork meat production system can be achieved by using better genotypes and optimising the diet composition.**

## INTRODUCTION

The contribution of livestock industries to environmental pollution has become a major concern in many countries, especially in regions with high animal density. This has led, in some countries, to the introduction of legislation aimed at reducing/minimizing the environmental impact of mineral excretion by farm animals. The pig industry is no exception and reducing mineral excretion is one of its major challenges. The other challenge is to maintain profitability in a market environment, where production costs are increasing and returns diminishing.

Today, computerised pig growth models are used commercially to identify best feeding practices for individual pig farms (de Lange et al., 2001). Such models simulate nutrient utilization for different genotypes kept in different environments and are generally used to maximize profitability. For a given farm, the number of diets fed, their energy and amino acid content, and the quantity fed can vary, thus giving a very large number of possible feeding strategies (as many as $10^{50}$). Only one, however, will result in maximal profitability and minimal nitrogen excretion. Even with the computer growth models available, finding the optimal solution may be more than a lifetime job. Mathematical optimisation offers the opportunity to find such a solution quickly. Computer programs linking linear programming, pig growth modelling and mathematical optimisation have been developed at Massey University and applied to different problems (Morel et al., 2001, Sirisatien et al., 2004).

In this paper, a computer-based growth simulation study was undertaken to show how economic profitability is affected when the environmental effects associated with nitrogen wastes are minimised. The simulation was conducted using Swiss data.

## METHODOLOGY

The computer program (Bacon Max) used in this study links a linear program for least-cost diet formulation, a stochastic pig growth model to simulate profitability and nitrogen excretion, and a genetic algorithm to find the best solution for a given objective function. A description of the model is presented below.

### Modeling Nitrogen Excretion in Grower-Finisher Pigs

The pig growth model described by de Lange (1995) was amended to keep track of the nitrogen flow. It was assumed that 1g protein was equal to 0.16g nitrogen. The components representing protein metabolism are:

*Crude protein intake (CP)* = protein content of the diet multiplied by the daily kg feed intake.
*Digestible protein intake (DP)* = digestible protein content of the diet multiplied by the daily kg feed intake.
*Undigested protein intake (UDP)* = CP - DP and representing the quantity of protein (nitrogen) excreted into the faeces.
*Maintenance protein (Pm)* = 0.9375 x live weight$^{0.75}$ (LW) and excreted in urine.
*Inevitable protein catabolism (IPC)* = 0.15 x protein deposition and excreted in urine.
*Amino acid imbalance (AAi)* represents the protein in excess of the ideal balanced protein and excreted in urine.
*Excess protein supply (EP)* represents the available protein for growth in excess of the maximum protein deposition potential of the genotype (Pdmax), and excreted in urine.
*Preferential protein catabolism (PPC)* represents the quantity of protein catabolized to provided energy, and excreted in urine.
*Protein deposition (Pd)* is the quantity of protein deposited in the pig's body.
*Nitrogen excretion* was calculated as nitrogen content in CP less the nitrogen content in Pd.
*Nitrogen retention* = Pd / CP

### Genotype

In the model described by de Lange (1995), pig genotypes were characterised by the following three parameters: maximal protein deposition potential (Pdmax), minimum lipid to protein ratio (MinLP) and the energy intake potential expressed as a percentage (p) of a standard curve (NRC 1988).
Three genotypes were investigated in this study:

| Genotype | Pdmax (g/d) | MinLP |
|---|---|---|
| Fat | 120 | 0.9 |
| Normal | 160 | 0.75 |
| Lean | 200 | 0.6 |

It was assumed that the *ad libitum* energy intake of pigs in Switzerland was 80% of the standard NRC curve at the beginning of the growth period and 85 % towards the end.

**Stochasticity**

Instead of simulating growth for a single average pig, our model simulated growth for a normally distributed population of pigs. The stochasticity in the program was in the form of normally-distributed multiplication factors for p, MinLP and Pdmax. The standard deviations for these parameters were set to 10 % of the mean values (coefficient of variation = 10 %). Therefore, each pig had a different set of p, Minlp and Pdmax.

**Objective Function**

The following objective function (OF) was used for the optimisation,

$$OF = a \times GMPPY + b \times NePPY$$

where,

| | |
|---|---|
| *a,b* | are weighting factors |
| GMPPY (CHF) | is the gross margin per pig place and year |
| NePPY (kg) | is the total nitrogen excreted per pig place and year. |

This function allowed the determination of an optimal feeding strategy for either maximal profitability or minimal nitrogen excretion or any combination of the two.

GMPPY was defined as the gross margin per pig (Carcass return - Feed cost - Weaner cost) times the number of rotations per pig place and year.

Carcass return is calculated from the price schedule based on carcass weight and backfat thickness. The cost for a 25kg pig was set to CHF 145.75. The empty time between rotations was set to 14 days.

**Genetic Algorithm**

A genetic algorithm (Reeves and Rowe, 2002) was used to find a feeding strategy that maximizes the objective function. A feeding strategy *F* is a finite set of diets,

$$F = (d_1, r_1, p_1, t_1; d_2, r_2, p_2, t_2; \ldots; d_n, r_n, p_n, t_n)$$

where each diet consists of a quadruple (*d, r, p, t*) with

$d$ = Digestible energy density, in MJ/kg

$r$ = Minimum lysine to digestible energy ratio, in g/MJ

$p$ = Proportion of the standard NRC voluntary daily digestible energy intake

$t$ = Feeding period in days

In the genetic algorithm the number of parental genomes was set to 10 and the search was stopped when no improvements in the objective function were achieved after 5 consecutive iterations.

**Feed Ingredients and Price Schedule**

The computer simulations were made using the feed cost and price schedules current in Switzerland in 2002.

**Simulation Experiment**

Simulations were conducted with Bacon Max to investigate how animal potential for lean growth (different genotypes), different relative economic weighting of gross margin per pig place and year (coefficient *a*), and nitrogen excretion (coefficient *b*) affected nitrogen excretion and profitability under either practical or optimized feeding alternatives in Switzerland. The practical feeding alternative was based on the diet specification of a commercial feed company and the possibility of restriction feeding after seven weeks. Three different diets (I, II and III) only were fed over the growth period, the first diet for 14 days, the second one for 35 days and the last one up to slaughter. The slaughter day is determined by the program, and is the day where the maximal value for the objective function during the growth period is achieved. The possible values of *d, r, p* and *t* for the two feeding alternatives investigated are presented below.

| | **Practical** | | | **Optimised** | | |
|---|---|---|---|---|---|---|
| **Diet** | **I** | **II** | **III** | **I** | **II** | **III** |
| ***d*** | 13.2 | 13.6 | 13.6 | 12-17 | 12-17 | 12-17 |
| ***r*** | 0.89 | 0.75 | 0.75 | 0.3-1.2 | 0.3-1.2 | 0.3-1.2 |
| ***p*** | 0.8 | 0.8 | 0.65-0.85 | 0.8 | 0.8 | 0.65-0.85 |
| ***t*** | 14 | 35 | Open | 14 | 35 | open |

The number of different possible feeding strategies (*F*) was 20 for the practical feeding alternative and $1.458 \times 10^{13}$ for the optimised feeding alternative.

For each combination of genotype (fat, normal, lean), *b* value (0,1,5,10,20,40,80,120), and feeding alternative (practical, optimised), pig growth was simulated for a population of 100 pigs starting at 25kg live weight. Each simulation was replicated 5 times. The weighting factor for GMPPY (*a*) in the objective function was always set to 1.

The data generated in the simulations were statistically analysed with a factorial model (with factors of Genotype, Coefficient *b* and Feeding Alternative) carried out using Minitab v 13.1.

**RESULTS**

The least squares means for live weight at slaughter (LW), gross margin per pig place and year (GMPPY), nitrogen intake per pig place and year (NiPPY), and nitrogen excreted per pig place and year (NePPY) are presented in Table 1. In all the cases investigated, nitrogen excretion was reduced and profitability increased when the pigs were from a leaner genotype (lean > normal > fat). When the *b* value in the objective function was set to 0 (thus maximising GMPPY only), nitrogen excretion was reduced and profitability was slightly improved when optimized diets were fed; this was noted across genotypes.

In the practical feeding alternative a small reduction in NePPY was associated with a large reduction in GMPPY. In the optimised feeding alternative, however, a greater reduction in nitrogen excretion was achieved before any major reductions in profitability were observed (Figure 1). For each genotype, similar GMPPY to the practical diets were obtained with the optimised diets when the b value was set to 20 (Fat 134 vs 127.4, Normal 157.1 vs 153.3, Lean 169.8 vs 164.5), but NePPY was greatly reduced (Fat 15.84 vs 8.36, Normal 12.37 vs 6.85, Lean 9.96 vs 5.82). This showed that across genotypes, a 45% reduction in nitrogen excretion could be achieved with only a 3.5% drop in profitability when diets designed to maximize profitability and minimize nitrogen excretion are used.

The reduction in nitrogen excretion was caused by a reduction in nitrogen intake (NiPPY) and an improvement in nitrogen retention (N Ret, Table 1).

The nitrogen retention and the percentages of the different components of nitrogen excretion (UDP, Pm, ICP Aai, EP and PPC) are presented in Table 1. As the b values in the objective function increased from 0 to 120, the nitrogen retention increased from 28.9% to 44.9% for the fat genotypes, from 39.5% to 52.6% for the normal genotype, and from 44.2% to 57 % for the lean genotype.

The amount of undigestible protein (UPD) represented around 30% of the nitrogen excreted in diets maximizing profitability (b=0) and around 25% in diets placing a large emphasis on reducing nitrogen excretion (b=80 or 120). The protein digestibility of ingredients commonly used in pig diets is one of the main limiting factors for further reduction of nitrogen excretion.

Only a small variation in the percentage of nitrogen excreted from the maintenance requirement (Pm, 6-7 %) and inevitable catabolism (ICP, 9-10 %) was observed. These two components are closely associated with normal pig growth and, therefore, cannot be manipulated to improve nitrogen retention.

The percentage of unbalanced amino acids in the diet (AAi) was reduced from 6% (b=0) to less than 1% (b=80 or 120), thus contributing to an increase in nitrogen retention for the normal and lean genotypes. Reducing the excess protein (EP) in the diets can also contribute to a reduction in nitrogen excretion. In all cases investigated, the nitrogen excreted from catabolised proteins for energy requirements (PPC) was negligible (< 1.0).

## DISCUSSION

The results of our simulations show that differing genotypes exhibit large differences in nitrogen retention (excretion). Genotypes with a high lean growth potential can be more profitable and have improved nitrogen excretion. For example, the fat genotype fed the practical diet had a gross margin per pig place and year of 134.1 CHF and excreted 15.8 kg nitrogen per pig place and year, whereas those values for the lean genotype were 169.8 CHF and 10.0 kg, respectively.

Moreover, a large reduction in nitrogen excretion can be achieved through dietary manipulation before profitability is compromised. For example, across genotypes, nitrogen excretion per pig place and year can be reduced by 5.7 kg with a drop in profitability of only 5.40 CHF. In 2000 in the Netherlands, approximately 50% of pig farmers produced more nitrogen than their quota and were charged a levy of 3.0 Euro per kg N (or 1.54 CHF) (Kanis and De Greef, 2004). In such cases a reduction in nitrogen excretion would more than compensate for the drop in profitability.

Our simulations have shown that a reduction in nitrogen excretion is mainly achieved through a reduction in nitrogen intake, which is equivalent to a reduction in the crude protein (CP) content of the diet. It has been demonstrated that a reduction in dietary crude protein can minimize nitrogen excretion without affecting growth performance. Dourmad et al. (1993) showed that pigs fed a diet with 17.8% CP excreted 3.9 kg nitrogen between 30 and 102 kg LW, and those a fed diet with 13.6% CP excreted only 2.9 kg N. Similarly, Canh et al. (1998) reported an increase in nitrogen retention from 38.37% to 47.30% when the dietary CP was reduced from 16.5% to 12.5%.

In our simulation, an increase in protein digestibility (reduction in UDP), a better amino acid balance (reduction in AAi), as well as matching amino acid intake to pig genotype (reduction in EP) are all associated with an improvement in nitrogen retention. In practice, it is well known that formulating a diet based on digestible ileal ideal balanced amino acid and using synthetic amino acid is the best way to maximise profitability and maximise nitrogen utilization (de Lange et al., 1999; Henman and Smits, 2001).

Considering that the amount of undigested protein in the feedstuffs currently used in pig diets is at least 20-25%, the losses associated with maintenance requirements are around 7% and the losses due to inevitable catabolism are near 10%, the maximum nitrogen retention is, therefore, around 60%.

This maximum can nearly be reached today with modern lean genotypes and best diet formulation practices. A further reduction in nitrogen excretion will only be achievable if the protein digestibility of feedstuffs is increased, and this without a major increase in their cost.

It is concluded that a more sustainable pork meat production system can be achieved by using better genotypes and optimizing diet composition. There will be a cost, however, associated with cases where nitrogen retention exceeds 55 %.

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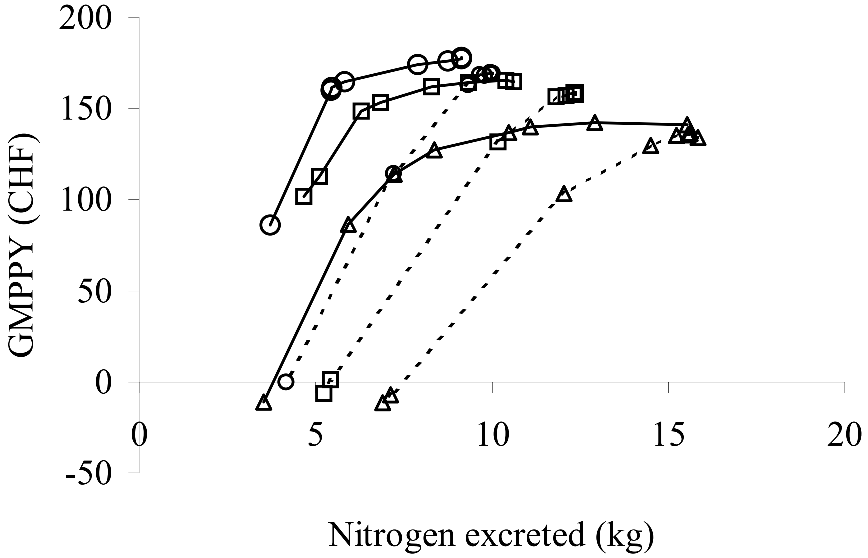


Fig. 1. Gross margin per pig place and year (GMPPY) and kg Nitrogen excreted per pig place and year for Fat (Δ), Normal (□) and Lean (○) pig genotypes fed either three practical diets (----) or three optimized diets (____)

Table 1. Live weight at slaughter (LW), gross margin, nitrogen intake and nitrogen excretion per pig place and year (GMPPY, NIPPY, NEPPY), percentage of nitrogen retention (N Ret), as well as the percentages of nitrogen excreted from undigested protein (UDP), maintenance (Pm), inevitable catabolism (ICP), amino acid unbalanced (AAi), excess protein (EP) and preferential catabolism (PPC) for fat normal and lean genotype fed either practical or diets optimized with different weighing factors for nitrogen excretion (b).

| | | | **LW** | **GMPPY** | **NIPPY** | **NEPPY** | **N Ret** | **UDP** | **Pm** | **ICP** | **AAI** | **EP** | **PPC** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Genotype** | **FS** | **B** | **Kg** | **CHF** | **kg** | **kg** | **%** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Fat** | **Practical** | **0** | 115.8 | 134.1 | 22.2 | 15.8 | 28.6 | 29.7 | 5.5 | 9.7 | 2 | 24.2 | 0.2 |
| | **Optimized** | **0** | 115.2 | 141 | 21.9 | 15.5 | 28.9 | 31.7 | 5.4 | 9.4 | 1.2 | 23 | 0.3 |
| | | **5** | 115.8 | 139.7 | 17.2 | 11.1 | 35.8 | 34.8 | 6.9 | 8.8 | 6.4 | 7.3 | 0.1 |
| | | **20** | 114.1 | 127.4 | 14.2 | 8.4 | 41.1 | 28.3 | 7.9 | 9.6 | 8.1 | 4.9 | 0 |
| | | **40** | 107.6 | 114 | 12.7 | 7.2 | 43 | 26.4 | 8.1 | 9.8 | 7.6 | 5.1 | 0 |
| | | **80** | 96.6 | 86.4 | 10.5 | 5.9 | 43.4 | 26.1 | 7.7 | 9.9 | 9.2 | 3.7 | 0 |
| | | **120** | 72.1 | -11 | 6.4 | 3.5 | 44.9 | 25.7 | 7.1 | 10.1 | 10 | 2.2 | 0 |
| **Normal** | **Practical** | **0** | 117.6 | 157.7 | 19.4 | 12.4 | 36.1 | 29.7 | 5.4 | 9.7 | 2 | 15.2 | 1.8 |
| | **Optimized** | **0** | 118.1 | 164.6 | 17.6 | 10.6 | 39.5 | 33.1 | 6 | 9.1 | 6.2 | 5.4 | 0.6 |
| | | **5** | 117.3 | 164.4 | 16.0 | 9.3 | 41.7 | 34.4 | 6.6 | 8.9 | 5.9 | 2.1 | 0.4 |
| | | **20** | 116.7 | 153.4 | 13.5 | 6.8 | 49.3 | 27.7 | 7.6 | 9.7 | 2.5 | 3.1 | 0.1 |
| | | **40** | 115.7 | 148.5 | 12.9 | 6.3 | 51 | 25.4 | 7.7 | 10 | 1.3 | 4.5 | 0 |
| | | **80** | 101.1 | 112.6 | 10.5 | 5.1 | 51.3 | 25.5 | 7.1 | 10.1 | 1.1 | 4.7 | 0.3 |
| | | **120** | 97.9 | 101.8 | 9.9 | 4.7 | 52.6 | 25.1 | 7.1 | 10.2 | 0.8 | 4 | 0.2 |
| **Lean** | **Practical** | **0** | 118 | 169.8 | 17.2 | 10.0 | 42 | 29.6 | 5.1 | 9.8 | 2 | 10.1 | 1.4 |
| | **Optimized** | **0** | 118.5 | 177.8 | 16.4 | 9.1 | 44.2 | 32.7 | 5.7 | 9.2 | 6.2 | 1.6 | 0.3 |
| | | **5** | 118.5 | 176.1 | 15.9 | 8.8 | 45.1 | 33.3 | 5.9 | 9.1 | 4.8 | 1.6 | 0.3 |
| | | **20** | 117.9 | 164.5 | 12.9 | 5.8 | 54.7 | 25.6 | 7.1 | 10.1 | 0.4 | 1.9 | 0.2 |
| | | **40** | 117.5 | 161.5 | 12.4 | 5.5 | 55.8 | 24.8 | 7.2 | 10.2 | 0 | 1.9 | 0.1 |
| | | **80** | 116.7 | 159.9 | 12.3 | 5.4 | 55.7 | 24.9 | 7.2 | 10.2 | 0 | 1.9 | 0.1 |
| | | **120** | 93 | 85.9 | 8.6 | 3.7 | 57 | 24.6 | 6.7 | 10.3 | 0 | 1.4 | 0 |
| **SE** | | | 0.882 | 3.477 | 0.191 | 0.162 | 0.347 | 0.324 | 0.083 | 0.047 | 0.408 | 0.413 | 0.084 |