Swine production simulation model: LIFE SIM

2007-3 Working Paper

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Table of Contents

Preface

The following document prepared by a team from the Natural Resources Management Division of the International Potato Center (CIP) describes the formulae of the swine model, an integral constituent of the Livestock Feeding Strategies Simulation Models, LIFE-SIM.

The swine production simulation model can be adapted to different local conditions. The model used in different workshops is related to the assessment of year-round feeding strategies in smallholder crop-livestock systems in which sweetpotato can play an important role. Information utilized in the workshop's exercises came from different sources, and were integrated as the main components to estimate animal performance under different feeding strategies. During the workshops, participants used their own data as inputs for running and validating the model. Several case studies were prepared and presented by workshop participants complementing the use of the LIFE-SIM models.

The development of the swine model was sponsored by the International Potato Center (CIP) and the System-wide Livestock Program (SLP) / International Livestock Research Institute (ILRI). The SLP/ILRI contributions were channeled through the following projects executed by CIP: Using system analysis and modeling tools to develop improved feeding strategies for small-scale crop-livestock farmers in Southeast Asia, Enhancing Crop – Livestock Productivity while Protecting Andean Ecosystem and Virtual Laboratory on Systems Analysis in Mixed Crop-Livestock Systems.

Acknowledgements

The authors are indebted to the members of the NRM research team for their technical support. Several investors have contributed to the development of these tools and their validation. Major contributors were the SLP/ILRI, STC-CGIAR (Peru) and INIA-Spain. We are most grateful for their support. The model has been greatly enhanced with feedback received from participants in the workshops held in Latin America, Asia, and Africa. We also gratefully acknowledge the valuable comments and suggestions of Dr. Victor Mares M. on the technical aspects of this document.

Thanks to all.

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SUMMARY

Non-ruminant animals are essential in many resource-poor production systems, particularly in Asia. The feeding strategies are as varied as the different agro ecosystems, thus increasing the challenge faced by researchers and extension agents in the search for appropriate solutions to feeding limitations. Systems analysis provides a unique opportunity to translate existing knowledge into process-based models that can be used to assess year-round feeding strategies at the farm level. Although livestock models have been developed to address similar situations for ruminant animals, swine are seldom included. The present work describes a swine model that analyzes the bioeconomic response to feeding strategies in different production systems. This swine model has been incorporated into the software Livestock Feeding Strategies Simulation Model (LIFE-SIM) complementing the existing models for ruminant species: Dairy, Beef, Goat, and Buffalo (León-Velarde *et al*., 2006) The model simulates a confined group of animals (at least two females or males) with a weight ranging from 15 to 120 kg, under either an *ad libitum* or controlled feeding regime with a feed value characterized in terms of dry matter (%), metabolizable energy (ME/kg), crude fiber (%), lysine (%), methionine + cystine (%), threonine (%), and tryptophan (%). The model can store a number of different rations and their prices allowing a comparison during a defined fattening period. Weight gain and the bioeconomic performance of each ration can then be estimated and analyzed.

INTRODUCTION

Three types of variables are considered in the development of mathematical models (León-Velarde et al., 2006): exogenous variables, endogenous or state variables and output variables. The exogenous variables are independent variables of the system that constitute the data entry for the simulation process and act on the proposed calculation system. In the swine model the exogenous variables were: animal genetic potential, feed ingredients and environmental conditions of the swine pen.

The endogenous variables are generated by the interaction of exogenous variables and parameters in the algorithm sequence and are calculated during the simulation period. The food intake (determined as a function of the animal weight) and the feed nutrients of the daily ration are example of endogenous or state variables. The model also determines other state variables such as the animal's requirements and balances them with the total nutrient intake. Diet protein quality is estimated by comparing the amino acid availability in the diet with the muscle protein. The most sensitive variable is the genetic growth potential of the swine. The model was validated with data from commercial operations in Chile, Peru, Vietnam, and China. Data from experimental trials including animals with different genetic growth potential, ranging from “very low” (70 g protein-deposition per day) to “very high” (150 g protein-deposition per day) were used to validate the model. The model’s predictions were in close agreement with experimental data; the error was less than 6%. The swine model is useful for identifying the most profitable feeding strategy when comparing different alternatives used in swine production systems. Thus, results from different bioeconomic scenarios defined by the user into a structured central composite rotatable design, allows the construction of a response surface to assess the usefulness of a particular feeding strategy. The flexibility and the “user-friendliness” of the software make it an apt tool for identifying research gaps, making appropriate management decisions, facilitating extension work, and conducting training in animal production.

SWINE MODEL STRUCTURE

Knowledge in swine science and technology allows the systematic construction of a swine production simulation model, which can be used to estimate or predict with adequate levels of precision, an animal’s performance under different environmental conditions and feeding regimes. This kind of model could be considered as a tool to identify profitable feeding strategies in different production systems.

The swine production model described here was programmed taking into account the prevalent way of feeding pigs on a typical swine farm. The model considers the characteristics of the animals in a specific environment including the weather. Also a database of different feeds allows selecting stored feed data or adding new feeds to be used in a particular ration formulation to feed pigs year round. Output includes information on weight gain and production cost, as well as food intake and limitation of amino acids (protein quality) during a fattening period. Additionally, different bioeconomic scenarios are shown graphically, which can be analyzed to support a particular decision on how to feed pigs in a profitable way. Figure 1 shows the model’s graphic interface, which allows test running a specific ration under different bioeconomic scenarios. Text reports of results are shown in the annex (Table A).

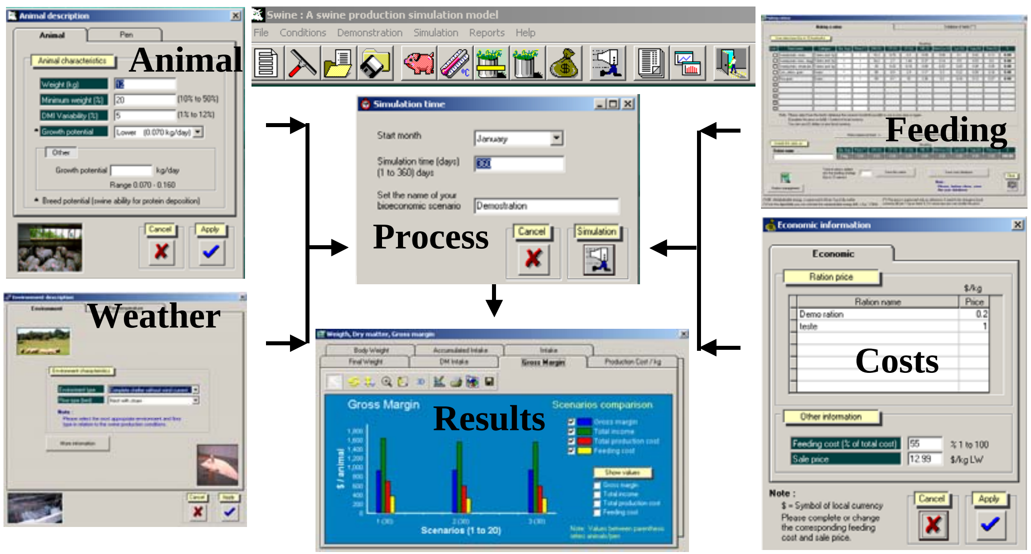


Figure 1. Interface graphics of the swine production model showing the interaction of animal, weather, feeding strategy and cost with the bioeconomic scenarios analyzed.

CHARACTERISTICS OF THE MODEL

The swine model is based on protein quality. Figure 2 schematically shows the flow chart of the process of exogenous and endogenous variables in a daily step.

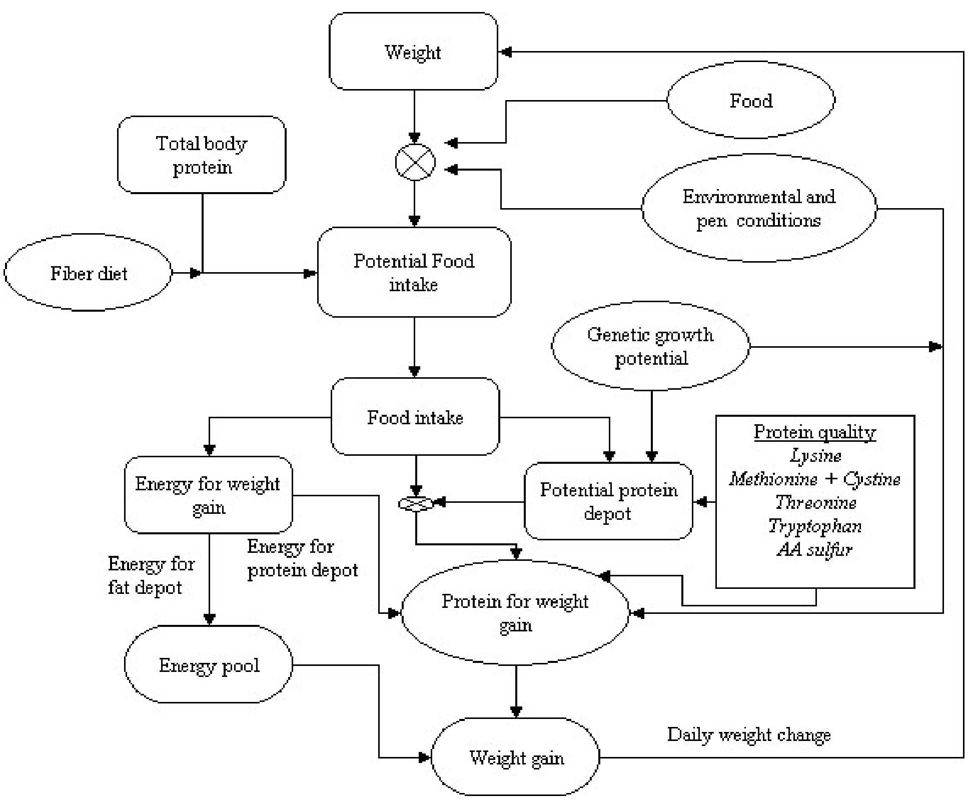


Figure 2. Schematic representation of the process of exogenous and endogenous variables considered in the swine model.

Exogenous variables

- Animal characteristics, defined by the average body weight and the genetic growth potential ranging from "very low" (70 g protein-deposition per day) to "very high" (150 g protein-deposition per day).
- Environmental conditions, defined by pen space (m^2) and number of animals per pen, temperature (yearly, monthly or seasonal average), floor characteristics, and isolation from wind.
- Feed attributes, defined by metabolizable energy (Mcal /kg), dry matter, crude fiber, and available amino acids (lysine, methionine + cystine, threonine and tryptophan), expressed as percent (%).

Endogenous variables

The estimation of the food intake (FI) is based on the potential feed intake (PFI), which is expressed in kilograms, and estimated by the following equation:

$$PFI = \frac{13.1620 * (1 - e^{-0.1192*PT} * 0.96)}{ME} * FCMS - FCRTCMS$$

Where:

PT	=	Animal protein mass, kg (Whittemore, 1986).
ME	=	Metabolizable energy, Mcal/kg
FCMS	=	Dry matter correction factor; estimated by the equation: 0.3333+0.00833* Dry Matter diet (%)
FCRTCMS	=	Environmental correction factor for food intake estimated by the equation: 0.001*Animal weight (kg)*(EET-MCT)*
Where: EET	=	Effective environmental temperature (ºC), and
MCT	=	Maximum critical temperature (ºC); both coefficients are estimated by using Whittemore (1986) equations.

Food intake (FI) is calculated from PFI corrected by two factors:

(a) Density of the ration; based on diet crude fiber content, estimated as: 0.5865-0.0139*CF(%)

(b) Animal density per space; estimated as: 1.5-(0.005* (Total animal weight, kg/Pen area, m^2) (Edmonds et al.,1998).

Once FI (kg) is calculated, each nutrient intake is estimated multiplying FI by the specific nutrient content of the feed.

Potential protein weight gain (PPWG)

The potential protein weight gain is a function of the animal's genetic growth potential for weight gain (GENPOT), and the protein quality of the diet (PQ). It is estimated as:

$$PPWG\ (g) = (GENPOT^{*})^{*}(1/CRPRT)$$

Where:

GENPOT is the potential amount of protein that the animals can deposit depending on their genetic characteristics or quality (Table 1); and, CRPRT is the relative optimum protein intake based on the FI and feed's lysine content.

Genetic quality	Potential protein deposition (kg/day)
Very low	0.070
Low	0.090
Medium	0.110
High	0.130
Very High	0.150

Table 1. Potential protein deposition as a function of genetic quality in the swine industry.

Genetic quality ranges from "very low" (equivalent to wild boar, with a potential protein deposition of 0.070 kg/day) to "very high" (0.150kg/day), which corresponds to the genetic quality of a commercial breed available from different breeding companies in the year 2001.

The protein quality (PQ) of the diet is estimated by comparing the actual intake of each amino acid with the amino acid content of deposited protein; which is assumed to be constant and independent of animal genetic quality (Table 2).

Amino acids	Content in protein depot. (%)
Lysine	7.8
Methionine + cystine	3.8
Threonine	5.1
Tryptophan	1.4

Table 2. Amino acid content of animal protein depot.

Once the FI of each nutrient and the PPWG have been calculated, the model compares nutrient intake with nutrient expenses to determine the quantity of nutrients available for deposit. When the energy covers the ecological maintenance requirement (EMR), and protein deposit, the surplus is used for fat deposition (PFD), in accordance with the animal's genetic characteristics.

Energy expenditure (EE)

Energy expenditure, Mcal per day, expressed as metabolizable energy utilized for different physiological processes, estimated by the following equations:

Energy maintenance requirement (EMM) = 0.5584*(0.17*BW 0.75)*0.95 (Pomar et al., 1991)
Temperature regulation (TR) = 0.0029*BW 0.75*(Tc-Te); (Whittemore, 1986)
Tc = Minimal critical temperature (oC), estimated as 27-(0.6*PC)
Te = Effective temperature, estimated by T*Ve*Vi
Where:

BW	=	Body weight, kg
PC	=	Heat production (Mcal), estimated by: EMM + (7.41*PPWG) + (3.35*PFD)
T	=	Pen temperature (°C)
Ve	=	Wind velocity factor, depending on the exposure of the pen, value range from 0.6 (outdoor conditions) to 1.0 (completely indoors/enclosed)
Vi	=	Pen floor characteristics factor, depending on floor material, value ranges from 0.7 (ground) to 1.4 (straw).

Thus the total Ecological Maintenance Requirement (EMR) is calculated as:

EMR = EMM+TR+HC

The HC (harvesting cost) is the amount of metabolizable energy (ME) that the animal expends to obtain its food. In the model, with *ad libitum* feeding under confined conditions, the value of HC is a constant equivalent to 10% of EMM (Cañas et al., 2003). The model also allows for the energy cost per day, Mcal, for protein and fat deposition and protein deamination; they are calculated from fat and protein depots:

Deamination cost;	MEDEAM	=	0.5258 Mcal per kg of deaminated protein.
Energy cost for protein deposition;	MEPD	=	10.492 Mcal per kg of protein depot.
Energy cost for fat deposition;	MEFORFD	=	12.787 Mcal per kg of fat depot.

The energy available for fat deposition, MEASFAT, is calculated as:

MEASFAT	=	(FI*ME)-EMM-MEDEAM-MEPD-MEFORFD
Fat depot, kg; FD	=	MEASFAT*12.787-1

Protein deposition

The protein deposition is calculated as the balance between PPWG and protein available for production, PAP, calculated as;

PAP, g	=	(PI*PQ) - MPR
MPR, kg	=	ENDPROT + MFPROT + SURFPROT
MFPROT, kg	=	68*DMI*(1-DIGDMI)/PQ
ENDPROT, kg	=	Endogenous protein, =: 0.146*BW 0.75*6.25*PQ
SURFPROT (kg/day)	=	(0.1125*BW^0.75)/PQ

Where:

PAP,	=	Protein available for production, g
PI	=	Daily protein intake, kg
PQ	=	Protein quality factor, based on the minimum value of an amino acid of the feed, %
MPR	=	Maintenance protein requirement, kg; which includes endogenous (ENDPROT) metabolic fecal (MFPROT) and superficial protein (SURFPROT).
DMI	=	Dry matter intake, kg
DIGDMI	=	Food intake digestibility, %

Lean deposition

Lean deposition, LPD, is the amount of lean weight gain obtained by protein deposition, which depends on animal weight, and is estimated by:

LPD, kg = (11.1609+2.2559*ln(BW))/100

Daily weight gain

The daily weight gain is the sum of lean protein and fat deposition:

Daily weight gain, g = LPD + FD

The sum of the consecutives daily weight gains gives the body weight at a specified fattening period.

MODEL RESTRICTIONS

The model's mathematical structure determines its use and restrictions. Thus, animals are considered to be female or castrated male, fed in confinement, with a body weight ranging from 15 to 120 kg. The ingredients of a daily feed ration must be characterized in terms of: dry matter (%), metabolizable energy (ME Mcal/kg), crude fiber (%), and main available amino acids as lysine (%), methionine + cystine (%), threonine (%), and tryptophan (%).

VALIDATION

Models can be validated by using observed and simulated data (Mitchell and Sheehy, 1997). Thus, the model was validated using data from 19 different feeding experiments (Chile, Vietnam and China), which involved different animal weights, genetic growth potentials, and environmental conditions, covering many different diets in terms of DM, ME, CF and lysine. Summaries of the results including the absolute error and model precision, which vary from 0 to 12.0%, are shown in Annex 1 (Table B).

The average of absolute error of the model, estimated as the difference between observed and simulated values was 0.04 kg/day; which represents a relative error of 5.88% over observed values. Figure 3 describes the range of observed and simulated values.

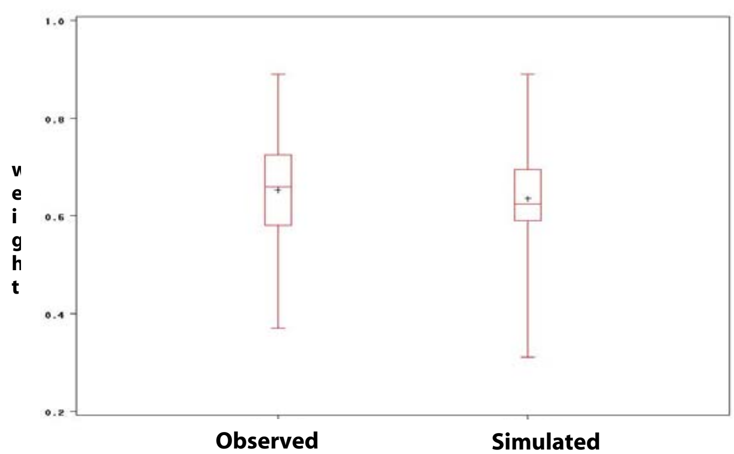


Figure 3. Box plot of observed and simulated weight gain values estimated by the Swine production simulation model for different rations.

The correlation between observed and simulated weight gain values was 92.79% indicating a good agreement between values produced by any particular feeding strategy. However it is necessary to mention that some discrepancies were observed in some diets (4, 10, 14, 16 and 23) attributable to the diet formulation and swine management information. This was observed when users did not have adequate information to appropriately feed into the model. An internal analysis of the observed data related to the animals for each experimental diet showed that the most sensitive model parameter is the animal's genetic growth potential. Thus, it is necessary to define more precisely the genetic growth potential of the animals as well as the management conditions. The model variation factor, FMV, (Cañas and Baldwin, 1973), expressed as percent was estimated as a fraction of the mean square error relative to the average of observed data.

The FMV indicates a 2.16% variation allowing for acceptance of results within a confidence limit of 95%; a situation that can be met by the user in no less than 90% of the cases, depending on the real data observed.

A regression analysis of simulated and observed data to test the hypothesis of Ho: a=0; Ha: a≠0 and Ho: b=1; Ha: b≠1 was performed. The parameters of the regression were a=0.0219±0.053 and b=0.940±0.0.081, which did not show significant differences from 0 and 1, respectively, Figure 4.

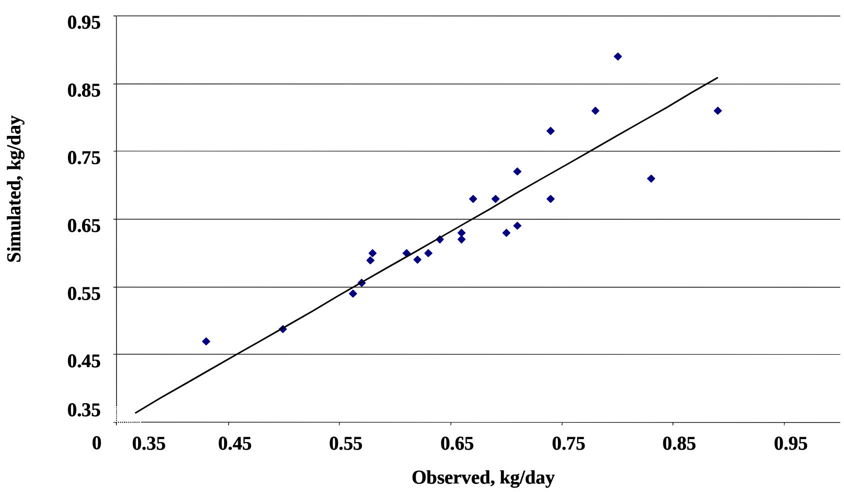


Figure 4. Graphic representation of regression analysis to determine agreement between simulated and observed results from different experimental diets.

MODEL USE

Results from a sensitivity analysis of the variables included in the model showed that the genetic growth potential of the animals is the most sensitive model parameter. Therefore, in order to use the model with different diets and conditions, the growth potential of the animals needs to be clearly defined.

To demonstrate the use of the model, a simulation of a set of treatments under a surface response method based on a central composite rotatable design (León-Velarde and Quiroz, 1999) was used to analyze the genetic growth potential and the stock density of penned animals, all with the same feeding ration. Table 3 shows the structure of the design and Figure 5 shows graphically the results for both variables.

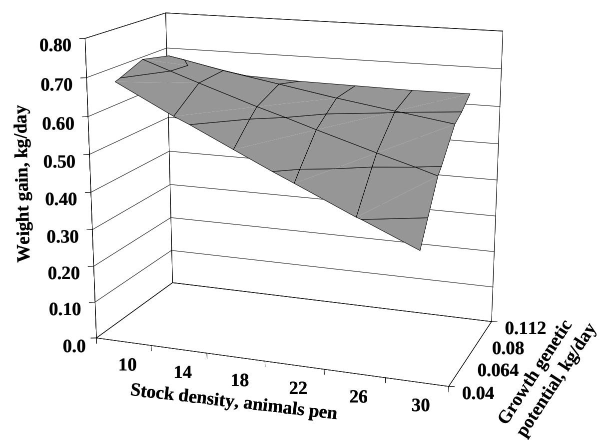
Table 3. Variables, coded values, and treatments used in the application of the response surface method in a simulated study of a swine production system using the swine model

Variables			code				
	-2	**-1.41**	**-1**	**0**	**1**	**1.41**	**2**
Genetic growth potential (GP), kg/day	0.04	0.06	0.07	0.10	0.13	0.14	0.16
Stock density (SD), animals/pen	30	27	25	20	15	13	10
			Code values		Values		
Treatments combinations (factorial 2K*2^K+5n)			GP	SD	GP kg/day	SD Animal/pen	Weight gain, kg/day
1			-1	-1	0.07	25.00	0.435
2			1	-1	0.13	25.00	0.530
3			-1	1	0.07	15.00	0.617
4			1	1	0.13	15.00	0.569
5			-1.41	0	0.06	20.00	0.678
6			1.41	0	0.14	20.00	0.582
7			0	-1.41	0.10	27.07	0.737
8			0	1.41	0.10	12.93	0.681
9[1]			0	0	0.10	20.00	0.640[2]

[1] Corresponds to the central point; repeated 5 times[2] Average of five observations.

Analysis of the data resulted in a quadratic polynomial equation relating stock density and genetic growth potential with weight gain. The values were plotted to observe the pattern of both factors. Figure 5 shows that weight gain is reduced at high stock density whereas higher genetic growth potential tends to increase weight gain.

Figure 5. Response surface for stock density and genetic growth potential



By the same token, the swine model can be used to make bioeconomical comparisons between different rations as well as to determine the efficiency of a particular breed or cross-bred stock under a given feeding and management regime. Figure 6 shows the results of the comparison between a commercial concentrate and a ration in which 30% of the concentrate was replaced by sweetpotato silage during a fattening period of three months, starting from 25 kg live weight. Both rations produced the same final live weight. However, the replacement feed caused a 12.8% increment in the overall gross margin of the concentrate ration. Similar scenarios can be analyzed by using the swine production simulation model.

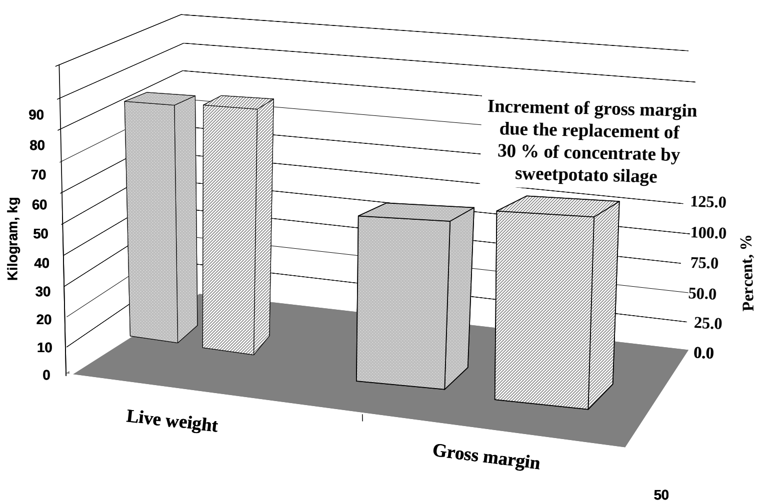


Figure 6. Schematic representation of scenario analysis comparing rations with commercial concentrate alone and when 30% of concentrate is replaced by sweetpotato silage.

CONCLUDING REMARKS

The swine model provides an adequate estimation of swine performance obtained in a real situation. However, the model must be parameterized with reliable and valid information about the system. The combination of the swine model with a response surface methodology constitutes a good tool for the analysis of different management strategies, including biological responses as well as production costs. Its use results in a considerable reduction of time and cost required to test any particular feeding or management strategy before its implementation as an actual farm intervention.

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ANNEX

Table A. Text report of the bioeconomic scenario result obtained from the swine simulation model.

Scenario: Example		
Description: Test 1		
Simulation days	120 days	
Number of animals per pen	30	
Initial body weight	30.00 kg	
Final body weight	94.61 kg	
Increment of body weight at 120 days	64.61 kg	
Daily weight change(average)	0.538 kg	
Weight gain efficiency (percentage)	0.68	
Fat percentage	47.99 %	
Protein percentage	52.01 %	
Accumulated food intake	Per animal	Per pen (30) pigs
kg as fed	317.10	9512.89
kg of Dry Matter	285.39	8561.61
Feed conversion rate	4.42 kg DM per kg BW gained	
Economics		
The costs are expressed in	US Dollar	
Feeding cost as 55.0% of total cost ($)	63.42	1902.58
Sale price ($/kg)	3.10	
Based on final body weight (kg):	94.61	
Fattening days	120	
	Per animal	Per pen (30)
Total income ($)	293.30	8799.11
Total cost ($)	115.31	3459.23
Gross margin ($)	178.00	5339.88
Production cost ($/kg)	1.22	
Gain or loss ($/kg)	1.88 (B/C = 2.54)	
Based on increment of body weight (kg)	64.61	
Fattening days	120	
	Per animal	Per pen (30)
Total income ($)	200.30	6009.11
Total cost ($)	115.31	3459.23
Gross margin ($)	85.00	2549.88
Production cost ($/kg)	1.78	
Gain or loss ($/kg)	1.32 (B/C = 1.74)	
Considering piglet initial price :	$ 25.00	
Weight (kg)	30.00	
$/kg	0.83	
Based on final weight kg:	94.61	
Fattening days	120	
	Per animal	Per pen (30)
Total income ($)	293.30	8799.11
Total cost ($)	140.31	4209.23
Gross margin ($)	153.00	4589.88
Production cost ($/kg)	1.48	
Gain or loss ($/kg)	1.62 (B/C = 2.33)	

Table B. Observed and simulated daily weight gain (kg/day) of animals obtained with different experimental diets and by using the swine model of LIFE SIM under similar conditions.

Diet [1]	Weight gain (kg/day)		Absolute error (kg/day)	Relative error model precision, average %
	Observed	Simulated		
1	0.43	0.47	0.04	9.30
2	0.66	0.62	0.04	6.06
3	0.89	0.81	0.08	8.99
4	0.80	0.89	0.09	11.25
5	0.63	0.60	0.03	4.76
6	0.66	0.63	0.03	4.55
7	0.74	0.78	0.04	5.41
8	0.78	0.81	0.03	3.85
9	0.58	0.60	0.02	3.45
10	0.70	0.63	0.07	10.00
11	0.74	0.68	0.06	8.11
12	0.71	0.72	0.01	1.41
13	0.61	0.60	0.01	1.64
14	0.71	0.64	0.07	9.86
15	0.67	0.68	0.01	1.49
16	0.83	0.71	0.12	14.46
17	0.69	0.68	0.01	1.45
18	0.64	0.62	0.02	3.13
19	0.62	0.59	0.03	4.84
20	0.56	0.54	0.02	3.91
21	0.57	0.56	0.01	2.46
22	0.50	0.49	0.01	2.20
23	0.37	0.31	0.06	16.67
24	0.58	0.59	0.01	1.90
Average	0.65±0.12	0.63±0.12	0.04±0.03	5.88±0.43

[1] Weight gains from diets (1-17) averaged from measurements of at least 4 animals/diet; Chile. (Robles and Aguilar, 1999).
[2] Weight gains from diets (18-24) averaged from measurements of at least 12 animals/diet; Vietnam, China.

CIP's Mission

The International Potato Center (CIP) seeks to reduce poverty and achieve food security on a sustained basis in developing countries through scientific research and related activities on potato, sweetpotato, and other root and tuber crops, and on the improved management of natural resources in potato and sweetpotato-based systems.

The CIP Vision

The International Potato Center (CIP) will contribute to reducing poverty and hunger; improving human health; developing resilient, sustainable rural and urban livelihood systems; and improving access to the benefits of new and appropriate knowledge and technologies. CIP will address these challenges by convening and conducting research and supporting partnerships on root and tuber crops and on natural resources management in mountain systems and other less-favored areas where CIP can contribute to the achievement of healthy and sustainable human development.

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