The Application of Modeling Research to Increase Lean Meat Products

M. W. Tess*

Introduction

Computer modeling techniques have been used to address several animal production questions. Models have been constructed as a means to better understand biological systems and/or target areas for further experimental research. Some models have been constructed to simulate animal responses to environmental variables, such as nutrition and temperature. Several models have been developed to evaluate production system responses to changes in management and/or animal genotype.

The objective of this paper is to illustrate some of the applications of computer modeling techniques in evaluating potential methods of improving efficiency of lean meat production.

Production Systems — Improving Efficiency

Often the objective function of a mathematical computer model is to simulate some measure of efficiency (i.e., some ratio of inputs and outputs) as it responds to one or more control variables in the system. Systems models generally account for inputs and outputs for an entire farm, business or industry. In contrast, experimental research in animal production often focuses on the individual animal.

Familiar measures of efficiency such as pigs/sow/year, feed/gain and average daily gain are based on individual performance measured at a single stage in the life-cycle. The producer, however, must pay for inputs needed at many or all points in the life-cycle and may harvest outputs in several ways (i.e., market animals plus cull breeding stock). Hence, of ultimate importance to the producer is the efficiency of the entire production unit. The efficiency of the animal is important, but may not adequately reflect the efficiency of the system of which the animal is only a component.

At the University of Nebraska, Drs. G. E. Dickerson, G. L. Bennett and I developed a mathematical computer model to simulate pork production systems (Tess et al., 1983a). Our primary objectives were to evaluate the effects of genetic change and alternate mating systems on production efficiency. Parameters and relationships used to simulate performance were developed from published experimental results. The production unit was assumed to be a Midwestern farrow-to-finish operation. Pigs were weaned at 28 d and marketed at 100 kg. Sows were allowed a maximum of three litters. Outputs from cull sows were discounted for their market value relative to market pigs. Economic costs were based on 1980 prices.

The model was used to assess the effects of several production traits on efficiency, including increased number born alive (NBA), preweaning viability (VIAB), growth rate (GR) and lean growth rate (LGR) plus decreased age at puberty (−PUB), percentage fat at 100 kg (−%F) and fat growth rate (−FGR). GR and %F were completely determined by LGR and FGR. Requirements for energy and protein plus feed/gain ratios were predicted by the model and determined by the lean weight maintained, LGR and FGR. Base levels for all performance traits were established at levels representative of high quality commercial pigs.

Postweaning performance has received considerable research attention. Because feed for growing-finishing pigs is probably the single largest expense in pork production and because carcass composition affects both feed efficiency and consumer demand for pork, the primary measures of feedlot performance have been growth rate, backfat (a predictor of carcass fatness) and feed/gain.

The model was used to simulate performance in response to 20% changes in the means for GR, %F, LGR and FGR (Table 1). Predicted effects on energy and protein utilization for feedlot pigs are presented in Table 2. The model is based on metabolizable energy (ME) and metabolizable protein (MP) to avoid confusion caused by substituting different energy and protein sources in the diet. ME/empty body weight (ME/EBWT) is closely related to feed/gain when diet composition is held constant and places no importance on the composition of gain. ME/carcass lean (ME/CLN) reflects the composition of weight marketed.

ME/EBWT was improved most by LGR and GR. Reduced %F yielded slightly less improvement, but −FGR yielded little change in ME/EBWT. Reduced %F affects ME/EBWT because less energy is required to deposit lean than is required to deposit fat. GR improves ME/EBWT effect primarily by reducing the amount of energy used for maintenance. LGR and −FGR affect both rate and composition of gain. These results indicate that reductions in the energy cost of gain caused by −FGR are largely offset by increases in energy costs for maintenance.

ME/CLN was improved most by −%F and LGR, followed by GR and −FGR. These results show that LGR and −FGR both have important effects on energy costs when a premium is placed on lean yield.

*M. W. Tess, 226 Polk Hall, North Carolina State University, Raleigh, NC 27650

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Table 1. Simulated Performance for 20% Changes in Means of Growth Traits.

	Base level	20% changes in: GR	−%F	LGR	−FGR
140-d wt, kg[a]	73.7	88.4	74.1	83.5	68.8
Age at 100 kg, days[a]	171.0	152.0	171.5	158.0	180.0
Percentage fat in empty body of pigs sold	35.7	34.1	28.7	30.6	31.4

[a]Average of barrows and gilts.

Table 2. Simulated Effects of Changes in Means for Growth Traits on Energy and Protein Utilization in Growing-Finishing Pigs[a] (28 days to 100 kg).

	Base level	20% changes in: GR	−%F	LGR	−FGR
ME/empty body weight (Mcal/kg)	9.50	8.94	9.11	8.88	9.48
(% of base level)	(100.0)	(94.1)	(95.9)	(93.5)	(99.8)
ME/carcass lean (Mcal/kg)	17.36	15.94	15.02	15.04	16.23
(% of base level)	(100.0)	(91.8)	(86.5)	(86.6)	(93.5)
MP/empty body weight (g/kg)	188.0	187.8	211.2	200.8	204.5
(% of base level)	(100.0)	(99.9)	(112.3)	(106.8)	(108.8)
MP/ME (g/Mcal)	19.8	21.0	23.2	22.6	21.6
(% of base level)	(100.0)	(106.1)	(117.2)	(114.1)	(109.1)

[a]Calculations do not account for any feed wastage.

When considering potential benefits from selection for rapid lean growth and/or decreased fat deposition, it is often ignored that leaner pigs may require more protein per kg feed. LGR, −%F and −FGR each increased MP/EBWT and MP/ME (Table 2). Although increased GR had little effect on the total protein requirement (MP/EBWT), MP/ME increased because ME/EBWT decreased. The cost of protein supplements is generally much higher than the cost of common energy sources, such as corn. Hence, faster growing and/or leaner pigs should be expected to require more expensive feed. This fact was taken into account by the model when computing production costs. In the short run this effect may be small, yet when considering long-term selection it seems worthy of consideration.

Data presented in Table 2 refer only to the growing-finishing phase. In Table 3, GR, −%F and NBA are compared for their effects on efficiency of the entire production system. Total ME and dollar inputs were divided into those for growing-finishing pigs and those for breeding sows. When only ME inputs were considered, −%F had the largest effect on efficiency, followed by GR and NBA. Increased GR primarily reduces feed inputs, while −%F also improves lean output. NBA affects energy use by spreading sow feed inputs over more output. When all production costs were accounted for ($/100 kg carcass lean), the importance of NBA increased relative to the growth traits, because more non-feed expenses are associated with sows than pigs.

When considering strategies for improving production efficiency, it may be practical to set some priorities in management improvement as well as in research and extension. At least one model has been developed solely for this purpose (Singh et al., 1980). Figure 1 compares the independent effects of changes in NBA, VIAB, GR, LGR, −PUB, −%F and −FGR on the cost of producing carcass lean, using the Nebraska model. Percentage changes in efficiency are expressed per phenotypic standard deviation change in each trait. The rankings in Figure 1 represent the opportunity for improvement relative to the existing variation and should be useful in establishing research, extension and management priorities for swine systems like those simulated. These results suggest that even though NBA and VIAB have minimal effects on carcass composition and postweaning feed utilization, they offer more opportunity for improvement in production efficiency than the growth traits.

When considering selection programs, differences among traits in heritability must be considered. Figure 2 presents percentage changes in efficiency per genetic standard deviation changes in each trait. Rankings in Figure 2 are appropriate for establishing selection goals for swine production units of the type simulated. These results indicate that even though maternal and litter traits have low heritabilities, they are worthy of consideration in selection programs. For a

Table 3. Simulated Effects of Changes in Growth Rate, Fat Percentage and Number Born Alive on Different Measures of Production System Efficiency

	Base level	20% changes in: GR	−%F	NBA
ME/carcass lean (Mcal/kg)				
Sow[a]	4.214	4.774	4.109	3.663
Pig	17.188	15.655	14.860	17.254
Total	21.402	20.430	18.969	20.917
(% of base)	(100.0)	(95.5)	(88.6)	(97.7)
$/100 kg carcass lean[b]				
Feed	96.08	93.51	90.01	93.99
Non-feed	73.06	70.08	65.91	66.19
Total	169.14	163.59	155.92	160.18
(% of base)	(100.0)	(96.7)	(92.2)	(94.7)

[a]Indicates ME fed to sows divided by total output.
[b]Based on 1980 production costs.

Figure 1

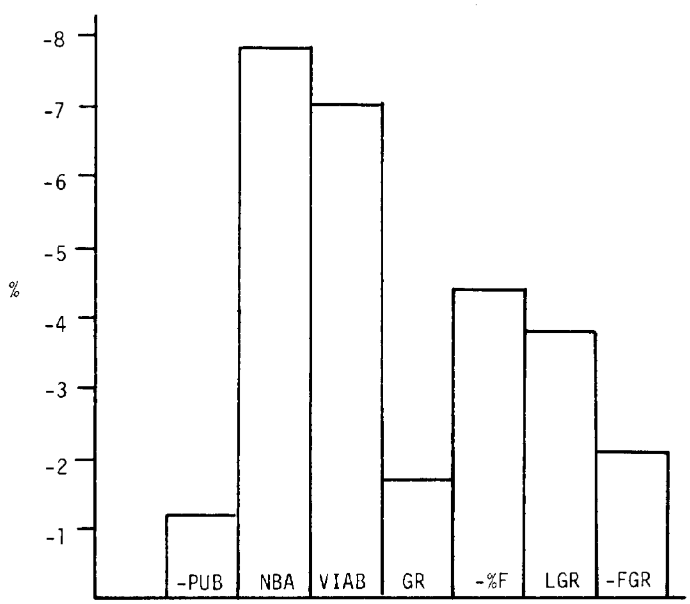

Figure 1. Percentage changes in cost/100 kg carcass lean per phenotypic standard deviation change in performance traits.

Figure 2

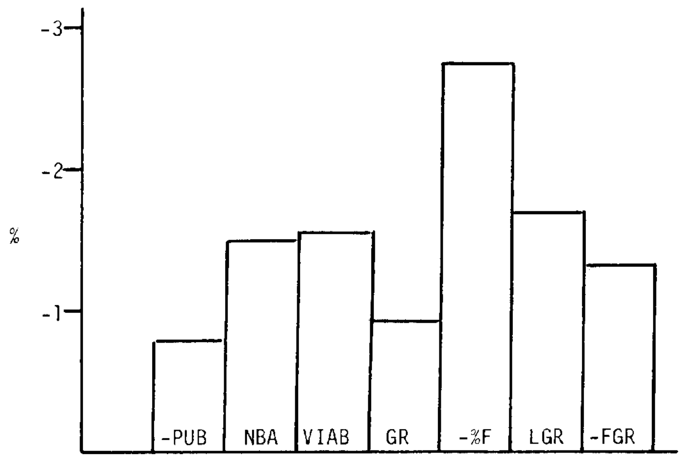

Figure 2. Percentage changes in cost/100 kg carcass lean per genetic standard deviation change in performance traits. Response for NBA divided by 2 because selection based on dam's record.

more complete discussion on model applications for designing breeding programs, see Tess et al. (1983b,c) and Bennett et al. (1983a,b).

Some management decisions do not directly attempt to alter performance traits of animals in the system. For example, the weight at which animals are sold does not alter the performance of the animal, per se, but may have a considerable effect on inputs and outputs.

Effects of sale weight on efficiency were evaluated by varying sale weight while not changing individual performance levels (Figures 3 and 4). As sale weight increased from 80 kg to 140 kg, average age at slaughter increased from 171 to 215 days and percentage fat at slaughter increased from 33.8 to 39.0% (Table 4). Efficiency of feed energy use declined, both on an individual and system basis, because the proportion of energy used for maintenance increased as weight increased. Total energetic efficiency closely followed that associated with pigs because the large majority of feed energy inputs is associated with the feedlot. However, the cost of producing carcass lean decreased as sale weight increased. Cost efficiency of producing lean improved as sale weight increased because expenses associated with sows were spread over more output.

These results illustrate an important point. On an individ-

Figure 3

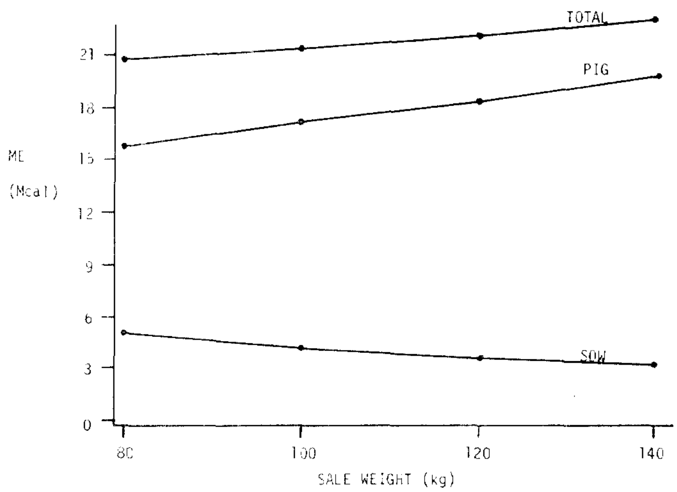

Figure 3. Effects of changes in sale weight on Mcal ME/kg carcass lean.

Figure 4

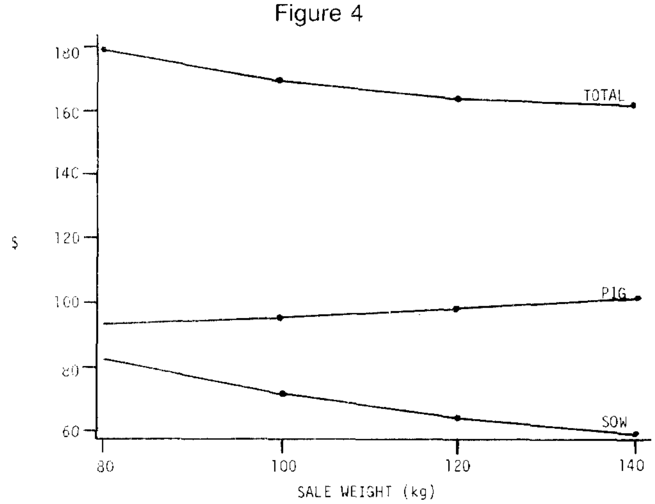

Figure 4. Effects of changes in sale weight on cost/100 kg carcass lean.

ual basis, animals become less efficient producers of lean as they increase in size, primarily due to slower relative rates of growth. However, the individual's inefficiency is outweighed by the benefits to the system; that of spreading fixed costs over more output.

It might be appropriate to point out that cost efficiency is not always equal to profit. For example, in the case of increasing sale weight, prices paid/kg of carcass lean for market hogs may be lower as animals become larger. Furthermore, if all producers increased sale weights, without reducing the number of pigs sold, market prices would go down due to oversupply. However, the fact remains that feed efficiency should not be the sole criterion upon which system efficiency is judged.

Prediction of Animal Performance in Different Environments

In the Southeast, the grazing of stocker cattle represents an important livestock enterprise. Stockmen are looking for ways to produce more beef (or weight) from the forage resources they manage. In forage-livestock systems, feed resources are unpredictable in supply and quality. Because forages are not as digestible as grains or other concentrates, nutrient intakes by grazing livestock may be limited by digestive tract capacity. In contrast to modeling pig growth under self-fed conditions, a major obstacle in modeling forage-livestock systems is the prediction of animal responses to below maximum levels of nutrient intake.

At North Carolina State University, Drs. T. Johnson and E. A. Tolley and I have initiated work on a bio-economic model of Southeastern forage-livestock systems. To date, our work has focused on problems associated with the mathematical prediction of cattle growth responses to varying levels of nutrient intake.

From a modeling viewpoint, the partition of feed nutrients between lean and fat is very important. The energy cost of fat deposition is much higher than the energy cost of lean deposition, primarily due to the high water content of lean. Animals on limited energy intake are likely to deposit a smaller proportion of fat in gains compared to animals which are not restricted. Large genetic differences exist among breeds in mature size and/or maturing rate. These differences are accompanied by different rates of growth and intake potentials. Finally, stocker cattle may experience a wide variety of backgrounding programs before the grazing season, which may affect composition and rate of growth.

Table 4. Simulated Pig Performance for Changes in Sale Weight

	Sale Weight (kg)			
	80	*100*	*120*	*140*
Pig Mcal ME/kg pig sold	761	987	1231	1485
Pig Mcal ME/kg live weight sold	9.51	9.87	10.26	10.61
Percentage fat in pigs sold	33.8	35.7	37.4	39.0

Data collected as part of a project entitled "Body Composition, Energetic Efficiency and Meat-Characteristics of Cattle" at Cornell University (S. Simpfendorfer, 1973; H. J. Ayala, 1974) were used to investigate alternate mathematical curves describing the effects of daily weight gain on daily protein gain. This is viewed as a preliminary step in the prediction of growth component responses to different energy levels. The Cornell experiment involved the feeding of a pelleted diet at two energy levels (ad libitum and 70% ad libitum) to Angus and Holstein bulls, steers and heifers. Animals were slaughtered after 64, 140 or 224 days of feed. Seventy animals (including an initial slaughter group) were used in the experiment.

Due to the limited number of animals within each breed-sex-feeding time subclass, meaningful response curves could not be estimated for each subclass. Hence, some pooling of the data was required. Four non-linear response curves were identified which "outlined" a three-dimensional growth response surface. Figure 5 schematically represents the surface as estimated from the data.

Figure 5

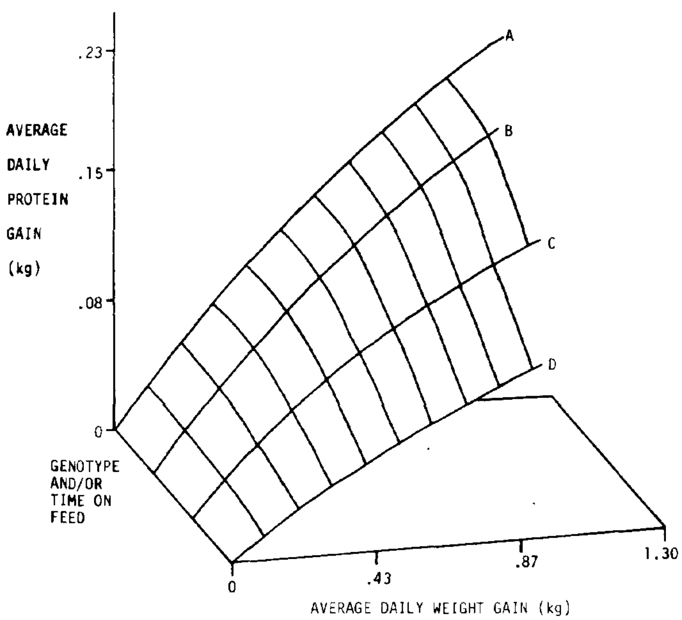

Figure 5. Effects of breed, sex, time on feed and average daily weight gain on average daily protein gain.

A = Holstein bulls 64, 140 d
Holstein steers 64 d

B = Holstein bulls 224 d
Holstein steers 140 d
Angus bulls 64 d

C = Holstein steers 224 d
Holstein heifers 64, 140, 224 d
Angus bulls 140, 224 d
Angus steers 64, 140 d
Angus heifers 64, 140 d

D = Angus steers 224 d
Angus heifers 64, 140 d

The diagram illustrates the effects of breed, sex and time on feed on rate and composition of growth when cattle are fed different levels of energy. Compared to curve D, animals on curve A were capable of higher maximum daily weight gains and deposited higher proportions of protein in gains. Curves B and C are intermediate. Holstein responses tended to be predicted by curves "higher up" the surface than Angus. This is consistent with the concept that Holsteins are physiologically less mature than Angus at a given age or weight. Similarly, responses for bulls were best predicted by curves "higher up" the surface than heifers. Steers were intermediate. Finally, as time on feed increased, average growth responses were characterized by curves "lower" on the surface, demonstrating that as age and/or weight increases, the proportion of fat in gains increases. Although difficult to detect from Figure 5, proportions of protein in gains at slow rates of growth were similar for all four curves, suggesting that differences in composition of gains among animals from different breeds or sexes are more likely to be realized at higher levels of feed intake.

From a modeling viewpoint, accurate predictors of growth responses are needed for each sex within a given breed (or biological type) over a range of energy intake and maturity. The schematic in Figure 6, constructed from the response curves which described Holstein steers, illustrates what such

Figure 6

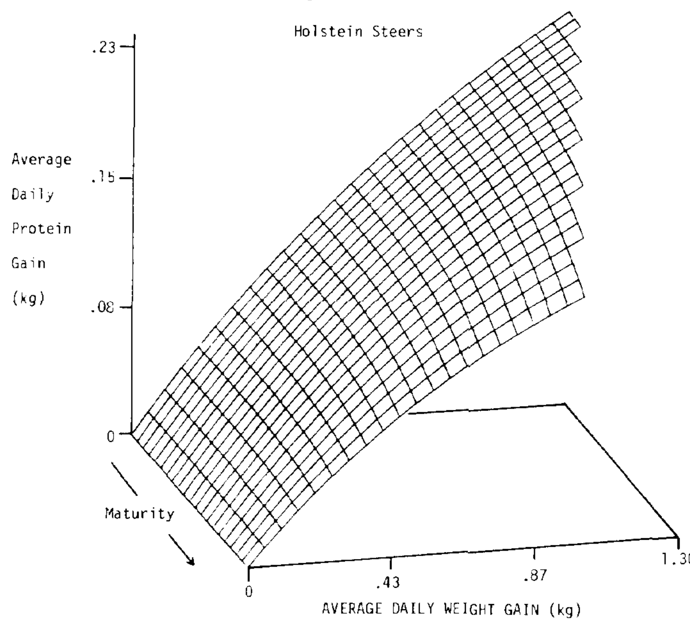

Figure 6. Schematic concept of average daily protein gain as affected by maturity and average daily weight gain.

a surface might look like. Cattle are most likely capable of their fastest growth early in the feeding period. These rapid gains also contain much protein or lean. As the animal matures, the maximum potential rate of growth declines and the proportion of fat in gains increases.

The effects of breed, sex or length of feeding period on growth component parameters cannot be estimated with much confidence from these data, due to the limited number of observations. However, I think the data do illustrate an interesting concept of animal growth very well. More experimental research will be needed to better understand and/or accurately predict growth responses of different genotypes to varying energy levels.

More Information is Needed

One of the greatest challenges to researchers attempting to construct biological models is finding and understanding the scientific literature that is relevant to the question(s) being addressed and integrating this information into a mathematical model. This problem is made even more difficult because research that is relevant to the system generally represents several different disciplines. Nevertheless, often the modeling effort identifies research areas where more information is needed. It may be useful to mention a few such areas that seem important.

First, there is a real lack of *quantitative* information concerning the chemical composition of growth and how body composition is affected by nutrition. Qualitative data is not useful from a predictive standpoint. This need is particularly great when considering potential genetic differences in growth responses and the wide variety of animal breeds available to U.S. producers.

In conjunction with the need for more data on chemical body composition is the need for methods of determining the chemical body composition in *live* animals. Comparative slaughter methods are time consuming, expensive and require the use of initial slaughter groups with their associated errors. This need includes the need to separate gut contents from tissue in the live animal. Chemical marker techniques are providing some information, yet they generally assume some fixed relationship between the chemical components of weight (i.e. water and lean). We know, however, that as animals mature the ratio of water to lean declines. Such assumptions may severely limit the accuracy of determinations made across different ages and genotypes.

More quantitative data is needed in the area of forage intake and utilization. We need to know how to predict forage intake as it is affected by animal characteristics as well as forage characteristics. We need to better understand and quantify how cattle respond to forages and how forages then respond to the cattle.

Research is needed to elucidate the physiological effects of genetic change. The large number of breeds currently available, plus the numerous types of environments and management used to produce animals (especially cattle), makes experimental evaluations of all possible combinations impractical. Rather than a statistical definition of "breed effects", we need to understand *why* certain genotypes excel under certain circumstances; then it may be possible to predict the performance of combinations of genotypes and environment which have not been experimentally evaluated.

In swine, it is common practice to limit feed intake for breeding sows. As pigs become genetically leaner and capable of faster growth, one would expect that "mature" or "asymptotic" weight for these genotypes should also increase. What potential interaction will this have with current feeding practice? Will such lean, fast-growing gilts be able to reproduce regularly or raise several litters under current management systems? These are questions that experimental research will need to address.

Conclusions

In this paper, I have tried to illustrate some of the types of information that may be obtained through the use of computer models. Mathematical computer models can be valuable tools for addressing many research questions, particularly those requiring the integration of information from several disciplines. Modeling, however, should never be considered as a replacement for well-designed experimentation. With the current information explosion in science and the trend for greater specialization in graduate training and research, there will be an increasing need for integration and interpretation of information from many disciplines in order for research to have maximum benefit to producers and consumers. One of the most important contributions of modeling efforts may be in facilitating such integration and communication between the disciplines concerned with animal production.

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