Gordon Dickerson:
Defining Economic Efficiency of Beef Production

M.W. Tess and K. C. Davis
Animal and Range Sciences Department
Montana State University

Summary

Dr. Gordon E. Dickerson was a visionary and productive scientist whose many scientific contributions included a systems approach to the genetic improvement of economic efficiency of beef production. His most important contributions to the improvement of beef efficiency include: 1) insisting on an economic definition of the biological objectives of livestock production, 2) promoting multi-disciplinary approaches to the study of production systems, 3) comparing different domestic species to identify opportunities for genetic improvement, 4) elucidating the economic impacts of changes in beef cattle performance traits, 5) demonstrating the utility of index selection for genetically managing undesirable genetic antagonisms in production systems, 6) demonstrating the benefits of structured crossbreeding systems in exploiting heterosis and breed complementarity, 7) calling for value-based pricing of market animals to provide economic incentives for genetic improvement, and 8) stimulating a significant volume of experimental work targeted at answering scientific questions posed via his research.

Introduction

To describe the contributions of Dr. Gordon E. Dickerson to the understanding and improvement of beef production efficiency is to view just a portion of a large mosaic. His influence reaches far beyond just production efficiency and far beyond just beef cattle. Like a pioneer scout riding far ahead of the wagon train marking out places to camp, he navigated areas to research long before the livestock industry was ready to apply many of his ideas. Production efficiency was one of those “camps.”

We will attempt to highlight and organize Dr. Dickerson’s contributions to the genetic improvement of beef production efficiency. Because I (MWT) regard Dr. Dickerson as my mentor and friend we will refer to him subsequently as simply Gordon. I could not respect a scientist more highly than I respect Gordon Dickerson.

Biological Objectives

Proper definition of breeding goals motivated much of Gordon’s work on production efficiency. He repeatedly emphasized that management decisions, and especially genetic decisions -- i.e., choices among breeds, choices among mating systems, and decisions regarding the relative emphasis of different traits in selection schemes -- should all be based on “biological objectives” (Dickerson, 1969, 1970, 1976, 1982c). He defined biological objectives as “the relative economic importance of the major components of performance in terms of the approximate direct effect of each on cost per unit of production" (Dickerson, 1969). Because changes in production/marketing systems can change biological objectives Gordon stressed that genetic decisions should be made with an eye to the future of animal production (Dickerson, 1970, 1982b). Due to the implications of genotype x environment interactions (Dickerson, 1962), he recommended that each biological type should be evaluated under the production/marketing system for which it is best suited (Dickerson, 1978).

During his day, Gordon felt that genetic research had placed high priority on developing effective methods to effect genetic change, but had given little consideration to which traits to change or how much to change them (Dickerson, 1982bc; Dickerson and Willham, 1983). This gave further impetus to his work on biological objectives. One could easily draw the same conclusion today, some 20 years later.

Economic versus Biological Efficiency

The fact that "biological" objectives were in fact based on economic costs and returns rather than just biological inputs and outputs was intuitive to Gordon (Dickerson, 1982c; Dickerson et al., 1982). Biological inputs (e.g., feed energy) were only worthy of consideration if they were associated with an expense. For example, water is a major "biological" input into animal production systems, yet seldom considered in efficiency studies due to its low relative cost. Hence, even though several of his publications dealt with solely biological components (e.g., Mcal energy and weight of product), the fact that the inputs (or outputs) represented major sources of expense (or return) justified their study (e.g., Green et al., 1991ab). He also recognized that non-feed costs represented major sources of expense in livestock production, and were not always directly related to animal performance. Further, Gordon realized that production systems used different types of inputs, each with potentially different prices, and yielded different types of products, each with potentially different market values. Hence, the relative economic value of inputs and outputs needed to be considered explicitly (Dickerson, 1976, 1978, 1982c). He argued that purely biological measures of efficiency could only be calculated by "ignoring" these facts, and that species comparisons based on biological efficiency were forced to "ignore" the differing costs of energy for ruminants and monogastrics (Dickerson et al., 1982).

Gordon preferred to define biological objectives in terms of efficiency (e.g., cost per unit of value produced) rather than profit (e.g., income minus expense). He stated that efficiency was more "realistic" than profit because sale prices tend to fluctuate around a narrow margin above production costs, so that lower costs benefit consumers more than producers (Dickerson, 1976). Hence, he considered efficiency "predictive" of consumer prices (Dickerson, 1982), and profit an "illusory criterion" (Dickerson, 1969).[1]

Multi-Species Systems Approaches

Gordon was one of the first animal scientists to truly embrace a systems approach in the study of livestock production. From his earliest works on biological objectives

[1] Interestingly, ratios that Gordon always referred to as measures of efficiency would be considered unacceptable today by the *Journal of Animal Science*, which insists that "efficiency" is an output/input ratio while input/output is termed "conversion."

(e.g., Dickerson, 1970) he demonstrated a rare ability to see a production system from a broad perspective and then dissect and analyze its dynamic and interacting components. Further, Gordon was evangelistic in his plea for a multi-disciplinary approach to systems analysis (e.g., Dickerson, 1982b; Dickerson and Willham, 1983), and led the way by his own example. His collaborators and co-authors included scientists from ruminant and non-ruminant nutrition, physiology, meats, agricultural engineering, and economics, as well as genetics.

One of the most amazing aspects of Gordon's work was that it focused on so many different species. Some of his earliest work on biological objectives was based on comparisons across species including rabbits, chickens (both meat and eggs), turkeys, sheep, pigs, dairy cattle, and beef cattle (Dickerson, 1970, 1976, 1978). His efforts were influenced by several other contemporary researchers and coworkers who worked with species such as broilers (Moav and Moav, 1966), pigs (Harris, 1970), and beef cattle (Cartwright, 1970).

A trademark of Gordon's papers from this era was his ingenious use of complex single-equation models (Dickerson, 1970, 1976, 1978, 1982a). The example shown in Figure 1 is a composite of several versions, all of which were quite similar. His papers and presentations included elaborate, and sometimes decorative, graphs and charts derived from exercises with these single-equation generalized models of animal production. I am still impressed by the fact that all of these results were calculated by hand using nothing more than an electronic calculator (i.e., not a computer)!

Although researchers like Tom Cartwright were first to develop dynamic computer simulation models of livestock production (Sanders and Cartwright, 1979ab), it could be argued that Gordon and his students made more extensive use of the technique; certainly they worked in more species. Gordon's graduate students modified and applied the model developed by Sanders and Cartwright (Notter et al., 1979abc), developed and experimented with a dynamic computer model of swine production (Tess et al., 1983abc; Bennett et al., 1983ab, Smith et al., 1983), modified and exercised (Wang and Dickerson, 1991abc) a dynamic model of sheep production (Blackburn and Cartwright, 1987), in addition to using systems approaches to several other beef cattle problems (e.g., Dickerson, 1984; Green et al., 1991ab; Núñez-Dominquez et al., 1992).

Effects of Beef Performance Traits on Efficiency

It is perhaps his interest in comparing species that provided Gordon some of his most unique and productive insights into the dynamics of economic efficiency of beef production systems. These insights motivated him to focus his work in beef cattle on four primary areas: growth rate, body composition, milk production, and reproductive rate.

Growth Rate and Mature Size. Certainly much of Gordon's understanding of the effects of growth and mature size on efficiency came from exercises with his single equation models (Dickerson, 1970, 1976, 1978; e.g., Figure 1). However Dave Notter's thesis research (Notter et al., 1979b) represented a more thorough investigation of the effects of growth rate within integrated production systems. Conclusions from these works were reviewed in several subsequent papers (e.g., Dickerson 1982a, 1983,1985).

Gordon largely viewed growth rate and mature size as highly correlated traits, as did other researchers (e.g., Sanders and Cartwright, 1979ab). His research demonstrated that the effects of mature size were largely a matter of trade-offs. He showed that increasing growth rate reduced maintenance costs (both feed and non-feed) for growing animals, especially if harvest weight remained constant (Dickerson, 1983). More rapid growth improved production system efficiency most when it provided a means of increasing slaughter weight without increasing fatness, because the high costs of maintaining and replacing breeding cows were spread over more output (Dickerson, 1976). However, rapid growth was also associated with proportional increases in mature size, which led to increased breeding female feed maintenance costs, increased age at puberty and longer gestation length. He showed that because breeding female costs constitute a much higher proportion of total costs in species that have lower reproductive rates, lowering breeding female costs was a key to improving beef production efficiency (Dickerson, 1976). His papers also emphasized that, in many systems, increased growth rate was associated with increased dystocia and calf mortality, and longer rebreeding intervals (Dickerson, 1970, 1978, 1982a).

As a partial remedy to these opposing effects of growth rate, Gordon was one of the first researchers to suggest the idea of growth curve "bending"[2] – i.e., the concept of selecting for rapid early growth but restricting birth weight and mature size (Dickerson, 1970, 1976). This also led to what many breeders and researchers call the "Dickerson Index" (Index = Yearling weight – 3.2 Birth Weight) (Dickerson et al., 1974).

Body Composition. Gordon tended to regard lean meat production or edible protein output as the desired product of meat-animal production systems (Dickerson, 1985). Hence, he often defined the denominator of efficiency as "product value," implying that carcass composition determined value per unit of weight. His early work even included adjustments for carcass marbling (Dickerson et al., 1974). His work of 30 years ago, in which he called for a more value-based carcass pricing system to provide incentives for genetic change (Dickerson, 1983), seems right in step with the grids used today in the beef industry; perhaps another indication of his forward thinking.

Gordon's multi-species/multi-discipline approach to livestock production probably fueled his fascination with body composition. Although Gordon should certainly be remembered as a world-class geneticist, his work included a great deal of research on the effects of body composition on input costs in animal production. His experimental work addressed such things as the effects of body composition on maintenance requirements (Tess et al., 1984a; Olthoff and Dickerson, 1989; Buckley et al., 1991; Baker et al., 1991), digestibility, and energy and nitrogen metabolism (Yen et al., 1983), the energetic cost of protein and fat deposition (Tess et al., 1984b), and dietary protein requirements for different biological types of animals (Tess et al., 1983b). These studies showed that selection for increased leanness or substituting for leaner biological types were expected to improve the energetic efficiency of growth, primarily due to the high water content of lean tissue, yet increase protein requirements (percent of diet), and

[2] This conclusion is largely based on the date of the paper, which gave no reference to another source. To my knowledge Gordon may have been the first to use this term (1976), although he suggested the concept in 1970.

increase maintenance requirements. He sought to apply these concepts to beef production systems (Dickerson, 1978, 1983, 1985).

Milk Production. Although he often included milk production in his discussion of biological objectives, compared to measures of growth, body composition and reproductive traits, milk yield received relatively less emphasis in Gordon's papers. This suggests that he thought that genetic specification of milk production was not critical to economic efficiency in most beef systems. It may also reflect the fact that Gordon usually modeled beef production as an integrated system (i.e., conception to slaughter), rather than systems that marketed calves at weaning.

Gordon's principle contribution to the understanding of milk production in beef systems was via Dave Notter's thesis research (Notter et al., 1979a). Their results suggested that for midwestern integrated systems, economic efficiency was relatively insensitive to milk production level. Economic efficiency declined if milk production was low enough to decrease calf survival or high enough to decrease weight weaned per cow exposed due to decreased cow condition and reproduction. Higher milk yield was more economical if breeding cow TDN price was lower relative to feedlot TDN price.

Reproductive Rate. Another by-product of Gordon's multi-species comparisons was his interest in improving the reproductive rate of beef cattle. Comparisons of production costs between beef cattle and species like swine convinced him that, due the high costs of maintaining brood cows, the beef industry had potentially much more to gain from increasing reproductive rate than other species (Dickerson, 1970, 1976).

By the early 1980's Gordon proposed that beef cattle might benefit from genetic improvement of litter size (i.e., twinning) in spite of the low heritability for twinning rate in beef cattle (Dickerson and Willham, 1983). He fully realized the risks associated with multiple births in beef cattle, including increased dystocia, freemartin calves, and increased mortality (Dickerson, 1983). He further understood that increased twinning rate, like most other forms of genetic change, would require adjustments in nutrition and management (Dickerson, 1982b). Using data from an embryo-transfer experiment, he and his coworkers concluded that twinning had the potential to improve economic efficiency by up to 24% (Dickerson et al., 1988; Guerra-Martinez et al., 1990).

Certainly his ideas, and most likely his persistence, influenced the development of the "twinning herd" at the U.S. Meat Animal Research Center, which was established to evaluate the effectiveness of selection for increased twinning as well as to identify the management adaptations required to facilitate increased reproductive rate in beef cattle (Gregory et al., 1990).

Perhaps twinning is one piece of Gordon's vision for the beef industry that has yet to be applied. For most beef producers the problems still outweigh the advantages. However, the current era of rapid structural change in the beef industry may yet find a place for such an "outside the box" idea.

Effects of Mating Systems and Breed Choices on Efficiency

As a geneticist, Gordon's contributions to the understanding of direct and maternal breed effects, heterosis and epistasis rank among his most important works (Dickerson, 1969; 1973). I would guess that these papers have been "standard fare" in graduate animal breeding courses for 30 years. Never one to miss the big picture, seldom did Gordon write about biological objectives or economic efficiency without including the importance of choices among breeds and mating systems (Dickerson, 1970, 1976, 1978, 1982a, 1983, 1984).

The research reported by Notter et al. (1979c) and Núñez-Dominquez et al. (1992) represent his most complete economic studies of crossbreeding systems for beef cattle. These studies clearly demonstrated that economic efficiency was most improved in systems that exploited both individual and maternal heterosis, and that the wise use of terminal sire breeds with smaller maternal breeds was an effective way to reduce or eliminate the negative effects associated with increased lean growth and mature size on maternal performance.

Gordon viewed heterosis as too important to ignore, and saw structured crossbreeding as an important tool by which to manage the biological and economic trade-offs associated with genetic change. I think he would be disappointed in the apparent departure from structured crossbreeding seen in the beef industry today.

Reflections

As a geneticist, Gordon Dickerson had a persistent and unique focus on livestock improvement. His philosophy might be captured in his introduction to the Third World Congress on Genetics Applied to Livestock Production:

> "Perhaps we should not be too critical of the emphasis placed by earlier breeders on pleasing color patterns, horns, and beauty of conformation. Such intangible esthetic rewards for the breeders' efforts are not as easily snatched away by the unfeeling laws of supply and demand, as are the returns from increased efficiency of production. However, to the extent that our role is to help reduce costs of animal products to consumers, we do need to focus on those genetic changes in form and function that are most relevant" (Dickerson, 1986).

Gordon had an amazing talent to appreciate and study the interactions of biological components as they contributed to the function of larger whole systems. In many ways he was ahead of his time. The weight of his contributions lays in that they are still as fresh and valuable today as they were two and three decades ago.

He owned a rare ability to nurture and encourage the best from his students and collaborators. Perhaps his influence on his coworkers was best felt through his questions . . . probing, penetrating questions. For all his brilliance, what made Gordon so easy to respect were his humility and his kind and gentle spirit. He was genuinely interested in others and communicated value to those around him. If he were here today, I'm sure he would praise the contributions of his partners, and discount his own. He never sought the spotlight for himself. He was that kind of man --- a genuinely good man. It remains an honor for me (MWT) to have worked with him.

Figure 1. General equation for bio-economic efficiency for animal production (Adapted from Dickerson, 1970, 1976, 1982a).

$$\frac{\text{Expense}}{\text{Product}} = \frac{\overbrace{(R_d + I_d + B_d \cdot F_{md} + F_{pd})}^{\text{Per breeding female}} + \overbrace{N_o[D_o(I_o + B_o \cdot F_{mo} + F_{po}) + S_o]}^{\text{And her offspring}}}{P_d \cdot V_d + N_o \cdot P_o \cdot V_o}$$

Where,

R_d = annualized replacement cost per breeding female.

I_d = annual non-feed cost per breeding female (i.e., dam).

B_d = average metabolic body size of breeding female.

F_{md} = annual maintenance feed cost per B_d.

F_{pd} = annual above-maintenance feed cost per breeding female.

N_o = annual number of offspring marketed per breeding female.

D_o = days from weaning to market age for offspring.

I_o = daily non-feed cost for offspring during the postweaning period.

B_o = average metabolic body size of offspring during the postweaning period.

F_{mo} = daily maintenance feed cost per B_o.

F_{po} = daily above-maintenance feed cost.

S_o = annual non-feed cost per offspring marketed.

P_d = annual product marketed per breeding female.

V_d = value per unit of breeding female product.

P_o = annual product marketed per offspring.

V_o = value per unit of offspring product.

Literature Cited

Baker, J. F., B. A. Buckley, G. E. Dickerson, and J. A. Neinaber. 1991. Body composition and fasting heat production from birth to 14 months of age for three biological types of beef heifers. J. Anim. Sci. 69:4406-4418.

Bennett, G. L., M. W. Tess, G. E. Dickerson, and R. K. Johnson. 1983a. Simulation of breed and crossbreeding effects on costs of pork production. J. Anim. Sci. 56:801-813.

Bennett, G. L., M. W. Tess, G. E. Dickerson, and R. K. Johnson. 1983b. Simulation of heterosis effects on costs of pork production. J. Anim. Sci. 56:792-800.

Blackburn, H. D., and T. C. Cartwright. 1987. Description and validation of the Texas A&M sheep simulation model. J. Anim. Sci. 65:373-386.

Buckley, B. A., J. F. Baker, G. E. Dickerson, and T. C. Jenkins. 1991. Body composition and tissue distribution from birth to 14 months for three biological types of beef heifers. J. Anim. Sci. 68:3109-3123.

Cartwright, T. C. 1970. Selection criteria for beef cattle for the future. J. Anim. Sci. 30:706-711.

Dickerson, G. E. 1962. Implications of genetic-environmental interaction in animal breeding. Animal Prod. 4:47-63.

Dickerson, G. E. 1969. Experimental approaches in utilizing breed resources. Anim. Breed. Abstr. 37:191-202.

Dickerson, G. E. 1970. Efficiency of animal production – molding the biological components. J. Anim. Sci. 30:849-859.

Dickerson, G. E. 1973. Inbreeding and heterosis in animals. Pages 54-77 in Proc. Anim. Breeding Genet. Symp. in Honor of Dr. J. L. Lush, Am. Soc. Anim. Sci. Am. Dairy Sci. Assoc., Champaign, IL.

Dickerson, G. E., N. Kunzi, L. V. Cundiff, R. M. Koch, V. H. Arthaud, and K. E. Gregory. 1974. Selection criteria for efficient beef production. J. Anim. Sci. 39:659-673.

Dickerson, G. E. 1976. The choice of selection objectives in meat producing animals. Pages 449-462 in Meat Animals, Plenum Pub. Corp., N. Y.

Dickerson, G. E. 1978. Animal size and efficiency: basic concepts. Anim. Prod. 27:367-379.

Dickerson, G. E. 1982a. Effect of genetic changes in components of growth on biological and economic efficiency of meat production. Proc. 2nd World Cong. Genet. Appl. Livest. Prod., Madrid, Spain V:252-267.

Dickerson, G. E. 1982b. Present and potential contributions of genetics to animal production. Proc. 2nd World Cong. Genet. Appl. Livest. Prod., Madrid, Spain V:15-22.

Dickerson, G. E. 1982c. Principles of establishing breeding objectives in livestock. Proc. World Cong. Sheep Beef Cattle Breed., New Zealand 1:9-22.

Dickerson, G. E., M. W. Tess, and G. L. Bennett. 1982. Biological models in pig improvement. Proc. 2nd World Cong. Genet. Appl. Livest. Prod., Madrid, Spain V:578-587.

Dickerson, G. E. 1983. Potential genetic improvements in the efficiency of beef production. Page 85-119 in Strategies for Most Efficient Beef Production. Proc. International Symposium on Beef Production, Kyoto, Japan.

Dickerson, G. E., and R. L. Willham. 1983. Quantitative genetic engineering of more efficient animal production. J. Anim. Sci. 57(Suppl. 2):248-264.

Dickerson, G. E. 1984. Effective use of animal genetic and production resources. Proc. 2nd World Cong. Sheep Beef Cattle Breed., Pretoria, RSA 1:67-78.

Dickerson, G. E. 1985. Measuring efficiency of beef production. Pages115-137 in Breeding Beef Cattle in a Range Environment, Ft. Keogh Livestock and Range Station, ARS, USDA, Miles City, MT.

Dickerson, G. E. 1986. Genetic engineering of livestock improvement. Proc. 3rd World Cong. Genet. Appl Livest. Prod. IX:3-10.

Dickerson, G. E., P. Guerra-Martinez, G. B. Anderson and R. D. Green. 1988. Twinning and performance efficiency in beef production. Proc. 3rd World Cong. Sheep Beef Cattle Breed., Paris, France 1:190-193.

Green, R. D., L. V. Cundiff, and G. E. Dickerson. 1991a. Life-cycle biological efficiency of *Bos indicus, Bos taurus* and *Bos taurus* crossbred cow-calf production to weaning. J. Anim. Sci. 69:3544-3563.

Green, R. D., L. V. Cundiff, T. G. Jenkins, and G. E. Dickerson. 1991b. Output/input differences among non-pregnant, lactating *Bos indicus-Bos taurus* and *Bos taurus-Bos taurus* F_1 cross cows. J. Anim. Sci. 69:3156-3166.

Gregory, K. E., S. E. Echternkamp, G. E. Dickerson, L. V. Cundiff, R. M. Koch, and L. D. Van Vleck.1990. Twinning in cattle: I. Foundation animals and genetic and environmental effects on twinning rate. J. Anim. Sci. 68:1867-1876.

Guerra-Martinez, P., G. E. Dickerson, G. B. Anderson, and R. D. Green. 1990. Embryo-transfer twinning and performance efficiency in beef production. J. Anim. Sci. 68:4039-4050.

Harris, D. L. 1970. Breeding for efficiency in livestock production: defining the economic objectives. J. Anim. Sci. 30:860-865.

Moav, R., and J. Moav. 1966. Profit in a broiler enterprise as a function of egg production of parent stocks and growth rate of their progeny. Brit. Poul. Sci. 7:5-15.

Notter, D. R., J. O. Sanders, G. E. Dickerson, G. M. Smith, and T. C. Cartwright. 1979a. Simulated efficiency of beef production for a Midwestern cow-calf feedlot management system. I. Milk production. J. Anim. Sci. 49:70-82.

Notter, D. R., J. O. Sanders, G. E. Dickerson, G. M. Smith, and T. C. Cartwright. 1979b. Simulated efficiency of beef production for a Midwestern cow-calf feedlot management system. II. Mature body size. J. Anim. Sci. 49:83-91.

Notter, D. R., J. O. Sanders, G. E. Dickerson, G. M. Smith, and T. C. Cartwright. 1979c. Simulated efficiency of beef production for a Midwestern cow-calf feedlot management system. III. Crossbreeding systems. J. Anim. Sci. 49:92-102.

Nu_n_ez-Dominguez, R., G. E. Dickerson, L. V. Cundiff, K. E. Gregory, and R. M. Koch. 1992. Economic evaluation of heterosis and culling policies for lifetime productivity in Hereford, Angus, Shorthorn and crossbred cows. J. Anim. Sci. 70:2328-2337.

Olthoff, J. C., and G. E. Dickerson. 1989. Relationship between fasting heat production and body composition in mature ewes from seven breeds. J. Anim. Sci. 67:2576-2588.

Sanders, J. O., and T. C. Cartwright . 1979a. A general cattle production systems model. I. Description of the model. Agric. Systems 4:217-227.

Sanders, J. O., and T. C. Cartwright . 1979b. A general cattle production systems model. II. Simulation of animal performance. Agric. Systems 4:289-302.

Smith, C., G. E. Dickerson, M. W. Tess, and G. L. Bennett. 1983. Expected relative responses to selection for alternative measures of life-cycle economic efficiency of pork production. J. Anim. Sci. 56:1306-1314.

Tess, M. W., G. L. Bennett, and G. E. Dickerson. 1983a. Simulation of genetic changes in life-cycle efficiency of pork production. I. A bio-economic model. J. Anim. Sci. 56:336-353.

Tess, M. W., G. L. Bennett, and G. E. Dickerson. 1983b. Simulation of genetic changes in life-cycle efficiency of pork production. II. Effects of components on efficiency. J. Anim. Sci. 56:354-368.

Tess, M. W., G. L. Bennett, and G. E. Dickerson. 1983c. Simulation of genetic changes in life-cycle efficiency of pork production. III. Effects of management systems and feed prices on importance of genetic components. J. Anim. Sci. 56:369-379.

Tess, M. W., G. E. Dickerson, J. A. Nienaber, and C. L. Ferrell. 1984a. The effects of body composition on fasting heat production in young pigs. J. Anim. Sci. 58:99-110.

Tess, M. W., G. E. Dickerson, J. A. Nienaber, J. T. Yen, and C. L. Ferrell. 1984b. The energy costs of protein and fat deposition in pigs fed ad libitum. J. Anim. Sci. 58:111-122.

Wang, C. T., and G. E. Dickerson. 1991a. A deterministic computer model for simulation of life-cycle lamb and wool production. J. Anim. Sci. 69:43212-4323.

Wang, C. T., and G. E. Dickerson. 1991b. Simulation of life-cycle efficiency of lamb and wool production for genetic levels of component traits and alternative management options. J. Anim. Sci. 69:4324-4337.

Wang, C. T., and G. E. Dickerson. 1991c. Simulated effects of reproductive performance on life-cycle efficiency of lamb and wool production at three lambing intervals. J. Anim. Sci. 69:4338-4347.

Yen, J. T., M. W. Tess, W. G. Pond, and G. E. Dickerson. 1983. Digestibility and metabolism of dietary nitrogen and energy in contemporary, genetically lean and obese pigs as estimated by total fecal collection and acid insoluble ash. J. Anim. Sci. 56:426-430.