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ESTABLISHING NUTRIENT REQUIREMENTS OF HORSES AND OTHER ANIMALS IN AN ERA OF MODELING

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Energy and essential nutrients such as amino acids, minerals, and vitamins are required by horses and other animals for the various processes of life, including maintenance, growth, reproduction, lactation, and work. Having accurate estimates of dietary nutrient requirements of animals is important. Deficiencies of even a single nutrient in a diet will limit an animal's performance and well-being, and diets with excessive nutrients are expensive and contribute to environmental pollution.

The National Research Council (NRC) plays a major role in establishing the nutrient requirements of horses and other animals. The NRC is a private, nonprofit organization that was established in 1916 to provide advice to the U.S. government on issues of science and technology. The NRC is the "working arm" of The National Academies, which includes the National Academy of Sciences (NAS), an honorary society instituted 137 years ago (in 1863) by President Abraham Lincoln through an act of Congress. Members are elected to the Academy based on their contributions to science. The NRC has ten major units, one of which is the Board on Agriculture and Natural Resources (BANR). The Committee on Animal Nutrition (CAN) is the oldest standing committee of the BANR and the NRC. Dating back to the establishment of the NRC itself, CAN has addressed issues of animal feeding since 1917. Its series of publications on nutrient requirements, written by subcommittees and overseen by CAN, covers nearly 30 species of food, companion, and laboratory animals. These reports have been translated into seven languages and are used worldwide.

The first of the nutrient requirement publications, Recommended Nutrient Allowances for Swine and Recommended Nutrient Allowances for Poultry, were published in 1944. These were concise documents (the swine publication was 10 pages) that identified the nutrients known at that time to be essential for pigs and poultry and that listed dietary requirements for some of these nutrients. The following year, similar publications were released for beef cattle, dairy cattle, and sheep. The first publication of this type for horses, Recommended Nutrient Allowances for Horses, was published in 1949. In 1961, there was a second printing of this publication with a new title, Nutrient Requirements of Horses. Since the initial release in 1949, this publication has been revised four times, in 1966, 1973, 1978, and 1989.

It has now been 11 years since the last edition of Nutrient Requirements of Horses was published. New research findings have emerged over the past 10-15 years and a better understanding of the finer points of equine nutrition has occurred. As a result, the previous edition is in serious need of revision. The

CAN recognizes this fact and has recommended that the publication be revised. The BANR and the NRC have approved CAN's recommendation to convene a subcommittee to produce a new revision.

NRC's Process of Producing Reports

The process by which nutrient requirement publications are prepared is relatively simple, but it is thorough, rigorous, and somewhat time-consuming. Once the study proposal has been approved, and an understanding exists between the sponsor and BANR, the study may commence. Studies may have one or several sponsors from government or the private sector, or both. Because the NRC offers a one-of-a-kind service, not duplicated by other organizations, it does not compete for federal contracts. The NRC provides a public service, which is supported by the users of its products. In the case of nutrient requirement publications, the reports are produced by the nonprofit NRC and are published and disseminated throughout the world by the nonprofit National Academy Press. It is through the dedicated work of volunteer experts and the financial support of end-users that the reports are made widely available for use in the industry, government, research, and teaching communities.

The search for candidates for subcommittee membership is initiated by staff with input and oversight from the relevant boards. In defining the areas of expertise that should be represented on a subcommittee and identifying individuals qualified to serve, the staff reviews scholarly literature and consults widely with members of the National Academies, CAN, knowledgeable authorities, and professional associations. Sponsors may offer suggestions but are not responsible for selecting subcommittee members. Subcommittee members are chosen on the basis of their experience in the various areas of nutrition, and after careful review by CAN and BANR, they are appointed by the chair of the NRC, who also is president of the NAS. Subcommittee members serve as individuals, not as representatives of organizations or interest groups. Members are sought with background and experience in academia, government, and industry. Each person is selected on the basis of his or her expertise and good judgment, and is expected to contribute accordingly to the study. Potential sources of bias and conflict of interest are significant issues that are taken into consideration in the selection of subcommittee members.

A successful report is the result of a dynamic group process, requiring that subcommittee members be open to new ideas and innovative solutions, and be willing to learn from one another and from other individuals who provide input. Subcommittees are expected to be evenhanded and to examine all evidence dispassionately. The CAN subcommittees review the world's literature, particularly research published since the last edition. Although all interested parties should be heard and their views given serious consideration, one of the subcommittee's primary roles is to separate fact from opinion, and analysis from advocacy. Scientific standards are essential in evaluating all arguments and alternatives. Experience suggests that completing the consensus process and writing a report that clearly represents the subcommittee's findings is the most difficult, frustrating, yet rewarding aspect of serving on a study subcommittee. The report is used by many audiences--regulatory, research, and industry, to name a few--and for this reason, the report must be of the highest quality. Although each subcommittee may approach the drafting of its report differently, every report is the collective product of a group process.

Like all good science, reports should be based on fact and rigorous analysis. All CAN reports must undergo an independent review by anonymous expert panels of reviewers. Review is a multitiered process, which ensures the level of highest quality that sets the NRC apart from any other organization. While the report is reviewed by expert scientists, a review coordinator and monitor, as well as the NRC's report review subcommittee, oversee the entire process.

Upon completion of the report, it is published by the National Academy Press. The Press prints and sells the report at cost, and strives to make the report widely available to users on a global scale.

The Swine Model - A New Approach to Estimating Requirements

Several subcommittees have used a modeling approach to more precisely estimate nutrient requirements. The beef and swine subcommittees utilized models in their 1996 and 1998 publications and the dairy subcommittee is currently utilizing models to estimate requirements of dairy cattle. To illustrate the value of models in estimating nutrient requirements, let me review some of the background that went into the development of the models used in the NRC's Nutrient Requirements of Swine publication.

Prior to the last edition of the swine publication, requirement estimates for growth were based mainly on weight classes of pigs and single estimates were made for pregnant and lactating sows without consideration for genetic differences among pigs. Environmental factors that are now known to have a profound influence on the pig's nutrient requirements also were not considered. Simply put, this "one size fits all" approach to defining nutrient requirements is no longer acceptable in the current highly technical arena of swine nutrition.

A new approach was taken by the NRC subcommittee to produce more accurate estimates of nutrient requirements that take into consideration not only the pig's body weight, but also its accretion rate of lean (protein) tissue, gender, health status, and various environmental factors. Similarly, to accurately estimate nutrient needs of gestating and lactating sows, one needs to account for body weight, weight gain during gestation, weight loss during lactation, number of pigs in the litter, weight gain of the litter (a reflection of milk yield), and certain environmental factors.

A series of integrated mathematical equations was needed for the new edition to account for the many factors that are now known to influence nutrient requirements. These integrated equations provide the framework for "modeling" the biological basis of predicting requirements. Unfortunately, no models were available that met the needs for the task at hand. While there were a number of commercial models used in the swine industry, the equations are tightly guarded for proprietary reasons. Also, most simulation models predict animal performance as an output when certain levels of nutrients and various environmental factors were given as inputs. The NRC models are just the opposite; they predict the levels of nutrients (model output) needed to achieve a certain level of production under a given set of environmental conditions (model inputs). Therefore, it was necessary for the subcommittee to develop their own models.

Five principles guided the NRC swine subcommittee as it developed its models. The models were: (1) made for easy use by people with varying levels of nutritional expertise and with limited information; (2) developed for continued relevance for several years to come (i.e., until the next edition will be published); (3) intended to be structurally simple, so they can be understood easily by users; (4) developed to be transparent so that all of the equations are available to the user; and (5) firmly anchored to empirical data at the whole-animal level rather than being simply based on theoretical values.

The tedious task of building the models from scratch took the subcommittee over two years. As the models were developed, they were tested with previously established requirements and with data sets from recently conducted research. The models were modified and refined to ensure that the requirement estimates produced were supported by empirical data. Finally, the models were validated with independent data from experiments that had not been used in the construction of the models. To allow nutritionists to understand the inner workings of the models, all of the equations are presented in the publication.

Three independent models were developed: a growth model, a gestation model, and a lactation model. The growth model estimates amino acid requirements of pigs from weaning to market weight, and the gestation and lactation models estimate energy and amino acid requirements of gestating and lactating sows. Along with energy and amino acid requirements, the software also allows the user to estimate mineral and vitamin requirements, which are based on mathematical equations. The models are included in commercially produced, user-friendly software on a compact disk (CD-ROM) that accompanies the NRC publication.

Swine Growth Model

This model estimates the amino acid requirements of pigs over the range of 20 to 120 kg of body weight. The model estimates requirements on an available amino acid basis, which is based on true absorption of amino acids at the terminal ileum. The amino acid requirements are estimated on a daily (grams/day) basis. The estimates are the sum of the pig's daily requirements for (1) maintenance and (2) deposition of whole-body protein.

Lysine is recognized as the first limiting amino acid in essentially all practical swine diets, so it is estimated first. The daily lysine requirement for maintenance is related to metabolic body weight (kilograms of weight raised to the 3/4 power) and is considered as 0.036 g of lysine per kg of $BW^{0.75}$. The daily lysine requirement for protein deposition is considered as 0.12 g of true ileal digestible lysine per gram of whole-body protein accreted. The value of 0.12 entails two components: the lysine content of whole-body protein (~7.0%), and the partial efficiency of incorporation of digestible lysine into whole-body protein (~58%) (i.e., 7.0/0.58 = 0.12).

Naturally, to use this information, the daily rate at which pigs deposit protein in the body tissues must be known. This can be calculated if one knows the rate at which pigs deposit lean tissue in the carcass, which can be determined from equations utilizing data from packing plant kill sheets. In the model, whole-body protein is calculated from carcass fat-free lean, using a conversion factor of 2.55. In other words, carcass lean is divided by 2.55 to obtain whole-body protein. Thus, a pig having 325 g/day of carcass lean gain is predicted to have a whole-body protein gain of 127 g/day (325/2.55=127).

The user inputs mean daily lean gain (lean gain per day averaged over the period from 20 to 120 kg of body weight), and the model calculates the daily protein accretion at any given weight. This calculation is based on the overall mean lean gain per day along with an assumed shape to the lean gain (protein accretion) curve. The model uses a default curve (Figure 1) to make this calculation. The shape assumes that daily protein accretion rate accelerates during early growth, reaches a plateau, then the rate declines during the finishing period. Pigs with different lean growth rates have the same general pattern of protein accretion but the heights of the curves will differ (Figure 2). The user can input different shaped curves, if desired.

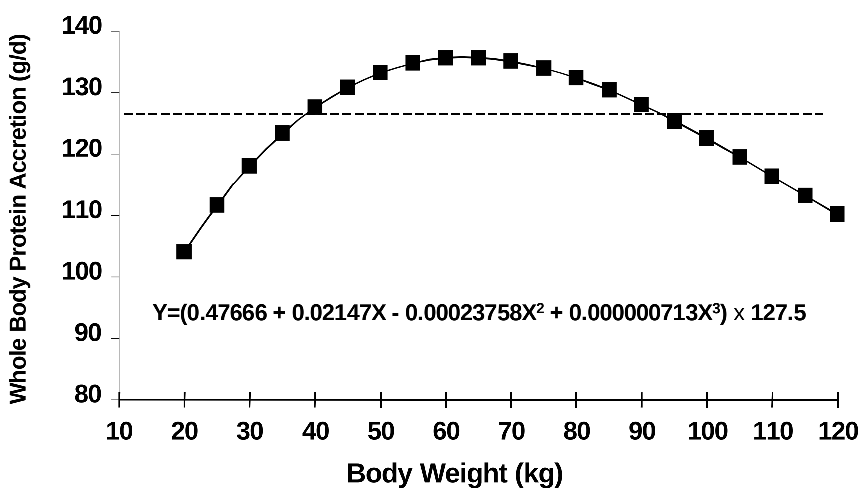

Figure 1. Potential whole body protein accretion rate of pigs of high-medium lean growth rate with a carcass fat-free lean gain averaging 325 g/day from 20 to 120 kg of body weight using the NRC growth model. The lean growth rate of 325 g/day is converted to a mean whole-body protein accretion rate of 127.5 g/day (325/2.55 = 127.5).

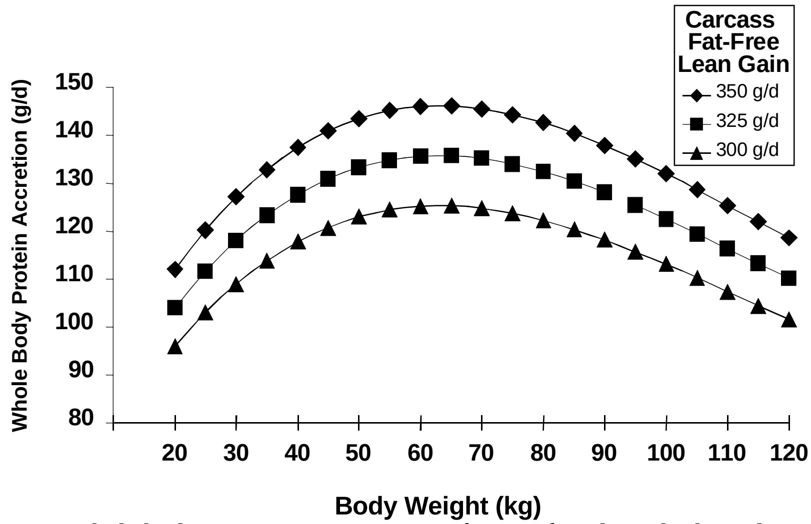

Figure 2. Whole body protein accretion rates of pigs of medium, high-medium, and high lean growth rates with carcass fat-free lean gains averaging 300, 325, and 350 g/day from 20 to 120 kg of body weight as estimated

After the daily lysine requirement is determined, the requirements for the other amino acids are estimated using blends of amino acids patterns. The "ideal protein" concept is used, which assumes that there is an ideal pattern of amino acids for maintenance and an ideal pattern for body protein accretion. These two patterns are blended depending on the proportion of lysine being used for maintenance and protein accretion in a given situation. Requirements are then converted to a percentage basis by dividing the daily amino acid requirements by the daily feed intake. Daily feed intake is predicted from body weight using a digestible energy (DE) intake equation in the model (Figure 3). Alternatively, feed intake can be entered by the user.

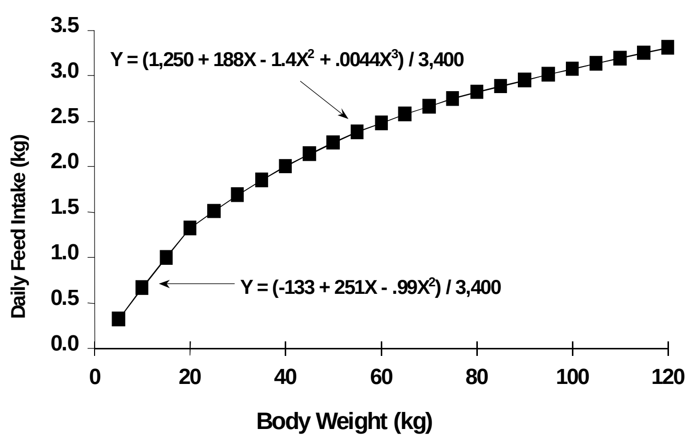

Figure 3. Estimated feed intake of a diet containing 3,400 kcal of DE/kg of pigs from 3 to 120 kg of body weight as estimated by the NRC growth model.

The dietary percentage requirements of amino acids differ depending upon the gender of the pig (females and males require higher percentages of amino acids than castrates), environmental temperature, space allowance, and energy density of the diet. These factors, which are user inputs, affect energy intake, which, in turn, affects the requirements on a percentage basis. From the true ileal digestible amino acid requirements, apparent ileal digestible and total amino acid requirements are then calculated from equations. All three sets of requirements are presented to the user.

The growth model effectively estimates amino acid requirements of pigs based on their genetic ability to deposit lean tissue. Figure 4 illustrates the dietary lysine requirements, expressed as a percentage of the diet, from 20 to 120 kg body weight in pigs (1:1 mix of females and castrates) with medium, high-medium, and high lean growth rates (300, 325, and 350 g/day of carcass fat-free lean) under standard conditions.

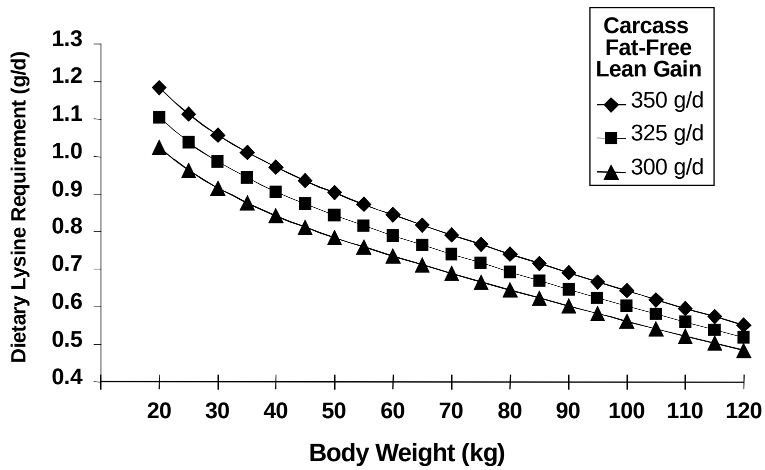

Figure 4. Dietary lysine requirements (%) of pigs of medium, high-medium, and high lean growth rates with carcass fat-free lean gains averaging 300, 325, and 350 g/day from 20 to 120 kg of body weight as estimated by the NRC growth model. The requirements are for total lysine, assuming a corn-soybean meal mixture.

The model adjusts the lysine requirements if changes are made in the gender ratio, energy density of the diet, environmental temperature, animal space, or other factors.

The amino acid requirements for the young pig (3 to 20 kg) are estimated strictly from empirical data, due to a lack of information needed to model the requirements in the same manner as for growing-finishing pigs. The model uses an equation that fits a curvilinear regression line across estimated lysine requirements for several weight categories. The other amino acids are then handled by blending ideal patterns for maintenance and protein accretion.

Mineral and vitamin requirements are not modeled but are estimated from an exponential equation that fits the requirements, on a percentage basis, according to the mean body weights of several weight categories. An example is shown in Figure 5. Daily requirements are then generated by multiplying dietary percentage requirements by daily feed intake.

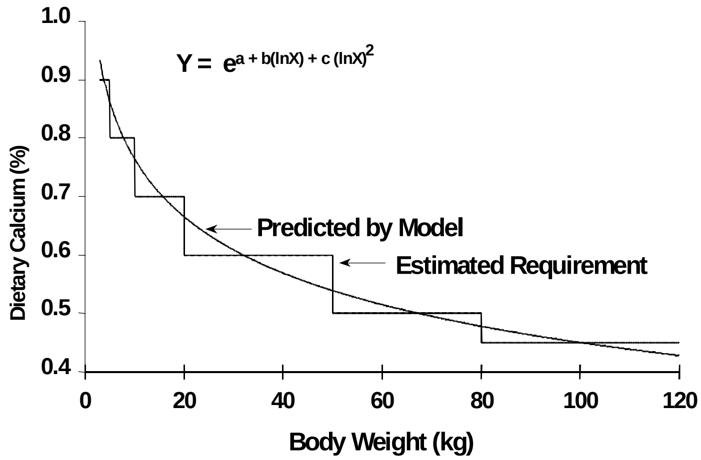

Figure 5. Dietary calcium requirement (%) of pigs from 3 to 120 kg of body weight using the generalized exponential equation in the NRC growth model.

Swine Gestation and Lactation Models

These two models operate much like the growth model in terms of the amino acid requirements. Daily amino acid requirements of gestating sows are based on maintenance and the estimated protein accretion in the sow's body and in the products of conception (uterus, fetuses, placental tissues and fluids, etc.), which are calculated based on user inputs of breeding weight, gestational weight gain, and assumed litter size. Similarly, daily amino acid requirements of lactating sows are based on maintenance, body protein gain or loss during lactation, and milk production of the sow. These are calculated by the model from user inputs of the sow's postpartum weight and projected lactation weight change, lactation length, number of pigs nursed, and daily weight gain of the nursing pigs.

As with the growing pig, lysine is estimated first, then blends of ideal ratios of amino acids for maintenance, protein accretion, milk synthesis, and body protein breakdown are used to estimate requirements for the other amino acids. Daily energy requirements and feed intake are estimated by the model and the percentage requirements are then calculated. The user also has the option of entering daily energy intake; in that case, gestation weight gain or lactation weight loss (or gain) is then calculated by the model. Mineral and vitamin requirements are not calculated by the sow models. Instead, they were estimated by the committee on a dietary concentration basis, then the daily amounts are calculated by multiplying the dietary concentration by the daily feed intake.

Model Supporting Information

A comprehensive set of appendix tables in the tenth edition of Nutrient Requirements of Swine gives added information relative to the models. All of the equations in the models are given such that one could produce the models in spreadsheet form if one so desires. This would allow the user to interface the model with other programs, such as feed formulation programs. A second appendix gives procedures for determining the mean lean gain of pigs based on initial and final estimates of carcass fat-free lean content. A third appendix gives procedures for developing alternative carcass lean gain curves or whole-body protein accretion curves. Finally, two additional appendices include a user's guide and help screens to aid in the use and application of the models.

Software containing the model programs is included on a CD-ROM that accompanies the publication. The software can be easily loaded to a personal computer and it produces both screen and printed copies of requirements. The software also contains detailed feed composition tables that are available on screen or as hard copy.

Obtaining the Models

The NRC publication Nutrient Requirements of Swine, Tenth Revised Edition and the compact disk containing the model programs can be purchased from National Academy Press, 2101 Constitution Avenue N.W., Lockbox 285, Washington, DC 20055. A discount is provided if the order is placed online from the web bookstore at: www.nap.edu. The publication and model as well as other NRC publications can be downloaded from the National Academy Press web site at www.nap.edu, then click on "Reading Room." For more information, contact Charlotte Kirk Baer, Committee on Animal Nutrition, Board on Agriculture and Natural Resources, National Research Council, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

Summary

The NRC plays an important role is establishing nutrient requirements of horses and other animals used for food, service, recreation, companionship, and other purposes. Nutrient Requirements of Horses, last published in 1989, is becoming outdated and needs to be revised. Approval has been granted by the NRC to pursue a revision of the horse publication and it is CAN's desire that the public support for this revision will lead us to a new era of estimating nutrient requirements for horses. A modeling approach taken by several NRC subcommittees (beef cattle, swine, and dairy cattle) represents a major step forward in estimating nutrient requirements. Models allow nutritionists to formulate diets and develop feeding programs that will more precisely meet the requirements of animals under widely varying conditions.