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NUTRIENT REQUIREMENTS OF SWINE

Tenth Revised Edition

1998

NUTRIENT REQUIREMENTS OF DOMESTIC ANIMALS

Nutrient Requirements of Swine

Tenth Revised Edition, 1998

Subcommittee on Swine Nutrition
Committee on Animal Nutrition
Board on Agriculture
National Research Council

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competencies and with regard for appropriate balance.

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Preface

Swine production represents an important segment of the food animal industry in the United States and throughout the world. Pork is an important source of energy, protein, minerals, and vitamins, and is the most widely consumed red meat in the world. Proper formulation of diets is fundamental to the efficient production of swine in systems that address environmental concerns, and this process depends on a knowledge of the nutrient requirements of swine and the nutritional characteristics of nutrient sources. This tenth edition of *Nutrient Requirements of Swine* contains a reassessment of the nutrient requirements of swine and incorporates new information that was used to establish the requirements.

An abundance of new knowledge in swine nutrition has surfaced since the last edition of *Nutrient Requirements of Swine* was published in 1988. There is now a greater awareness and understanding of the effects of growth rate, carcass leanness, gender, health, environmental temperature, crowding, and carcass modifiers on the nutrient requirements of growing pigs. The higher nutrient requirements of prolific sows nursing large litters are now better understood. Additionally, new information on the bioavailability of nutrients is now available. A better understanding of the nutrient requirements and nutrient sources allows one to accurately formulate diets to meet the pig's dietary requirements without producing overages of nutrients that are excreted into the environment.

A major change was made in this edition in that the subcommittee provided the biological basis used to establish energy and amino acid requirements in the form of integrated mathematical equations (models). The models were developed by the subcommittee with the goal of keeping them simple, transparent (i.e., inner parts understandable to the user), and firmly anchored to empirical data. The process of model development and validation was an extremely laborious and time-consuming task. While these versions of the models are not perfect, the subcommittee believes that they represent a marked improvement over previous systems of establishing requirements and provide the groundwork for development of improved models by future subcommittees.

The model for growing-finishing pigs allows the user to generate tables of nutrient requirements for various body weights of pigs, based on the pig's lean growth rate, gender, and environmental conditions. Similarly, the energy and amino acid requirements of gestating and lactating sows are estimated by models, and the user can generate nutrient requirement tables for sows with different body weights and weight gains during gestation and for various levels of lactational productivity. To accomplish this, a user-friendly computer program containing the models is included in this edition.

Requirements for amino acids in the models were generated on a true ileal digestible basis. The amino acid requirements are provided to the user on a true and apparent digestible basis as well as on a total basis, using corn and soybean meal as the major ingredients. The models also estimate energy requirements for gestating and lactating sows and energy intakes of growing pigs given ad libitum access to feed. Equations to estimate mineral and vitamin requirements at various body weights are also included in the growth model.

Other new information is presented in this tenth edition. Minimizing nutrient excretion is addressed and a discussion of nonnutritive feed additives was expanded. New information on the nutrient composition of an expanded list of feed ingredients and on the bioavailability of amino acids (true and apparent ileal basis), phosphorus, and other nutrients is also included in this edition. Finally, the nutrient requirement tables also provide more information than did those in previous editions.

This three-year study was conducted by the Subcommittee on Swine Nutrition, which was appointed in 1994 under the guidance of the Board on Agriculture's Committee on Animal Nutrition. The subcommittee began its work in November 1994 and the study was completed in December 1997, with the release of the report in April 1998.

GARY L. CROMWELL, *Chair*
Subcommittee on Swine Nutrition

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The subcommittee wishes to thank Charlotte Kirk Baer, Program Director, Board on Agriculture, for her untiring efforts in seeing this project to completion. Appreciation is also given to staff members Melinda Simons and Juliemarie Goupil for their assistance with the report, and to Mary Poos for her help during the first year of planning. Finally, the work by Ron Haugen, Easy Systems, Inc., in developing the software interface for the model is acknowledged.

The generous support of this study provided by the National Pork Producers Council is gratefully acknowledged. In addition, the subcommittee appreciates the support provided by the U.S. Department of Agriculture's Agricultural Research Service, the Center for Veterinary Medicine of the Department of Health and Human Service's Food and Drug Administration, and the American Feed Industry Association.

This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the authors and the NRC in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The content of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report: R. Dean Boyd, Pig Improvement Company, USA; Thomas Crenshaw, University of Wisconsin; C.F.M. deLange, University of Guelph; Darrell Knabe, Texas A&M University; Harley W. Moon, Iowa State University; Robert Myer, University of Florida; Carl Parsons, University of Illinois; Tim Stahly, Iowa State University; Michael Tokach, Kansas State University; and Gawain Willis, Purina Mills, Inc. While the individuals listed above have provided many constructive comments and suggestions, responsibility for the final content of this report rests solely with the authoring committee and the NRC.

Tables and Figures

TABLES

2-1 Ideal Ratios of Amino Acids to Lysine for Maintenance, Protein Accretion, Milk Synthesis, and Body Tissue, 18

2-2 Research Findings on Amino Acid Requirements of Growing Swine Since 1985, 20

2-3 Lysine Requirements of Gestating and Lactating Sows, 25

3-1 Equations for Converting Percentages of Amino Acids from a True Ileal Digestible Basis to an Apparent Ileal Digestible Basis, from an Apparent Ileal Digestible Basis to a True Ileal Digestible Basis, and from a True or Apparent Ileal Digestible Basis to a Total Basis in a Corn–Soybean Meal Diet, 36

3-2 Coefficients Used in the Growth Model to Predict Mineral and Vitamin Requirements (percentage or amount/kg of diet) for Pigs of Various Body Weights, 43

3-3 Evaluation of Data of the Growth Model, 43

3-4 Evaluation of Data of the Lactation Model, 44

6-1 Evaluation of Water Quality for Pigs Based on Total Dissolved Solids, 94

6-2 Water Quality Guidelines for Livestock, 95

9-1 Nutrients in Corn and Corn + Soybean Meal (Dehulled) Compared with the Nutrient Requirements of a 40-kg Growing Pig of High-Medium Lean Growth Rate (325 g of carcass fat-free lean/day), 108

9-2 Fortified Swine Diet, 109

10-1 Dietary Amino Acid Requirements of Growing Pigs Allowed Feed Ad Libitum (90 percent dry matter), 111

10-2 Daily Amino Acid Requirements of Growing Pigs Allowed Feed Ad Libitum (90 percent dry matter), 112

10-3 Dietary Amino Acid Requirements of Barrows and Gilts of Different Lean Growth Rates and Allowed Feed Ad Libitum (90 percent dry matter), 113

10-4 Daily Amino Acid Requirements of Barrows and Gilts of Different Lean Growth Rates and Allowed Feed Ad Libitum (90 percent dry matter), 114

10-5 Dietary Mineral, Vitamin, and Fatty Acid Requirements of Growing Pigs Allowed Feed Ad Libitum (90 percent dry matter), 115

Contents

PREFACE . . . vii

ACKNOWLEDGMENTS . . . ix

OVERVIEW . . . 1

1 ENERGY . . . 3
Classification of Energy, 3
Gross Energy, 3
Digestible Energy, 3
Metabolizable Energy, 4
Net Energy, 4
Heat Production, 5
Temperature, 5
Activity, 5
Energy Requirements, 5
Maintenance, 5
Growth, 6
Pregnancy, 6
Lactation, 7
Developing Boars and Gilts, 7
Sexually Active Boars, 8
Energy Sources, 8
Sugars and Starch, 8
Nonstarch Polysaccharides, 8
Lipids, 9
Voluntary Feed Intake, 10
Suckling Pigs, 10
Weanling Pigs, 10
Growing-Finishing Pigs, 10
Sows, 11
References, 11

2 PROTEINS AND AMINO ACIDS . . . 16
Essential and Nonessential Amino Acids, 16

Amino Acids in Diets, 17
Ratios Among Amino Acids (Ideal Protein), 17
Bioavailability of Amino Acids, 18
Amino Acid Isomers, 19
Amino Acid Deficiencies and Excesses, 19
Amino Acid Requirements, 19
Starting Pigs, 19
Growing-Finishing Pigs, 24
Sows, 25
Boars, 25
References, 26

3 MODELS FOR ESTIMATING ENERGY AND AMINO ACID REQUIREMENTS 31
Overview of the Models, 31
Growing-Finishing Pigs, 32
Requirement for Lysine, 32
Requirements for Other Amino Acids, 35
Expression of Amino Acid Requirements, 35
Gestating Sows, 36
Composition of Weight Gain, 37
Requirement for Energy, 37
Requirement for Lysine, 38
Requirements for Other Amino Acids, 38
Expression of Amino Acid Requirements, 38
Lactating Sows, 38
Requirement for Energy, 39
Requirement for Lysine, 39
Requirements for Other Amino Acids, 40
Expression of Amino Acid Requirements, 40
Weanling Pigs, 40
Mineral and Vitamin Requirements, 41
Evaluation of the Models, 42
Growth Model, 42
Gestation Model, 44
Lactation Model, 44
References, 44

4 MINERALS 47
Macro Minerals, 47
Calcium and Phosphorus, 47
Sodium and Chlorine, 49
Magnesium, 50
Potassium, 51
Sulfur, 51
Micro/Trace Minerals, 51
Chromium, 51
Cobalt, 52
Copper, 52
Iodine, 53
Iron, 54
Manganese, 55

Selenium, 55
Zinc, 56
References, 57

5 VITAMINS 71
Fat-Soluble Vitamins, 71
Vitamin A, 71
Vitamin D, 73
Vitamin E, 73
Vitamin K, 74
Water-Soluble Vitamins, 75
Biotin, 75
Choline, 76
Folacin, 77
Niacin, 78
Pantothenic Acid, 78
Riboflavin, 79
Thiamin, 79
Vitamin B_6 (The Pyridoxines), 80
Vitamin B_{12}, 80
Vitamin C (Ascorbic Acid), 81
References, 82

6 WATER 90
Functions of Water, 90
Water Turnover, 90
Water Requirements, 91
Suckling Pigs, 91
Weanling Pigs, 91
Growing-Finishing Pigs, 92
Gestating Sows, 93
Lactating Sows, 93
Boars, 93
Water Quality, 93
References, 95

7 NONNUTRITIVE FEED ADDITIVES 97
Additives, 97
Antimicrobial Agents, 97
Anthelmintics, 98
Microbial Supplements, 98
Oligosaccharides, 98
Enzymes, 98
Acidifiers, 98
Flavors, 99
Odor Control Agents, 99
Antioxidants, 99
Pellet Binders, 99
Flow Agents, 99
Mineral Supplements, 99
Carcass Modifiers, 99
Safety Concerns, 99

Regulations, 100
References, 100

8 MINIMIZING NUTRIENT EXCRETION 103
References, 105

9 DIET FORMULATION 107
Formulating a Corn–Soybean Meal Diet, 107
Formulation, 107

10 NUTRIENT REQUIREMENT TABLES 110

11 COMPOSITION OF FEED INGREDIENTS 124
References, 142

APPENDIXES
1 Equations Used to Model the Biological Basis for Predicting Nutrient Requirements, 143
2 Equations for Determining Lean Growth Rate of Pigs, 148
3 Method to Create a Cubic Regression Equation, 150
4 A User's Guide for Model Application, 153
5 Help Screens, 171

AUTHORS 179

INDEX 180

Overview

Energy, amino acids, minerals, vitamins, and water are needed by pigs for body maintenance, growth, reproduction, and lactation. Synthesis of muscle and adipose tissue, bone, hair, skin, and other body components, resulting in accretion of water, protein, lipid, and ash, is dependent upon an adequate dietary supply of nutrients. Pigs must be provided these essential nutrients in adequate amounts and in forms that are palatable and efficiently utilized in order for optimal growth, reproduction, and lactation to occur.

Since 1944, the National Research Council has published nine editions of *Nutrient Requirements of Swine*. This publication has guided nutritionists and other professionals in academia and the swine and feed industries in developing and implementing nutritional and feeding programs for swine. This tenth edition continues that tradition, but the format of this edition is quite different from that of previous ones. The text has been expanded with new sections that address contemporary issues, and the tables are more comprehensive. A new approach using integrated mathematical equations (models) was utilized to generate estimates of energy and amino acid requirements, and a computer program and software allow the user to create tables of nutrient requirements for swine of a specific body weight and level of productivity.

The first chapter deals with energy and reviews new information on digestible energy (DE), metabolizable energy (ME), and net energy (NE) requirements of swine. Equations for predicting DE, ME, and NE from chemical components are presented. New information on factors affecting energy requirements of swine also is included in this chapter.

In the chapter on proteins and amino acids (Chapter 2), much of the discussion relates to lysine, the first limiting amino acid in most diets for pigs, and to new information on lysine requirements. The concept of "ideal ratios" of essential amino acids to lysine for maximum lean tissue synthesis in growing pigs and optimal productivity in gestating and lactating sows is described. Discussion of bioavailability of amino acids, on a true and apparent ileal digestibility basis, has been expanded. A section on amino acid requirements of boars is now included.

Chapter 3 addresses the use of mathematical models to estimate energy and amino acid requirements of swine. This chapter describes the modeling approach that was taken by the subcommittee to generate the amino acid requirements of growing-finishing pigs from 20 to 120 kg body weight and for gestating and lactating sows. The growth model is based on the pig's lean growth rate and it estimates the daily true ileal digestible lysine needed to support maximum protein accretion at a given body weight. The dietary lysine requirement is then estimated based on the pig's daily feed intake, which, in turn, is based on body weight, gender, environmental conditions, and DE concentration of the diet. Estimates of the requirements for other essential amino acids are based on the ideal ratio of each to lysine for maintenance and protein accretion. The gestation model estimates the energy and amino acid requirements of sows based on their breeding weight, targeted gestational weight gain, and litter size. The lactation model estimates requirements based on the sow's postfarrowing weight, lactational weight change, and daily litter weight gain, a reflection of the amount of milk production.

Chapters on minerals and vitamins were updated with results from research studies reported since the previous edition. Chromium is recognized as an essential trace mineral for swine. The sodium and chlorine requirements of the young pig and the manganese requirement of the gestating and lactating sow were increased, and new information on the bioavailability of minerals is presented. The vitamin E and folacin requirements of gestating and lactating sows were increased, based on new research information.

The chapter on water was expanded. In addition to more discussion of the water requirements of all classes of swine, this section also reviews factors that affect quality of drinking water. The chapter on nonnutritive feed additives was expanded to include antimicrobial agents and other feed additives, including anthelmintics, microbial supplements, oligosaccharides, enzymes, acidifiers, flavors, odor control agents, antioxidants, pellet binders, flow agents, mineral supplements, and carcass modifiers.

A new chapter that addresses nutrient excretion was added to the tenth edition. This chapter discusses the potential environmental impact of excessive excretion of nutrients, particularly nitrogen and phosphorus, and addresses means of reducing excretion of these potential environmental pollutants by dietary manipulation.

The feed ingredient composition data have been updated and greatly expanded, with 23 additional ingredients added to the tables, for a total of 79 feed ingredients. Net energy, neutral- and acid-detergent fiber (NDF, ADF), and beta-carotene concentrations of feedstuffs were added, and crude fiber was deleted. Vitamin E levels in feedstuffs were modified to include only those assayed by high-performance liquid chromatography. New tables that give estimates of apparent and true digestible coefficients for the amino acids in feedstuffs are now included. Other new tables give the fatty acid composition of fat sources and estimates of the four most limiting amino acids in feedstuffs based on their crude protein content.

Finally, the tables of nutrient requirements have been revised and updated. The amino acid requirements are based on the subcommittee's assessment of the biological relationships that govern accretion of protein and fat for growth, reproduction, and lactation. The estimates for all nutrients, including amino acids, are based on the best judgment of the subcommittee members following their thorough review of the world's scientific literature.

As in previous editions, the estimated nutrient requirements in this publication are minimum standards without any safety allowances. Therefore, they should ***not*** be considered as recommended allowances. Professional nutritionists may choose to increase the levels of some of the more critical nutrients to include "margins of safety" in some circumstances (this comment does not apply to selenium). Another important point is that, for minerals and vitamins, the estimated requirements include the amounts of these nutrients that are present in the natural feedstuffs and are not estimates of amounts of nutrients that should be added to diets.

Knowledge of the nutritional needs of swine has expanded considerably since the last revision of this publication. Nevertheless, there is still conflicting, incomplete, or no information for several nutrients at different stages of the life cycle. This is particularly true for many of the vitamins and trace minerals, especially for the very young pig and the gestating and lactating sow. More research is encouraged to expand the knowledge base in these areas.

The user of this publication is reminded that knowledge of the principles and assumptions described in the text of this publication is absolutely essential for the proper use of the model and the tables of nutrient requirements.

1 Energy

Energy is produced when organic molecules undergo oxidation. Energy is either released as heat or is trapped in high-energy bonds for subsequent use for the metabolic processes in animals.

Energy content in feedstuffs can be expressed as calories (cal), kilocalories (kcal), or megacalories (Mcal) of gross energy (GE), digestible energy (DE), metabolizable energy (ME), or net energy (NE). Energy can also be expressed as joules (J), kilojoules (kJ), or megajoules (MJ) (1 Mcal = 4.184 MJ; 1 MJ = 0.239 Mcal; 1 MJ = 239 kcal). The terms used in this publication to describe energy requirements and energy content of feeds are similar to those defined and extensively discussed in *Nutritional Energetics of Domestic Animals and Glossary of Energy Terms* (National Research Council, 1981). Whittemore and Morgan (1990), Chwalibog (1991), Ewan (1991), Noblet and Henry (1991), and Hoffmann (1994) have published reviews of energy utilization by swine.

Determination of the energy values of feedstuffs for swine is a difficult and tedious task. Originally, energy values were estimated from studies with chicks or were calculated from Total Digestible Nutrients (TDN) (National Research Council, 1971). Since the original direct determinations of energy in feedstuffs for pigs by Diggs et al. (1959, 1965) and Tollett (1961), the database has grown. A summary of energy values of feedstuffs from around the world has been compiled by Ewan (1996). Still, where data are not available by direct means from pig studies, energy concentrations can only be estimated from chemical composition of the feedstuff. Prediction equations that have been used for estimating energy concentrations in feeds are given in the subsequent sections. In all of these equations, the energy and nutrient concentrations are expressed on a dry matter basis.

CLASSIFICATION OF ENERGY

Gross Energy

Gross energy is the energy liberated when a substance is combusted in a bomb calorimeter. The GE concentration of a feed ingredient is dependent on the proportions of carbohydrate, fat, and protein present in the ingredient. Water and minerals contribute no energy; carbohydrates provide 3.7 (glucose) to 4.2 (starch) kcal/g, protein provides 5.6 kcal/g, and fat provides 9.4 kcal/g. If the composition of a feed is known, GE can be predicted fairly accurately. The following relationship was reported by Ewan (1989) for predicting GE (kcal/kg) from ether extract (EE), crude protein (CP), and ash.

$$GE = 4{,}143 + (56 \times \%\ EE) + (15 \times \%\ CP) - (44 \times \%\ Ash),\ R^2 = 0.98 \qquad (1\text{-}1)$$

Digestible Energy

Dietary GE intake minus the GE of the excreted feces is DE. Apparent indigestible energy is a major variable in the evaluation of feed ingredients. Farrell (1978), Agricultural Research Council (1981), and Morgan and Whittemore (1982) suggest that DE is preferable in describing the energy requirements of swine and the energy content of swine feeds, because DE is easily and precisely determined and is, in principle, additive. In addition, DE values are available for most of the commonly used feeds. However, in the conventional scheme of energy utilization, DE is apparent, not true, because fecal metabolic energy is not considered.

Chemical composition of feed ingredients is a major determinant of DE, with positive effects of ether extract and negative effects of fiber and ash. The following equations have been reported for predicting DE (kcal/kg) from chemical composition:

$$DE = -174 + (0.848 \times GE) + (2 \times \%\ SCHO) - (16 \times \%\ ADF),\quad R^2 = 0.87;\ \text{Ewan (1989)} \qquad (1\text{-}2)$$

$$DE = 949 + (0.789 \times GE) - (43 \times \%\ Ash) - (41 \times \%\ NDF),\quad R^2 = 0.91;\ \text{Noblet and Perez (1993)} \qquad (1\text{-}3)$$

$$DE = 4{,}151 - (122 \times \%\ Ash) + (23 \times \%\ CP) + (38 \times \%\ EE) - (64 \times \%\ CF),\quad R^2 = 0.89;\ \text{Noblet and Perez (1993)} \qquad (1\text{-}4)$$

in which SCHO is soluble carbohydrate calculated as 100 − (% CP + % EE + % Ash + % NDF), ADF is acid detergent fiber, NDF is neutral detergent fiber, and CF is crude fiber.

Digestibility of dietary energy increases slightly with increased body weight (Noblet and Shi, 1993) because of increased degradation of undigested carbohydrate in the large intestine. Noblet and Shi (1993) proposed that for finishing pigs and particularly sows fed at restricted feed intakes, DE concentrations (kcal/kg) should be corrected by one of the following relationships.

$$DE = 1{,}391 + (0.58 \times DE) + (23 \times \%\ EE) + (12.7 \times \%\ CP),\quad R^2 = 0.96 \qquad (1\text{-}5)$$

or,

$$DE = -712 + (1.14 \times DE) + (33 \times \%\ NDF),\quad R^2 = 0.93 \qquad (1\text{-}6)$$

Metabolizable Energy

The DE minus the GE of gaseous and urinary losses is metabolizable energy (ME). The loss of energy as gas produced in the digestive tract of swine is usually between 0.1 and 3.0 percent of DE (Noblet et al., 1989b; Shi and Noblet, 1993). These amounts are generally ignored because they are small and not easily measured. For most practical swine diets used in North America, ME is 94 to 97 percent of DE, with an average of 96 percent (Farrell, 1979; Agricultural Research Council, 1981).

A correction is sometimes made to ME concentrations for nitrogen gained or lost from the body (ME_n, Morgan et al., 1975). ME is corrected to nitrogen equilibrium because the energy that is deposited as retained protein cannot be totally recovered by the animal if the amino acids are degraded for energy. This correction to nitrogen equilibrium may be valid for mature animals but is not valid for growing pigs that retain considerable amounts of nitrogen. Therefore, the correction probably is not necessary (Farrell, 1979) or should be made to a constant positive nitrogen retention. The correction factor that is used has been obtained by expressing the GE of urine per gram of urinary nitrogen. For swine, Diggs et al. (1959) used a correction factor of 6.77, Morgan et al. (1975) used 9.17, and Wu and Ewan (1979) used 7.83 kcal of ME/g of nitrogen to correct for each gram of nitrogen above or below nitrogen equilibrium. This correction is added to the determined ME for pigs in negative nitrogen balance and subtracted when animals are in positive nitrogen balance.

If protein is of poor quality or in excess, ME decreases because the amino acids not used for protein synthesis are catabolized and used as a source of energy, and the nitrogen is excreted as urea. Therefore, as the nitrogen content of the urine increases, the energy losses in the urine increase and the ME of the diet decreases.

Estimates of ME (kcal/kg) may be calculated from DE (kcal/kg) and CP using one of the following relationships.

$$ME = DE \times (1.012 - (0.0019 \times \%\ CP)),\quad R^2 = 0.91;\ \text{May and Bell (1971)} \qquad (1\text{-}7)$$

$$ME = DE \times (0.998 - (0.002 \times \%\ CP)),\quad R^2 = 0.54;\ \text{Noblet et al. (1989c)} \qquad (1\text{-}8)$$

$$ME = DE \times (1.003 - (0.0021 \times \%\ CP)),\quad R^2 = 0.48;\ \text{Noblet and Perez (1993)} \qquad (1\text{-}9)$$

The ME of diets fed to finishing pigs or to sows fed at restricted intakes increases because digestibility is improved. Noblet and Shi (1993) proposed that ME concentrations (kcal/kg) determined with growing pigs (<60 kg) should be adjusted by one of the following relationships for finishing pigs and sows.

$$ME = 1{,}107 + (0.64 \times ME) + (22.9 \times \%\ EE) + (6.9 \times \%\ CP),\quad R^2 = 0.96 \qquad (1\text{-}10)$$

or,

$$ME = -946 + (1.17 \times ME) + (3.15 \times \%\ NDF),\quad R^2 = 0.94 \qquad (1\text{-}11)$$

Net Energy

Net energy (NE) is the difference between ME and heat increment (HI). The HI is the amount of heat released because of the energy costs of the digestive and metabolic processes. The energy of the HI is not used for productive processes but can be used to maintain body temperature in cold environments. Net energy, therefore, is the energy that the animal uses for maintenance (NE_m) and production (NE_p). The energy used for maintenance (NE_m) is also dissipated as heat, so that total heat production is the sum of HI and NE_m. Evaluation of NE requires the measurement of energy balance or heat production. If energy is required to maintain body temperature or excess activity, NE_p is reduced. Although difficult to measure, NE is the best indication of the energy available to an animal for maintenance and production (Noblet et al., 1994).

For pigs fed conventional diets and kept at thermoneutral temperatures, the ratio of NE to ME ranged from 0.66

to 0.75 (Thorbek, 1975; Noblet et al., 1994). Ewan (1976), Phillips and Ewan (1977), and Pals and Ewan (1978) reported the efficiency of ME utilization for energy gain and maintenance (NE) in growing pigs to vary from 27 percent for wheat middlings, to 69 percent for corn, to 75 percent for soybean oil. Noblet et al. (1994) reported efficiencies of energy utilization of 90, 82, 80, 72, and 60 percent for rapeseed oil, cornstarch, sucrose, and mixtures of protein and fiber sources, respectively, for pigs ranging in weight from 45 to 150 kg. Some of the reported relationships between NE (kcal/kg) and chemical composition are as follows:

$$\text{NE} = 328 + (0.599 \times \text{ME}) - (15 \times \%\ \text{Ash}) - (30 \times \%\ \text{ADF}),\quad R^2 = 0.81;\ \text{Ewan (1989)} \qquad (1\text{-}12)$$

$$\text{NE} = (0.726 \times \text{ME}) + (13.3 \times \%\ \text{EE}) + (3.9 \times \%\ \text{St}) - (6.7 \times \%\ \text{CP}) - (8.7 \times \%\ \text{ADF}),\quad R^2 = 0.97;\ \text{Noblet et al. (1994)} \qquad (1\text{-}13)$$

$$\text{NE} = 2{,}790 + (41.2 \times \%\ \text{EE}) + (8.1 \times \%\ \text{St}) - (66.5 \times \%\ \text{Ash}) - (47.2 \times \%\ \text{ADF}),\quad R^2 = 0.90;\ \text{Noblet et al. (1994)} \qquad (1\text{-}14)$$

in which St is starch.

HEAT PRODUCTION

Measurement of total heat production includes the energy associated with HI, the energy required for maintenance, and energy expended in response to changes in the environment. The major environmental factors that influence heat production are temperature and physical activity.

Temperature

Cold thermogenesis influences energy requirements when the ambient temperature (T, °C) is below the critical temperature (T_c, °C). The critical temperature is the point below which an animal must increase heat production to maintain body temperature. Below T_c, the pig must increase its rate of metabolic heat production to maintain homeothermy (National Research Council, 1981). Factors that alter the rate of energy exchange between the animal and its environment will alter T_c (National Research Council, 1981). The energy cost of cold thermogenesis can be described by the following equation:

$$\text{MEH}_c\ (\text{kcal ME/day}) = ((0.313 \times \text{BW}) + 22.71) \times (T_c - T) \qquad (1\text{-}15)$$

where MEH_c is energy cost of cold thermogenesis, BW is animal weight in kg, and T_c and T are expressed in °C (Agricultural Research Council, 1981). Verstegen et al. (1982) estimated that during their growth period, from 25 to 60 kg, pigs needed an additional 25 g of feed/day (80 kcal of ME/day) to compensate for each 1°C below T_c. During the finishing period, from 60 to 100 kg, pigs required an additional 39 g of feed/day (125 kcal of ME/day) for each 1°C below T_c.

For each 1°C below the lower critical temperature (18 to 20°C), there is an increase in heat production of approximately 3.7 to 4.5 kcal of ME/kg of body weight raised to the 0.75 power ($BW^{0.75}$) (Noblet et al., 1985; Close and Poorman, 1993). The lower critical temperature is reduced by group housing, by use of bedding, and by decreased ventilation rate. For 180-kg sows in normal condition individually housed on concrete, the increase in energy required to maintain body temperature is about 4 percent of maintenance requirement per °C below the lower critical temperature (Verstegen et al., 1987).

Between the upper and lower critical temperatures, a zone of thermoneutrality exists where heat production is relatively stable. Environmental temperatures above the critical temperature will reduce feed intake (Ewan, 1976). The National Research Council (1987) suggested that DE intake is reduced by 1.7 percent for each 1°C that the effective ambient temperature of the pig exceeds the upper critical temperature. Here, effective ambient temperature is the temperature the animal experiences.

Activity

Physical activity also influences heat production. Petley and Bayley (1988) measured the heat production of pigs running on a treadmill and reported that heat production of the exercised pigs was 20 percent greater than that of control animals. Close and Poorman (1993) calculated that the additional expenditure of energy by growing pigs for walking was 1.67 kcal of ME/kg of BW for each kilometer. Noblet et al. (1993) measured the increase in heat production associated with standing by sows as 6.5 kcal of ME/kg of $BW^{0.75}$ for each 100 minutes. This figure was similar to reports by Hörnicke (1970) of 7.2, by McDonald et al. (1988) of 7.1, by Susenbeth and Menke (1991) of 6.1, and by Cronin et al. (1986) of 7.6 kcal/kg of $BW^{0.75}$ for each 100 minutes. Noblet et al. (1993) also determined that the energy cost of consuming feed was 24 to 35 kcal of ME/kg of feed consumed.

ENERGY REQUIREMENTS

Maintenance

The ME requirement for maintenance (ME_m) includes the needs of all body functions and moderate activity. These