FACTORS AFFECTING MAINTENANCE NUTRITION, FEED UTILIZATION, AND HEALTH OF FARM ANIMALS

by Louis L. Madsen

The first need of an animal is for sufficient food to maintain its body in good health. Then additional food must be given for production, whether the production is in the form of work or of some product such as meat or milk. Failing to supply fundamental maintenance requirements may seriously, perhaps permanently, injure the animal. Much thought and some research have been given to the question, and this article deals with the problem rather thoroughly, discussing overfeeding as well as underfeeding. Some technical material is included in the article.

Throughout the entire life span of all animals, whether they are young and growing, mature or aged, producing or not producing, working or resting, healthy or diseased, there is a continual need for food to support the vital functions of the body. The minimum amount of the various foods required to sustain the essential body processes at an optimum rate without gain or loss in body weight or change in body composition, exclusive of the food used in growth or expended in work or other productive functions, is called the maintenance requirement; and a ration which meets only the demands of maintenance is called a maintenance ration. To be ideal a maintenance ration must contain all the necessary nutrients in the proper amounts so that there is neither an excess nor a deficiency of any factor. If such a perfectly balanced ration is fed to an idle animal that is not growing nor yielding any product there would soon be an even balance between the food eaten and the materials lost from the body as body heat and excretions.

These definitions of the maintenance requirement and the maintenance ration refer to ideal conditions which are approached only during careful experimental studies. Values thus obtained serve as the minimum basal requirement of animals and provide control data to which must be added sufficient food to satisfy the additional factors incident to normal activity. The Conference on Energy Metabolism,1

1 Louis L. Madsen is Nutritionist, Bureau of Animal Industry.
which met under the auspices of the National Research Council to consider the status of energy metabolism and its place in the development of animal nutrition, recommended for tentative adoption the term "physiologic maintenance" to refer to the requirement of an animal under specified experimental conditions, and the term "economic maintenance" to include the additional requirements for muscular activity found under particular conditions of general feeding practice. Economic maintenance may be more literally expressed as "practical maintenance."

Growing and producing animals need food in addition to their maintenance requirement or their bodies will not be sustained intact. This is because a portion of the food supplied for maintenance will be utilized and even some of the body tissues themselves will be broken down in an attempt to provide for growth and production. Such a process cannot continue indefinitely without seriously interfering with the growth and development of the animal body or reducing its productive capacity. It is evident therefore, that growth, development, and economical production by farm animals depend upon (1) adequate food to maintain the vital functions, or internal work, of the body, plus normal activity, and (2) sufficient additional food to fulfill the demands for growth and production.

Cash returns above feed cost are the primary source of income in the livestock industry, and economy of production by animals depends upon how much food is consumed above that required for maintenance and how efficiently it is utilized and converted into products. Before any continued yield of products can be obtained or physical work performed by animals it is necessary that their maintenance nutrition be adequate. If an animal is forced to labor when existing on a maintenance or submaintenance level of food intake, wasting of body tissues will occur and working efficiency will steadily decrease. A good dairy cow will not stop secreting milk as soon as the ration becomes inadequate to sustain optimum production. Milk production will continue for a time, but at a decreasing rate and at considerable expense to the body tissues, and before it stops entirely considerable damage and possibly permanent injury may result.

Uneconomical production by farm animals is not the only result of a failure to supply them with adequate food for maintenance and production. Other serious losses result from the so-called nutritional deficiency diseases, which not only may impair the development and producing capacity of animals but may be so severe as to cause death. Disease resulting from nutritional deficiencies may be mistaken for or complicated by the presence of certain parasitic and infectious diseases. In fact, animals suffering from the lack of one or several essential nutrients may lose their ability to withstand infection and will be overcome through the combined effects of malnutrition and disease.

Henry Prentiss Armsby (1853–1921), an expert in animal nutrition for the United States Department of Agriculture and first director of the Institute of Animal Nutrition of the Pennsylvania State College, was one of the first American investigators to emphasize the importance of the maintenance requirements in the nutrition of farm animals. He wrote (32). 3

1 Italic numbers in parentheses refer to Literature Cited, p. 1075.
A very considerable fraction of the feed actually consumed by farm animals—on the average probably fully one-half—is required simply for maintenance. But if half of the farmer's feed bill is expended for maintenance, it is clearly important for him to know something of the laws of maintenance—how its requirements vary as between different animals, how they are affected by the conditions under which animals are kept, how different feeding stuffs compare in value for maintenance, etc.—as well as to understand the principles governing the production of meat, milk, or work from the other half of his feed.

Farm animals must be supplied, therefore, with sufficient food to maintain their essential body functions before they can economically convert feeds into useful products or work. Inadequate nutrition leads to uneconomical production or faulty growth and development. A deficiency of essential nutrients in the ration, on the one hand, or over-feeding on the other will lead to nutritional diseases that may either impair the animal for further production or cause death. Adequate maintenance and the preservation of the health of farm animals enable them to use additional food for growth, development, and production.

**MAINTENANCE NUTRITION SUSTAINS VITAL FUNCTIONS**

Some of the essential body processes that are supported by the maintenance requirement are: (1) Heat production and the control of body temperature; (2) mastication, digestion, and assimilation of food and passage of material through the digestive tract; (3) glandular secretion; (4) circulation of the blood; (5) respiration; (6) normal muscular activity associated with a nonproductive life; (7) conduction of and response to nervous impulses; (8) excretion of waste products.

**CONTROL OF BODY TEMPERATURE**

Farm animals are warm-blooded and consequently must maintain their body temperature within rather narrow limits. The normal body temperature of all farm animals is usually above that of the surrounding air, so a continual supply of heat is required to keep the body warm. During the hottest days of summer the environmental temperature may at times approach or even surpass that of the body and at such times less heat is required to maintain body temperature. In winter, of course, more heat and consequently more food are required to keep the body temperature constant.

The principal means by which heat escapes from the body are radiation, conduction, convection, and the evaporation of water both from the surface of the skin, as sweat, and by respiration, in which heat is lost in vaporizing water in expired air. The control of these mechanisms is called physical regulation, and is accomplished mainly by increasing or decreasing the blood flow near the surface of the body to facilitate or retard heat loss and the evaporation of water. Within a certain range of air temperature physical regulation operates to maintain a practically constant body temperature without requiring a noticeable change in the rate of heat production.

If the environmental temperature continues to rise to a point where physical regulation of temperature is not sufficient to prevent the body heat from increasing above its normal level, there is an increase in body metabolism. This temperature is known as the point of hyper-thermal rise. When the surrounding air temperature is decreased there is a minimum temperature at which the heat produced in the
body is just sufficient to replace that lost without increasing metabolism. This point is known as the critical temperature. Below the critical temperature extra food must be oxidized in order to prevent the body from cooling off. This means of regulating body temperature is known as chemical regulation. The range of temperature between the point of hyperthermal rise and the critical temperature is known as the zone of thermal neutrality, and it represents the favorable air temperatures between which the metabolic rate, or heat production, is constant. Food is utilized most efficiently for maintenance or production when the air temperature is kept within the zone of thermal neutrality, and consequently a point within this favorable air-temperature range is established during experiments when the heat production during maintenance is being measured.

The approximate critical temperature for several species of farm animals has been determined. Preliminary work at the Agricultural Research Center, Beltsville, Md., indicates that the critical temperature of hens is about 28.3° C. (83° F.) and for chicks 1 to 4 days of age, 35.6° C. (96° F.). Other published values are: Pig, 21° C. (69.8° F.); steer with hair closely shaved, higher than 18.3° C. (64.9° F.); steer with full coat of hair, less than 15.6° C. (59.9° F.); dog, before clipping, 13.6° C. to 15.1° C. (56.5° F. to 59.2° F.); dog, after clipping, 23.8° C. to 26.5° C. (74.8° F. to 79.7° F.); and man with ordinary clothing, 15° C. (59° F.). These values are not constant and may become higher under such circumstances as exposure to cold winds and stormy weather, or when an animal’s natural insulating coat of hair, wool, or feathers is sheared or clipped off. Fasting raises the critical temperature, while food consumption and good physical condition have the opposite effect. Diseases may also change the normal critical temperature of animals, depending on their effect on the complex heat-producing or heat-eliminating mechanism. This explains why well-fed, sheltered animals can stand cold weather much better than thin or underfed animals or animals that are exposed to wind and storm. Knowledge of the approximate critical temperature and heat production of animals and of the various factors which affect them is of use in estimating the amounts of heat and energy-producing foods which must be supplied for maintenance, and in providing for adequate ventilation, insulation, or heating in barns.

RELATIVE HEAT-PRODUCING VALUES OF FOOD CONSTITUENTS

Students of energy metabolism have known for many years that the three general classes of foods, carbohydrates (starches, sugars, cellulose, etc.), fats, and proteins, have different effects upon the heat production of fasting animals following ingestion. The consumption of protein causes the metabolic rate of heat production to increase much higher above a fasting level than an equal quantity of carbohydrate or fat. Rubner (1854–1932), a distinguished German scientist, called this effect of food in increasing the metabolic rate of animals “specific dynamic action,” and this term has been widely used. In the United States the extensive early work of Graham Lusk (1866–1932) and associates on this subject is particularly noteworthy. Specific dynamic action as defined by Rubner can be illustrated by one of the last published statements of Lusk (703):
If what we now call the basal metabolism of a typical animal be 100 calories per day and if 100 calories be administered to the animal in each of the several foodstuffs on different days, then the heat production of the animal after receiving meat protein will rise to about 130 calories, after glucose to about 106 calories, and after fat to about 104 calories. These are typical average results.

A completely satisfactory explanation for this phenomenon has not yet been agreed upon. The heat produced in the body following consumption of food serves only to keep the body warm. Animals are never fed on single nutrients in practice, therefore heat-producing values of feeds or mixed rations and the factors influencing them are of most importance in estimating feed values. The heat production caused by the ingestion of a mixed ration is not a simple additive function of its component nutrients but a value which varies considerably with such factors as composition of the ration, plane of nutrition, kind and individuality of the animal, and conditions under which the measurements are made.

The Conference on Energy Metabolism previously mentioned (footnote 2, p. 431) outlined several terms with definitions for tentative adoption for use in energy metabolism studies. The term "heat increment" is suggested for the increase in heat production following and incident to the ingestion of any nutrient or ration. "Specific dynamic effect" is defined as the heat increment of a specific kind of nutrient and is therefore not logically applied to combinations of mixed nutrients as they occur naturally in feeding stuffs and in rations. The term "specific dynamic action" is reserved for the process, as distinct from the result, of specific dynamic effect. If these definitions are applied to the example from Lusk (703) quoted above, the specific dynamic effect of glucose under the conditions stated was equivalent to a heat increment of 6 calories per day (106 calories minus the basal level of 100 calories per day), and the process by which the food (in this case glucose) stimulates heat production above the basal level is the specific dynamic action.

Most of the digestible food in a balanced ration that is consumed for the purpose of maintenance or production consists of energy- and heat-producing nutrients. Other feed constituents, however, such as protein, minerals, vitamins, and water, which make up the remainder of the ration, are just as important as an adequate supply of energy or heat. Feeds such as grains and grain products which are high in total digestible nutrients are called concentrates. Feeds high in bulky, indigestible constituents, and consequently relatively low in digestible nutrients, are called roughages. The relative values of these feeds in meeting the requirements of animals depend upon the age of the animal and its digestive ability. Swine and poultry are unable to utilize large quantities of bulky foods to advantage and therefore are fed largely on concentrates, while ruminants (cattle, sheep, and goats) and horses have digestive systems capable of utilizing large proportions of roughages as well as concentrates.

Cellulose, a complex form of carbohydrate, is an important source of heat and to some extent of energy, especially for ruminants. Cereal straws, such as wheat and oat straw, and other bulky roughages high in fiber or cellulose are of considerable feeding value for maintenance heat production of adult cattle, sheep, and horses, especially during cold weather. These foods, however, are low in feeding value
for growth, fattening, or other forms of production. This is because most of the food energy they contain is expended as heat incident to the greater work of mastication, digestion, and assimilation. This also explains some of the feeding value of browse, which though very bulky supplies the energy and heat requirement for maintenance for many thousands of cattle and sheep during the winter season, particularly in the Western States.

Proteins also may be used for heat and energy transformation in the body. They have approximately the same caloric value as the starches when utilized in this way, but it is usually uneconomical to depend upon foods rich in proteins as the major source of energy in maintenance or production rations, since only a portion of these compounds are available for this purpose and the remainder of the nitrogen-containing fraction is largely wasted. An equal weight of fat yields approximately two and a quarter times as much energy or heat as do the starches, sugars, or proteins. Even though the fats are the richest source of energy and heat for animals, it is necessary for starch or some other carbohydrate food that can be converted into sugar to be present in the body to aid in the last stages of fat oxidation. If there is a shortage of sugar in the body, resulting either from an inadequate supply of carbohydrates in the food or a derangement of carbohydrate metabolism in the body, certain harmful products of incomplete fat oxidation (acetoacetic acid, beta-hydroxybutyric acid, and acetone) will accumulate.

HEAT, ENERGY, AND PROTEIN REQUIREMENTS OF ANIMALS

Heat and energy transformation from absorbed food takes place in all the active, living tissues of the animal body. About 70 percent of the heat produced in the body comes from the skeletal muscles; most of the remainder originates from glandular activity (285). A constant source of energy is required to keep the skeletal or voluntary muscles in a state of tonus, or in a slightly contracted state, so that the animal can move about and have control over its posture, breathe, masticate food, etc. All of the muscles of the body are never completely relaxed during life. The involuntary muscles, which act independently of the will, also expend energy continually to maintain such important activities as blood circulation, passage of food and food residues through the digestive tract, and many others.

Activity increases the basal maintenance requirement for energy considerably, for example, a comparison of the metabolism of cattle during standing and lying indicates that the increase due to standing may be as much as 15 percent. Fat animals require more food per unit of body weight to maintain their live weight than thin animals. McCandlish and Gaessler (711) give some interesting data from limited observations on dairy cattle in high and low condition. They found that an average daily requirement of 0.62 pound of digestible crude protein and 6.67 pounds of digestible carbohydrate were needed per 1,000 pounds of live weight when the animals were in high condition, while 0.39 pound of digestible crude protein and 5.03 pounds of digestible carbohydrate per 1,000 pounds of live weight were adequate to maintain weight when the animals were thin.

Several methods have been used to measure the maintenance as
well as the production requirement of animals. Direct measurements of heat production and respiratory gas exchange of animals has been the basis of many studies. Other methods involve the collection of urinary constituents and their correlation with the metabolism of specific nutrients and of the body as a whole. For example, Smuts (1086), working with Mitchell, recently measured the basal metabolism and total endogenous nitrogen excretion of several species and found that in mature animals 2 milligrams of nitrogen was lost from the body for every calorie of basal heat. Since 2 milligrams of nitrogen is approximately equivalent to 12.5 milligrams of protein (nitrogen × 6.25), it is possible to calculate from the basal heat the amount of protein catabolized by the body equivalent to the endogenous nitrogen losses.

Brody and associates (157), analyzed a large amount of basal metabolism data on animals varying in size from mice to elephants and found that the basal metabolism of the animals within this range tends to vary with the 0.734 power of body weight. The general equation showing the relation between basal metabolism in calories (Q) and body weight (M) was calculated to be \( Q = 70.5 M^{0.734} \). In substituting the relation between endogenous nitrogen and basal metabolism in this equation, the amount of protein (P) required to replace the endogenous losses in maintenance of adult animals is \( P = 0.88 M^{0.734} \). To convert \( P \) into food protein, Smuts recommends multiplying by 2 in order to provide a margin of safety. This assumes that the food protein is only 50-percent utilized. This method of calculation of the maintenance requirement of protein results in 0.35 pound of protein for a 1,000-pound animal and 0.465 pound in a 1,500-pound animal, which is considerably lower than amounts given in older standards determined largely by the feeding-trial method. This new method must be further tested with the larger domestic animals and under conditions found in practice before it can be applied to general use.

It has been recognized for a long time that some relation existed between body size and metabolism, and between body surface and metabolism. Since the smaller animals have a larger surface in proportion to their body weight, their metabolism must be greater per unit of body weight in order to replace the extra heat lost. Brody and associates and Kleiber (633), who have made significant recent contributions on this subject, are in approximate agreement on the relation between body weight and metabolism.

Similar studies on the relation of endogenous urinary nitrogen and neutral sulfur excretion in adult animals indicated that these substances tend to vary with the 0.72 and 0.74 powers of body weight, respectively. Since the difference in the numerical value of the exponent of body weight for each of the relationships studied is remarkably small, Brody and associates conclude that the ratio between body weight and basal metabolism and the relationship between endogenous nitrogen and neutral sulfur excretion tend to remain constant for mature warm-blooded animals. These workers have assembled extensive prediction tables on the basis of these findings, as well as a feeding standard for maintenance that includes total digestible nutrients, digestible crude protein, and calories for animals of widely different body weights.
These findings are interesting since they relate nutritive requirements for maintenance of many different kinds of animals to the single function of body weight. However, there is still some question whether economic maintenance can be accurately expressed as a function of body weight. The activity factor and other factors such as age, sex, breed, species, and environmental conditions, all of which affect economic maintenance, are no doubt variables that cannot be evaluated by the same power of body weight. Gaines (405), has come to the conclusion that his “working maintenance” of dairy cows varies most nearly with the first power, or is directly proportional to body weight. Morrison (819) has arbitrarily used the 0.87 power of body weight in the calculation of digestible protein and total digestible nutrients required for maintenance by dairy cows of various live weights.

The interesting relations revealed by these studies have contributed some substantial progress toward scientific evaluation of feeds and consequently of the economical feeding of animals. More work is needed, however, concerning the factors that affect the digestibility of feeds and rations by various species before individual feeds can be accurately evaluated in terms of feeding standards. Considerable additional work has to be done also in order to understand the needs of animals under the numerous conditions found in practice, and to discover more about the role of other specific food substances such as vitamins and minerals and the requirements of animals for these substances.

**EFFECTS OF DIETARY DEFICIENCIES ON FEED UTILIZATION AND HEALTH OF FARM ANIMALS**

**QUANTITATIVE OR QUALITATIVE PROTEIN DEFICIENCY**

The question of quantitative and qualitative protein deficiencies in the nutrition of farm animals is a matter of much concern to livestock men and a subject of considerable interest to research workers in nutrition. All animals require a source of protein in their diet to utilize for growth, for the replacement of body tissues and fluids, and for the production of such materials as milk and eggs.

Growing animals require a higher percentage of protein in their ration than do adult animals. Experiments with swine fed rations containing increasing amounts of protein on equal food intakes are reported by Mitchell and Hamilton (800). Their studies indicate that as the protein content of the diet is increased from a low level the rate of nitrogen retention, rate of growth, and utilization of energy increase with increasing protein to a level that is higher for the younger animal. Hammoud, Hendricks, and Titus (468) report similar effects of protein on the growth and feed utilization of male chickens. The cockerels fed ad libitum during the first 14 weeks of life increased in efficiency on the basis of feed consumed up to a level of 21 percent of protein. After the birds were approximately half-grown there was only a slight difference in efficiency of food utilization down to as low as 15 percent of protein in the diet, and after maximum live weight had been attained 13 percent of protein in the diet was adequate for maintenance.

Proteins are very complex compounds made up of amino acids and
other simpler compounds. The protein requirement of an animal is really a requirement for certain amino acids. At least 22 amino acids have been identified chemically, and 10 of these have been shown to be essential for the growth of animals. An essential amino acid is one that is needed by the body in some particular phase of metabolism but cannot be manufactured or synthesized by the organism. An amino acid is said to be nonessential if it can be synthesized or is not required by the organism. If a protein contains a large proportion and variety of essential amino acids it has a high biological value for animal feeding and is called a protein of good quality. A protein that is deficient in one or several essential amino acids is called a protein of poor quality, because its use by the body for structural purposes is limited. As a general rule, proteins of animal origin such as those found in milk or meat contain a higher percentage and greater variety of the amino acids necessary for growth than do the proteins of plant origin.

Most of the work with purified amino acids has been carried out with laboratory animals. The question of growth requirements has been investigated more thoroughly than that of other requirements. Little is known of the amino acid requirements for maintenance or for reproductive functions such as fertility, lactation, and egg production, although it is known that a supply of protein adequate from both the qualitative and the quantitative standpoints is essential if these processes are to be carried on to the physiological capacity of the animal. Physical work does not increase the protein requirement of an animal if it is receiving enough for adequate maintenance and growth and if the ration is adequate in energy-producing nutrients.

If the protein intake of an animal is inadequate either quantitatively or qualitatively the most obvious symptom is a slowing up or a complete cessation of growth together with very poor development of the skeletal muscles. An example of protein deficiency can be demonstrated by comparing the growth, fattening, and development of young swine on a ration of yellow corn alone with a suitable mineral mixture as compared to corn supplemented with milk or meat meal. Morrison (819) has summarized experiments of this kind and gives data to show that a ration of corn alone required nearly 700 pounds of grain to produce 100 pounds of live-weight gain, while a properly supplemented ration requires only slightly more than half as much grain. This demonstrates the usual results of uneconomical conversion of food into livestock gains when the protein content of the ration is inadequate qualitatively or quantitatively.

The nutrition of swine and poultry is improved if some source of animal protein such as milk, tankage, or fish meal is included in the ration in addition to plant proteins, while the Herbivora—cattle, sheep, and horses—can of course be adequately nourished after normal weaning by proteins from plant sources alone. Leguminous roughages such as alfalfa and clover are important sources of protein for herbivorous animals, but if the nonleguminous roughages such as timothy, grass hays, corn fodder, cereal straws, or browse are fed, it is usually advisable to add some protein concentrate to the ration. This is especially true for young growing or breeding animals and for heavy-producing animals such as dairy cows. Linseed, cottonseed, and
soybean meals are typical plant protein concentrates used to supplement the rations of farm animals. A ration containing a mixture of proteins from several sources usually gives better results than one in which the protein is from a single source, since the amino acids of one protein will often supplement any amino acid deficiencies of the others. It is likely that some of the beneficial effects which feeds containing proteins of good quality have on the growth or production of animals may be due to other essential factors present in these feeds, such as riboflavin, nicotinic acid, etc.

In addition to poor growth and faulty muscular development a number of other abnormal conditions can result from rations low in protein. Pearson, Hart, and Bohstedt (903) have recently reported that a deficiency of amino acids interferes with the normal sexual rhythm of rats. However, no permanent sterility resulted from feeding diets qualitatively or quantitatively deficient in protein if adequate proteins were subsequently fed. Further studies, by Pearson, Elvehjem, and Hart (902), showed that regeneration of the hemoglobin level in nutritional anemia is affected by the level and quality of the dietary protein. These studies revealed that the proteins from liver or casein fed at a level of 4.8 percent permitted hemoglobin regeneration at approximately the same rate as the protein of corn or wheat gluten fed at about an 18-percent level.

A deficiency of protein or specific amino acids is one of the factors which can apparently lead to the development of certain intestinal lesions. Dogs develop peptic ulcers of the stomach and duodenum when maintained on a diet containing no animal protein and only a small quantity of vegetable proteins (1197). This same diet also results in a lowering of the blood proteins, or hypoproteinemia, and an accumulation of fluid in the tissues and the body cavities, known as nutritional edema. Weiss and Aron (1200) believe that certain peptic ulcers of dogs produced experimentally are a result of a specific amino acid (histidine) deficiency. Rats and mice also develop ulcerations of the stomach as a result of starvation or when fed diets deficient in quantity or quality of protein (525). Diets too low in protein or inadequate for growth because of qualitative deficiencies usually have an adverse effect on the appetite. This leads to lowered food consumption and a deficiency of other factors.

RELATION OF AN INADEQUATE INTAKE OF ENERGY-PRODUCING FOODS TO PROTEIN UTILIZATION

When an animal is receiving an optimum quantity of energy-producing nutrients in the form of carbohydrates and fats the amount of protein required for maintenance or production is reduced to a minimum. If the supply of energy becomes inadequate, some of the amino acids that should be used for protein nutrition are oxidized to furnish heat and energy. When amino acids are utilized in this way, the nitrogenous portion of the molecule is excreted as a metabolic waste in the urine because the body does not have the ability to convert this fraction into heat or energy. This causes an increase in food nitrogen lost from the body, and the efficiency of protein utilization is consequently lowered. To obtain maximum use of the protein
in a ration it is, therefore, essential that the supply of nonprotein energy-producing foods be adequate.

If foods high in protein but relatively low in digestible carbohydrates and fats, such as alfalfa and clover, are fed without grain or other carbohydrate-containing supplements, as is commonly done in many sections of the country, considerable amounts of protein are used to furnish energy and heat, with a resulting wastage of nitrogen. Turk, Morrison, and Maynard (1152) supplemented alfalfa and clover hay rations for lambs with starch, sugar, corn oil, or corn grain to increase the energy content of the ration. They demonstrated that the biological value of the protein of these hays could thus be materially increased. The average of the biological values obtained was 81 for clover protein, 79 for alfalfa protein, 80 for the protein in the combination of clover and corn, and 77 for the protein in the combination of alfalfa and corn, while the unsupplemented alfalfa ration gave an average value of 50. These investigators proved conclusively that the low biological value obtained when alfalfa hay alone is fed is not due to an inferior quality of protein but to an insufficient supply of energy-producing food in the ration.

**PHOSPHORUS DEFICIENCY AND FOOD UTILIZATION**

Probably no dietary deficiency of livestock, particularly cattle, is so common the world over as a deficiency of phosphorus. A lack of this mineral in livestock rations is due primarily to a deficiency of phosphorus in the soils on which the plants used for feed are grown. The question of soil relationships to plant and animal nutrition received special attention in the 1938 Yearbook of Agriculture (164,737). In the United States particular attention has been given to occurrence of phosphorus deficiency in Minnesota, Wisconsin, Michigan, Florida, Kansas, Montana, Utah, Texas, Pennsylvania, and California. The deficiency may be localized in certain areas within a State or may become evident only during seasons of drought.

Symptoms of phosphorus deficiency are similar in nearly all classes of livestock. Animals suffering from a lack of this mineral may soon be lacking in other factors as well, such as calcium, protein, vitamin A, etc., or they may develop toxic symptoms from consuming bones and putrid animal carcasses in an attempt to satisfy the deficiency. The symptom of depraved appetite is so common that this condition has been called the "bone-chewing" disease, though the animals may eat other things, including wood, hair, feathers, soil, and flesh, which are usually ignored under conditions of normal nutrition. As the deficiency progresses the animals develop low blood phosphorus and such symptoms as marked emaciation, stiffness of joints, loss of appetite, decreased milk flow, failure in reproduction, and a general unthrifty appearance.

The question of the effect of phosphorus deficiency on food utilization has been studied. Riddell and associates (963) at the Kansas Agricultural Experiment Station agree with the general conclusion of some previous workers that phosphorus deficiency is a limiting factor in the economical utilization of feed. They further conclude that this effect was not due to a lowered digestive ability of the animals but was a result of a higher energy metabolism as indicated by oxygen-
consumption measurements. Kleiber, Goss, and Guilbert (635) also found no difference in the digestibility of the food, but there was slightly lower utilization of energy.

Forbes (869) has studied the question with laboratory animals and reports findings during a 10-week period of growth in young rats. In the first experiment the phosphorus-deficient rats had 15 percent less phosphorus in their bodies at the end of the experiment than the controls, but there was no difference in growth or utilization of energy and protein. In the second experiment a difference of 18 percent in body phosphorus was obtained by feeding a ration deficient in this mineral. In this case, a slight depression of the digestibility of food protein resulted without affecting protein and energy utilization or growth. Forbes states that there is a lack of clear-cut evidence that variations in the phosphorus content of the diet under conditions of practical nutrition affects the efficiency with which the food is utilized.

VITAMIN DEFICIENCIES AND FOOD UTILIZATION

The effect of vitamin D on the utilization of calcium and phosphorus in the diet is the most conclusive relation between food utilization and vitamins that has been demonstrated. In the absence of vitamin D large losses of calcium and phosphorus from the body occur in spite of a sufficient dietary supply of these elements, but when vitamin D is given losses decrease and unusual quantities of calcium and phosphorus are stored in the body until the normal balance is resumed. This is generally true for farm animals. Wallis (1179) has recently demonstrated it for mature lactating dairy cattle by feeding them rations deficient in vitamin D and keeping them away from direct sunlight.

On a vitamin-deficient diet the appetite usually decreases, less food is eaten, and the animal begins to lose body weight. The food that is eaten is used principally for maintenance. Production decreases because of lowered food intake, and consequently economical conversion of food into useful products is seriously interfered with. Braman and coworkers (147) have conducted a series of experiments with rats on the effects of diets deficient in vitamins A, D, and G during limited periods on the utilization of energy-producing nutrients and protein. They found that in rats with moderate vitamin A deficiency the most prominent effect was to depress the appetite, while the complete diet resulted in slightly larger weight gains and nitrogen storage. The experiment was terminated soon after the symptoms of vitamin A deficiency became acute. When the effects of a normal ration were compared with those of a ration containing an equal number of calories but deficient in vitamin D, the rats on the deficient ration excelled those on the normal ration in utilization of food nitrogen, in body protein gained, and in heat lost. The animals on the complete ration showed better appetite, gained in body fat, utilized more energy, and eliminated more carbon in the urine. Vitamin G deficiency also depressed the appetite of rats and they grew less and formed less body protein and fat. None of these vitamin deficiencies appreciably affected the digestibility of the protein or energy foods of the diets.

If a state of vitamin deficiency progresses to the point where violent digestive disturbances develop, such as the diarrhea produced by
MAINTENANCE NUTRITION AND HEALTH FACTORS

vitamin A deficiency or pellagra, absorption of food may become impaired. In such cases a deficiency of other factors may result in spite of an apparently adequate intake.

Effect of Dietary Constituents on Vitamin D Requirements

The amount of vitamin D in the diet necessary to meet the requirement of an animal can be modified by the presence or lack of other substances in the diet. Early studies indicated that an adequate supply of vitamin D was not the only factor necessary for normal calcium and phosphorus metabolism and bone formation. Vitamin D exerted its optimum effect only when there was an adequate supply of calcium and phosphorus in the diet and when these elements were present in certain proportions with respect to each other. When either calcium or phosphorus is deficient in the ration or there are abnormally large quantities of either, efficient assimilation of these minerals does not occur even in the presence of vitamin D. A normal calcium-phosphorus ratio usually falls within 2:1 or 1:2. There are species differences with respect to the effect of the calcium-phosphorus ratio on the assimilation of these substances. Huffman (550) reports that ratios as wide as 1:4 to 10:1 did not interfere with calcium and phosphorus utilization in dairy cattle.

An excess in the diet of salts of iron, magnesium, manganese, beryllium, strontium, thallium, and aluminum may interfere with phosphorus assimilation and favor the development of rickets even in the presence of adequate vitamin D, because these compounds tend to form insoluble compounds with phosphorus (130). Huffman (551) demonstrated that magnesium favored calcium and phosphorus metabolism and bone calcification in dairy calves. This action is described as a "vitamin D-sparing" effect; it is most evident on rations low in but not entirely devoid of vitamin D. There is little danger of these unusual relationships developing in practice unless excessive quantities of iron are given for treatment or for prevention of anemia or amounts of manganese are given far above the known required level.

Too large a proportion of phosphorus in proportion to calcium tends to favor the formation of the insoluble calcium phosphate, which is not so readily absorbed. Milk sugar, or lactose, favors calcium, phosphorus, and magnesium absorption from the intestinal tract. This action is similar to that of vitamin D, and accounts for some of the favorable effects of milk on the calcification of bone in young growing animals.

RESULTS OF OVERFEEDING

Overfeeding of farm animals can result in heavy financial losses by causing temporary or permanent disability and even death of animals. Money and labor are also wasted by supplying more feed than the animals can utilize. Livestock will frequently overeat if given an opportunity. The consequences may be only temporary digestive disturbances or they may be so serious as to cause death. The productive capacity of farm animals has in many cases been increased beyond the point where they are physiologically able to assimilate enough food to maintain the desired level of high production. In the attempt to maintain a record performance, owners may induce
animals to eat more than they can continue to utilize, and unfortunate results usually follow. The animal is said to go "off feed," usually the result of a digestive upset. Such symptoms as diarrhea, constipation, bloat, colic, and failure to eat the usual quantities of food are danger signals, which if observed in time may be corrected. Digestive troubles from overeating may occur very suddenly, and even if the services of a veterinarian are immediately available a fatal outcome may not be prevented. Animals may be found dead in the morning without having shown any noticeable symptoms the evening before. Losses occasionally occur through accidental overfeeding, as when animals escape to the grain bin or into fields of abundant crops. Diseases due to overeating are best controlled by preventive measures, although some cases may be successfully treated by prompt medical and dietary attention.

Diseases from overeating of either balanced or unbalanced rations are an important cause of death among animals on a fattening ration. Newsom and Thorp (853) state that "overeating" may seem a peculiar designation for a disease, yet it probably causes more loss in the feed lots of Colorado than all other troubles combined. The "disease" as found in lambs has been called a variety of names descriptive of certain phases, such as apoplexy, indigestion, gastroenteritis, food intoxication, and diabetes. Animals may develop nervous symptoms such as head retractions, staggering gait, walking in circles, and rapidly progressing weakness, followed by prostration, coma, convulsions, and death. They may suffer for several days and then die or recover. Diarrhea is usually present when the animal lives more than a few hours. Acute cases usually have a marked glycosuria, or sugar in the urine, which suggests diabetes, but which has not been proved to be a true diabetic condition. Frequently the heartiest eaters and fattest lambs are the ones that die from this disease. Many feeders start culling out the fat lambs and selling them before the rest are ready in order to reduce the possibility of losses from this condition. Some lamb feeders become alarmed as the death toll rises and sell all their lambs before they have reached a desirable market finish, being forced to take a lower price for them and in many cases incurring a serious financial loss.

The exact cause of this disease and effective treatment of animals suffering from it still remain unsolved problems. Newsom and Thorp, in the reference previously cited, report work at the Colorado Agricultural Experiment Station in which the filtered (bacteria-free) intestinal contents from lambs dead of overeating were frequently found to be toxic to laboratory animals and sheep when injected but nontoxic when fed by mouth. The toxin in the filtrates was destroyed by heating to 60° C. (140° F.) or could be neutralized by antitoxins produced by bacteria of types B and D Clostridium welchii. Since bacteria of the Clostridium welchii group are normally found in the intestinal contents of sheep and other farm animals it seems probable that the character of the feed and overeating or conditions associated with a digestive disturbance may favor growth of the bacteria or excessive toxin production in the intestine, the absorption of which produces the disease. More work should be done on this important relation between dietary factors and the growth and toxin production of bacteria in the digestive tracts of animals.
Some preventive measures have been worked out that have helped considerably in holding large losses in check. Losses are often associated with heavy grain feeding and lack of exercise. If the grain allowance is reduced when deaths begin, losses usually cease; but a given level of grain feeding does not cause unfavorable results under all conditions. Among the puzzling features of this disease are its sporadic occurrence and the frequent failures encountered in attempts to produce it experimentally. Losses can usually be reduced to a minimum by starting lambs on feed slowly and gradually increasing the concentrate allowance, carefully watching the appetites of the animals and gaging the increase accordingly. Considerable success has been attained through self-feeding of lambs by grinding grains and roughage and mixing them in the desired proportions. The proportion of grain is increased as the feeding period progresses until a satisfactory fattening ration is established.

Cattle also are adversely affected by overfeeding. Frequent causes of heavy losses are bloat, indigestion, and acute distention or impaction of the stomach. "The eye of the master fattens his cattle" is a saying containing a wealth of advice. Satisfying the appetites of animals without feeding them beyond their ability to assimilate is the real problem.

Lactating animals, particularly dairy cows, also may be overfed, especially when record-breaking production is desired. Symptoms appear suddenly, the milk yield drops, and the animal begins to scour and refuses feed. Production which has fallen because of digestive disturbances is difficult to restore. Cows that develop milk fever incident to calving are usually high producers in extra-good condition because of abundant feeding. Sjollem (1062) recalls that both milk fever and acetonemia, or ketosis, were less frequent toward the end of the World War and just after it, a period when food was scarce. Metzger and Morrison (786) in studying the records of the Kentucky Agricultural Experiment Station herd found that a larger percentage of milk-fever cases occurred during the winter months and suggested a possible relation of the increased incidence at that time of year to factors affecting the calcium metabolism of the cattle, such as the quality of the roughage or the lack of ultraviolet radiation from sunlight or both.

The causes of milk fever and acetonemia are still not understood, but there is abundant evidence that they may be affected by nutrition, and this method of approach is being actively studied. Ketosis may occur in heavily fed, high-producing animals or in animals on a very poor ration. Chemical studies on the blood, milk, and urine of these animals show that they are unable to complete the oxidation of fats in the body and that the incomplete oxidation products, or ketone bodies (acetoacetic acid, acetone, and beta-hydroxybutyric acid), which are harmful to the body, accumulate in the blood and tissues and are excreted in the urine and milk. Moderate supplementary carbohydrate feeding, as of beet molasses, grain mixtures, etc., or good pasture tends to correct the condition if it has not progressed too far.

Calves overfed with milk frequently develop digestive disorders that may be followed by scours and pneumonia. Diarrhea caused by nutritional means must not be confused with that due to specific
infections, although the control methods for either condition must be carried out simultaneously with rational feeding and good management.

Horses are very susceptible to overfeeding, especially during seasons when heavy work and consequent heavy feeding are followed by days of idleness. The grain ration should be reduced as much as 50 percent and the animals should be given an opportunity to get sufficient exercise when not working. Various digestive disturbances known collectively among livestock men as colic may be caused by errors in quantity as well as in quality of food. This is also true of heaves (broken wind) and founder. Azoturia, a disease known to some as "Monday morning sickness," is frequently fatal to horses; its development usually follows a period of insufficient exercise and heavy concentrate feeding.

When breeding animals are too fat as a result of overfeeding they frequently fail to breed normally. Asdell (37) points out that an overfat condition affects the male as well as the female, and that because show-ring fashion tends toward very fat animals, some of the best stock is impaired, leaving the more mediocre animals to perpetuate the race.

**EFFECTS OF UNDERNUTRITION**

Undernutrition is the result of either quantitative or qualitative deficiencies in the ration or both, or of a failure of the ingested food to become available to the body. The effect of dietary deficiencies on an animal depends on a number of factors, chief among which are the nature of the deficiency; age and kind of animal, and whether it is producing or nonproductive; duration of the deficiency; and whether or not the animal has stored the missing essential nutrients from previous adequate nutrition. A long-continued deficiency of vitamins and minerals usually leads to the development of the so-called nutritional diseases. A deficiency of other factors, such as a moderate energy or protein deficiency, tends to retard growth but is not particularly harmful if not continued too long, especially if the animal is neither pregnant nor expected to produce efficiently. The body has considerable ability to repair itself and resume growth if normal nutrition is established after a period of deficiency, but a shortage of certain nutrients can cause irreparable damage and must be avoided. When an animal is growing more slowly or not producing at an optimum rate because of an insufficient supply of food or of specific nutrients, the major portion of the feed consumed is utilized for maintenance, and little or none is left for conversion into useful products or body increase.

Underfeeding of breeding animals, both male and female, greatly decreases their normal reproductive activity. The undernourished female may not come in heat regularly, and if she does become pregnant the young may not be carried to term, or if born, will probably be weak and unthrifty.

Pregnancy disease of ewes (315), or toxemia of pregnancy, is often associated with undernutrition of the pregnant animal. It is closely associated with a derangement of the carbohydrate and fat metabolism, and usually occurs during the last few weeks of pregnancy,
particularly when the ewe is carrying more than one lamb. Ewes fed forage of poor quality with little or no grain, and lambing before the pasture season begins are usually in poor condition and most susceptible to the disease. Typical symptoms of this condition are the development of a staggering gait, weakness, evidence of impaired vision, grinding of the teeth, and failing appetite. Breathing is usually labored and rapid, and the animal becomes progressively worse, finally going down and being unable to rise. The animals often lie with the head turned to one side of the body and may remain in this position for several days until death. A very yellow or clay-colored liver is usually found at autopsy. This disease may occur in fat ewes if they do not have an opportunity to get sufficient exercise. Animals subjected to periods of feed shortage due to stormy weather or while in transit, may also develop the disease. Curative treatment is not usually successful and the mortality is high. Preventive measures through adequate nutrition and exercise have given best results.

McCay and coworkers (716) have published some interesting data on the effect of a calorie or energy deficiency in an otherwise apparently adequate diet on the length of life and development of the albino rat. These investigators retarded the growth of rats by limiting their intake of energy, while the control animals that consumed all they wanted of the same diet grew to maturity and developed much faster. Individuals in the retarded groups, however, lived much longer than the control animals. These studies suggest the possibility of modifying the growth of young animals and thereby extending their productive life. Maynard (769) discusses this question further and points out that the present standards for optimum nutrition, based largely on rapid growth and development, may not be an index of the life performance of the animal. This subject should be investigated further from the standpoint of farm-animal and human nutrition.

Sherman and Campbell (1051) have reported a series of experiments in which they have shown that a diet of natural foods apparently adequate for rats results in further nutritional improvement when enriched by the addition of powdered milk. They have studied particularly the effect of increasing the allowances of calcium, vitamin A, and riboflavin, all of which have contributed to improvement in nutritional well-being, health, and length of life. Increasing the calcium content of the diet resulted in both more rapid growth and longer life. This work further emphasizes the fact that the minimum quantity of a nutrient necessary for normal nutrition may be less than the amount required for optimum performance when measured by the effects on life span and when observations are continued into successive generations. These results should not be interpreted as conflicting with those of McCay and coworkers, previously cited. By using vastly different diets and experimental procedures these investigators have demonstrated other means by which the life span can be significantly increased above the present recognized normal standards. These observations should be regarded as introductions to additional fields of study, demonstrating that investigators in the field of nutrition should go beyond studies on specific short periods of growth, development, and maintenance, to include observations on length of
life and lifetime production and the effects on successive generations, whenever possible or practical.

**MEASURING THE ECONOMIC, OR PRACTICAL, MAINTENANCE REQUIREMENTS OF ANIMALS**

In accordance with the recommendation of the Conference on Energy Metabolism, referred to on page 431, the term “economic maintenance requirement” as used in the following discussion refers to the total quantity of feed required for the maintenance of body weight without material change in the composition of the living animal and for the performance of all involuntary and voluntary muscular activity; it does not include any feed that is used specifically for the performance of work or for the production of meat, milk, or eggs.

In factoring the total feed cost of work, meat, milk, or eggs it is very desirable to be able to measure or estimate the economic maintenance requirement. Furthermore, there are times when it is desirable to feed merely for the maintenance of live weight. For these reasons practical methods of measuring or estimating the economic maintenance requirement are of value to the student of animal nutrition and to the animal husbandman.

The simplest method of determining the economic maintenance requirement of an animal is to ascertain by trial and error just how much feed it must consume each day to keep from losing weight. This method is applicable to adult animals but not to growing animals, because normal growth and maintenance of live weight do not occur simultaneously in the same animal. Moreover, this method is not very precise because an adult animal may consume appreciably more feed for several days than it needs for maintenance and still not show a gain in live weight.

As yet no simple and dependable method has been devised for determining the economic maintenance requirement of the growing animal. The method tentatively suggested by Hendricks, Jull, and Titus (504) gives results that are definitely too low for all but the final stages of growth. However, it is possible to estimate the economic maintenance requirement of a growing animal by assuming that it is proportional to the 0.85 power of the live weight. It has not been demonstrated that this assumption is valid, but its use will give an estimate that probably does not differ from the true value by more than 15 percent.

If the average economic maintenance requirement of a group of adult animals of approximately the same live weight is desired, the following procedure may be followed: Carefully select at least eight animals of very nearly the same live weight and condition; roughly estimate the quantity of feed required daily for maintenance; feed to one of the animals slightly more than this quantity of feed each day, and to the other seven animals eleven-twelfths, ten-twelfths, nine-twelfths, eight-twelfths, seven-twelfths, six-twelfths, and five-twelfths, respectively, of the quantity of feed fed to the first animal; continue feeding the eight animals at these levels of feed intake until the animal receiving the least feed has lost about 15 percent of its initial live weight. If more than eight animals are available, or if greater accuracy in making the estimate is desired, more than one animal

---

4 This section was prepared by Harry W. Titus, Senior Biological Chemist, Bureau of Animal Industry.
may be used at each of one or more of the higher and lower levels of feed intake.

Plot the change in live weight of each animal against the quantity of feed it consumed daily as in figure 1. Draw a straight line through the plotted points, and the daily economic maintenance requirement will be the daily feed consumption at the point where the straight line crosses the horizontal axis. If an estimate of the standard error of

\[
d = sr + i
\]

\[
d \text{ is the change in live weight;}
\]
\[
s \text{ is the slope of the straight line;}
\]
\[
r \text{ is the daily feed allowance;}
\]
\[
i \text{ is the point at which the straight line intercepts the } d \text{ axis; and}
\]
\[
i/s \text{ is the point on the } r \text{ axis at which it is intercepted by the straight line and, hence, is numerically equal to the daily economic maintenance requirement.}
\]

If the average economic maintenance requirement of a group of animals producing milk or eggs is desired, the general method of Wood and Capstick (1252), or the modifications of Titus (1139) and of Brody (155)\(^5\) may be used. However, as was shown by Hendricks and Titus (505), the original method of Wood and Capstick may yield questionable results and hence should be used with caution. Nevertheless, this general method of attacking the problem of estimating the quantity of feed required for economic maintenance and for production holds much promise and deserves further study and application.

\(^1\)See also pages 12 to 23 of the reference given in footnote 2.