Research of the New Hampshire Experiment Station in animal breeding and nutrition, Bulletin, no. 331

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New Hampshire Agricultural Experiment Station

Bulletin 331 June, 1941

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by

E. G. RITZMAN

THE AGRICULTURAL EXPERIMENT STATION

THE UNIVERSITY OF NEW HAMPSHIRE

Durham, N. H.

This 75th anniversary year of the University of New Hampshire in 1940-41 provides an excellent time for the New Hampshire Agricultural Experiment Station to pause and to take stock of itself and of its work and growth in the past, in order to take a firmer hold on the work looming up in the future. One of the longest continued and basic studies of the agricultural experiment station at the University is now nearing completion, and the anniversary has been accepted as a fitting time to explain publicly something of this piece of work, its purpose, and its value to agriculture.

Research of the New Hampshire Experiment Station in Animal Breeding and Nutrition

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INVESTIGATIONAL methods for the benefit of the stockman and farmer are of two distinct kinds.

One type, which is particularly popular in this country, seeks to determine the best practices in animal breeding and feeding by the "trial and error" method in which merely the end results are sought as a measure of comparative utility. Basic causes of differences in results, such as inherent adaptations of individuals or specific differences in chemical composition of substance, are not a matter of consideration for record. As a consequence the results from this type of procedure are about as varied as the number of attempts because differences in conditions have varied accordingly.

The second method of experimentation which can be considered as pure research is concerned primarily with specific fundamental causes which insure permanence of values for the establishment of laws so that the effect of an attempted venture in breeding or nutrition can be predicted with a greater degree of probability.

The character of the experimental program in animal husbandry at this station has been determined by the firm conviction that permanence of value in results is of more service than a temporary expedient; hence, the researches conducted during the last twenty-five years have been of the latter kind.

Applied Genetics in Sheep Breeding

The Experiment Station of New Hampshire is about to bring to a conclusion a unique series of experiments in animal breeding, with sheep, which has been in progress for over twenty-five years.

The plan of this research was originally outlined by Dr. C. B. Davenport, Director of the Department of Genetics of the Carnegie Institution of Washington, and one of the foremost international authorities on this subject.

When the investigation in sheep breeding was begun, the possible effect of inbreeding farm livestock on the principle of Mendelism suggested a great economic prospect.

While the history of practical breeding of large domestic animals even before that time records a marked achievement in the production of new breeds representing improved types to meet economic requirements, the greater part of this progress was accomplished by a relatively small number of resourceful practical stockmen who had no definite fundamental rule to go by except the old adage that "like produces like". This, however, only too frequently proved a disappointing delusion when applied by the average breeder.

The explanation for such seeming inconsistency has been supplied by the science of genetics as originated by Mendel, which has definitely established the fact that the heritable traits of an animal are transmitted by specific unit substances ("genes") and that each trait is always represented in the germ plasm by a definite number or a definite combination of such genes. The fact that only half of these genes from each parent can actually be used in the formation of any trait of the new individual, and that the physiological process of eliminating the excess is governed by pure chance in selection of those retained, explains why some characteristics are not always transmitted as expected. A gene representing a desirable trait in one parent may by chance be eliminated and its place taken by a gene from the less desirable ancestral line. The different genes retained from unlike parentage do not fuse nor form a composite. They merely mix and are present like any group of individuals and the trait whose development they determine retains the identity of the parent from which it came. Thus genes are handed down intact from generation to generation, but the numerical proportion of genes may be changed. By inbreeding, the type will be intensified because similar genes are available from both parents and the chance of reappearance is increased; by outcrossing, the character of genes in the offspring becomes more mixed and the chance of transmitting certain ancestral characteristics by this generation decreases accordingly.

It is in this critical difference between a mixture which assumes a fusion and a mixture which represents an aggregate of separable individuals that the pedigree system which assumes a fusion of germinal substance differs from the modern method based on a more specific foundation.

The study of applied genetics then becomes a study of heritable traits or characteristics of the individual.

The practical breeder, of course, regards the individual as a heritable composite which assumes a correlation of the different body characteristics that form a type. By crossing contrasting types the geneticist, however, has found that from the viewpoint of type transmission the animal is really composed of an innumerable number of independently heritable traits or characteristics, each dominated by its own genes.

Thus while leg length for example is commonly assumed to represent correlated inheritance of parts, our experiments have shown that the lengths of the different leg bones (humerus, radius, metacarpal, etc.) are dominated by independent gene complexes. These experiments have further shown that in a cross with sheep of unlike size, the mean body measurements of the first and of the second (inbred) offspring generations were both between the mean sizes of the parentage, but in their proportions of conformation each differed from the parent breeds, and they even differed from each other. That is, the combination of genes that were transmitted consisted of a chance mixture some of which were, of course, not desirable.

Originally, it was assumed that each body trait, or what may be considered as an independently heritable characteristic, is dominated by single determiners or genes as happened to be the case in the classic experiment with plants on which modern genetics is founded. If this were so, animal breeding would become a simple problem even for the novice. This, however, has proven to be the exception in animals.

The object of experimentally applying genetic principles to the breeding of livestock has thus been to design, if possible, what may be termed genetic patterns of the probable gene complexes possessed by parents for any given trait under consideration, in order to determine from them (mathematically) the chance combinations of such genes that will most probably occur in the offspring from a cross in which parents differ.

The practical application of such patterns is, however, limited to the study of inheritance of body traits which are represented in the germ plasm by a small number (2 or 3) genes. When the number of genes required to produce a given trait (as appears to be the case in most body characteristics pertaining to size) exceeds this, the possible combinations that may occur become so great as to lose significance for a practical purpose.

Crossing different breeds, or even species, for the production of new types is neither new nor unique, as most improved breeds of livestock have originated by that method. The unique feature of this experiment consists in the fact that this has been a methodical attempt to record measurements of about 60 different physical and physiological traits of parentage and of the various generations of their hybrid offspring as a basis for analyzing by statistical and mathematical means the fundamental laws that govern the transmission (i.e. the inheritance) of those traits.

The data include records of live weight and of the measurements of different parts of the body as representative of size and conformation; also weight, market grade, and physical characteristics of the wool; the size and number of accessory nipples as indicative of milk yield; the frequency of twin offspring; and a number of breed characteristics which have no direct economic significance.

During the time that this research has been in progress the birth of about 2000 lambs has been recorded and frequent periodical records have been obtained on all individuals.

We have thus far found only a few somatic traits; namely, horns, color, ear length, and accessory nipples and milk yield which are subject to interpretation of a sufficiently simple gene complex to have significance even for the trained breeder.

We have so far mainly pointed out the complex effect of the inheritance of type on function as a whole. How then does this help the practical breeder of livestock who tries to maintain a high standard of type and function, or one who tries to improve on a low standard?

The result of these experiments has shown that an individual which in itself represents a high standard of excellence of body or of function may at the same time possess undesirable germinal qualifications. This is born out by the history of animal breeding operations over many years which shows that animals selected on basis of their pedigrees or for their own individual physical merit have

FIGURE 1. ORIGINAL MULTI-NIPPLED FLOCK BRED BY DR. ALEXANDER GRAHAM BELL

The original group of four- to six-nippled ewes from the flock of Alexander Graham Bell donated to this Station. Dr. Bell spent 30 years developing this multi-nippled trait. Their fertility rate was about 150 per cent and milk was excellent, but their wool was coarse and sheared light and their conformation was only fair.

FIGURE 2. THE STATION FLOCK IMPROVED BY MULTI-NIPPLES

In the development of this flock only the extra nipples and high milk yield were retained from the group above. Their fertility was around 175 per cent and milk yield good. They sheared between 7 and 8 pounds of top price (3-8 blood) wool and the conformation was good.

FIGURE 3. A STANDARD BREED TYPE (SUFFOLK) IS BEING GIVEN TO THE FLOCK

The last step in combining traits from different sources. The flock in this picture is being given the external appearance of a standard breed. Conformation is same, wool is still mostly 3-8 staple, they are all four nippled and fecundity is 180 per cent. The group includes adults and yearlings.

not reproduced the desired traits with uniformly satisfactory results.

With the more recently accepted practice, particularly by dairymen, of using proven sires, a progressive step has been made toward a definite determination of the breeding potential. This has, however, serious drawbacks, as only a limited number of males can be tested, too much time is lost before the value (which may be negative as well as positive) becomes known, and too many offspring of indifferent value may result in the process.

This was recognized to be beyond the means of the average breeder, and as a consequence a new method of selection was devised. This was based on the principle that the individual's somatic traits constitute a partial and imperfect index to its germ plasm and that a better insight into that germ plasm is gained by considering the traits shown by as many close relatives as possible. Naturally the qualities of the proposed mates are considered, but only as members of their families.

The potency of the germ plasm for a given trait or for a group of traits (i.e., for a type of function) is proportional to the numerical representation of genes present for that trait. When a closely related group of individuals is uniform in type or function it is because the genes which have determined this type uniformity are numerically predominant.

It is thus also clear that improvement of type or function, as well as the establishment of new types that will reproduce their own traits with a relatively greater degree of certainty, depends on a process of intensification of a definite type of germinal determiners and that this can be attained only by inbreeding.

The older literature on heredity has dilated persistently on the harmful effects of inbreeding without supplying any compensating information on its possible benefits. The problem of avoiding undesirable consequences appears to depend on evaluating the germinal constitution of animals intended for parentage, followed by rigid culling of all those offspring in which the undesirable traits appear.

Many physical and physiological characteristics have been studied by following this method of selection and of inbreeding, and utility traits from different sources have been combined into a new breed thereby.

One of the most important contributions to this end has been obtained in the increased milk yield from a flock of multi-nippled ewes developed by the late Alexander Graham Bell. The flock was donated to this station for further research. It represented thirty years of careful experimental breeding with the practical object of increasing the fecundity and the milk yield of ewes, and its contribution has spared us much in time and expense.

The scientific significance of this type of research was recognized as of sufficient importance by the committee which organized the recent International Congress of Genetics, held at Ithaca, New York, to select it as representative of progress in applied genetics with domestic livestock. An exhibit to illustrate the effects of breeding on sheep, wool, and woolen products attracted particular attention because it represented the only research project applying genetic principles to the breeding and development of utility traits in farm livestock. Further evidence of the interest in this research may be cited in the request by the Agricultural Experiment Station at Rothamstead, England, for two stock rams of our hybrid strain. The rams were sent and were used for continuation of research at that station. One of our four-nippled rams heads a flock of purebred Suffolks in Kansas. More recently similar requests have been received from an interior province of China, and from different parts of this country.

Genetics, like all other sciences, appeals most strongly to the popular imagination when it can have a direct application to every-day problems. It is for this reason that it was selected by the Reader's Digest as one of the significant attempts of research to promote human welfare. This research, which still represents the only attempt to apply a highly theoretical science to the practical improvement of livestock, and has thus attracted national attention, appears to have been justified by the results.

Metabolism—A Study of the Energy Requirements for the Varied Activities of Life

The research in animal nutrition carried out at this laboratory during the last 23 years was begun originally as a War emergency project. During the stress of the last great war the problem of conservation of food resources became a matter of such primary concern that practically every country was forced to apply measures restricting the food intake of humans and of animals as well. In many countries undernutrition was the rule rather than the exception. Physiological observations partly of a laboratory and partly of a nation-wide nature were begun to determine the effect of insufficient nourishment, for both short and long periods, on the recuperative ability of humans. As undernourished livestock are of no great economic value an extension of this investigation to domestic livestock became of vital importance also.

Dr. F. G. Benedict of the Carnegie Institution of Washington, grasping the practical significance of extending his studies of the problem on humans to a study of undernutrition on livestock, proposed to this laboratory a cooperative physiological research of the problem. A one-year program with the joint resources of the nutrition laboratory of the Carnegie Institution of Washingon and the experiment station was thus begun.

While the project as originally planned was limited to the solving of one particular problem with a specific one-year time limit, this was extended to another year to check the results under still more critical laboratory control.

The result was so unexpected as to challenge the validity of concepts held at that time concerning the basal metabolism of cattle in particular and possibly of the comparative basal metabolism in gen-

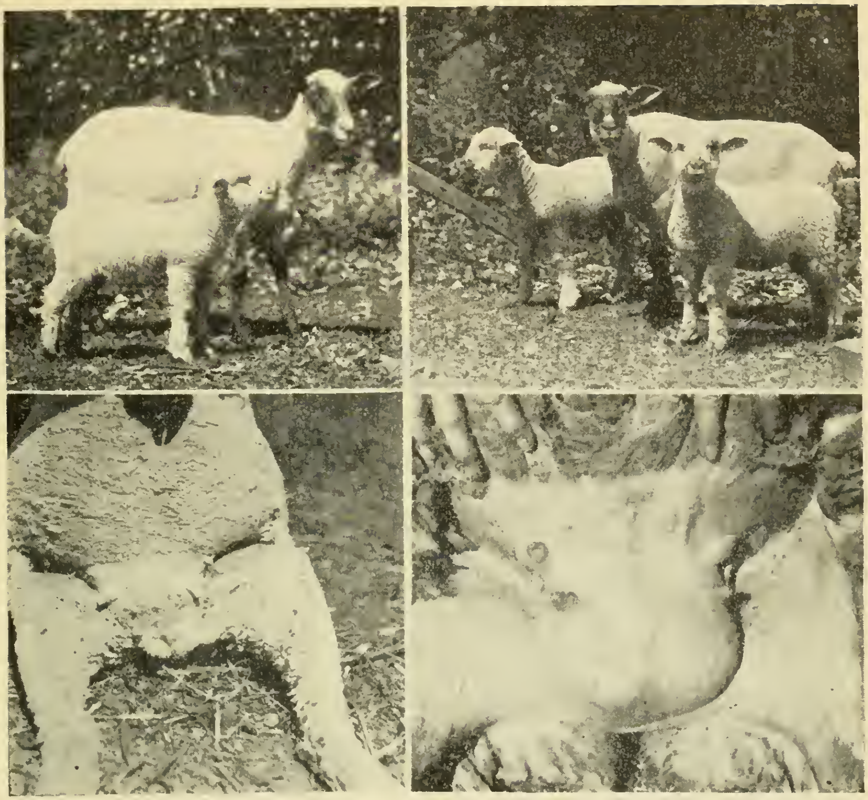

FIGURE 4. MORE MILK IS A PRACTICAL OBJECTIVE
Both growth rate and milk yield are inherited traits but growth cannot materialize without milk. Age of the lamb on the left is the same as that of the twins on the right. Weight of twins is 91 pounds, weight of the single lamb is 26 pounds.

eral. The initiation of a further long range study of this fundamental aspect of physiology based on modern scientific methods of procedure thus clearly seemed imperative for the sound progress of knowledge regarding animal nutrition.

In this modernization two radically new procedures were applied. One was the design and construction of new types of apparatus which would allow a greater research output at less expense, and the other was the study of the energy expended by the animal organism not only when subsisting on different nutritive planes, but also during a limited fast when its digestive apparatus was not filled with food.

It was at this stage that the initiative, the vision, and the experience of a great scientist came in to give research in animal nurition a rational scientific trend. With his usual prompt decision, Dr. Benedict remarked: "As nobody else will do this we will have to tackle it."

Thus was begun a cooperative research which stands today as a record in originality and volume output. It represents a material advance in the study of metabolism of farm livestock.

From its beginning to the present time this research has been in charge of E. G. Ritzman representing the Experiment Station. Until his retirement in December, 1937, the station was fortunate in having the consulting and advisory benefit of Dr. F. G. Benedict, without which this work, both in its scope and fundamental character would have been impossible.

Aside from the purely physiological objectives, this research has represented to a material degree pioneering in the improvement of procedure and design and construction of apparatus, so that energy transformations in livestock could be measured more rapidly and more economically. As a result this laboratory has been able to

FIGURE 5. TWO SIX-NIPPLED YEARLING RAMS FROM OUR FLOCK SENT TO THE ROTHAMSTEAD EXPERIMENT STATION, ENGLAND, FOR BREEDING PURPOSES

more than double the amount of work with a much smaller staff than had been previously required, and the cost, which had been a seriously limiting factor to the existance of research of this character, has been reduced correspondingly.

Thus during the past 21 years that this research has been in progress we have carried out over 1000 separate measurements of the heat production and energy demands of farm livestock under conditions comparing the effect of extremes in environmental conditions such as temperature and seasonal variations in sunlight, of age periods ranging from birth to maturity, of fasting and of the effect of food itself varying from prolonged under-nourishment to heavy fattening rations, of pregnancy and of lactation, and of the demands for active work, such as walking, trotting, and the pulling of heavy loads by horses.

In the nutrition studies with cattle these measurements of the energy transformation by the body were supplemented by 122 complete balances where the ingo of nitrogen and of energy in terms of food, and the outgo, or loss in terms of visible excreta, was chemically measured daily over periods of two or three weeks to show digestibility.

The animals which have been used in this work represented all species of farm livestock. These included a thoroughbred stallion with a notable turf record, a blue-ribbon Percheron stallion weighing over a ton, a Percheron mare, a draft gelding, a standardbred or trotting gelding, a range pony, and a small Shetland pony weighing

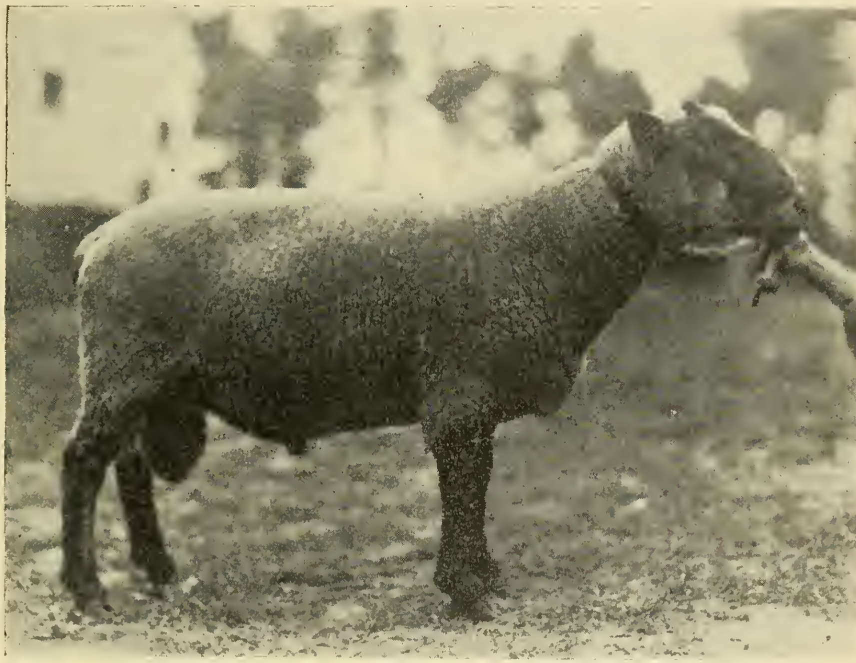

FIGURE 6. THIS FOUR-NIPPLED HYBRID RAM OF OUR BREEDING HEADS A FLOCK OF PUREBRED SUFFOLKS IN KANSAS

about 300 pounds, also 18 beef steers, 5 bulls, 13 cows and 12 heifers of recognized dairy breeds; over 100 sheep, 14 goats, and 32 pigs, ranging from a boar weighing 600 pounds down to suckling pigs weighing less than 10 pounds.

These animals, representing an estimated value of around $10,000, were nearly all obtained either through outside funds (Carnegie Institution) or by loan for this work. Only five cows and one pig were purchased with Experiment Station funds.

Likewise the greater part of the scientific apparatus which has made this type of research possible has been supplied by the Carnegie Institution of Washington. While the Carnegie Institution has found it necessary to discontinue further active financial support, this apparatus which could not be duplicated for less than $7000 has been left to this laboratory for use as long as their research of this type is continued. With the apparatus available, this is at present the best and most efficiently equipped laboratory in existence to carry out research in metabolism of farm livestock.

Much of this modernization of apparatus and of technique has followed principles successfully applied to studies of energetics in relation to human physiology by the Nutrition Laboratory of the Carnegie Institution of Washington (see New Hampshire bulletin No. 240.)

PLACID TYPE ACTIVE TYPE

FIGURE 7. SEAT OF THE VITAL ORGANS

An index of the comparative adaptation of contrasting functional types to use energy. The active type has a larger motor (i.e., vital organs) in proportion to its size. It uses up more fuel. The placid type stores more.

That this contribution to research in animal nutrition represents a very significant advance in both method and result is indicated by the scientific interest manifested in its progress and results.

Since our first results have been published our laboratory has been honored by 170 visitors interested in nutritional physiology and in applied practical nutrition. This number includes 39 scientists representing 17 different countries in Europe, Asia, Africa, South America and Australia.

A further example of this may be cited in the public interest shown in an exhibit prepared by this laboratory portraying in summary the conclusions and the fundamental physiological signifiance of our comparative studies in metabolism. This exhibit was originally prepared for the annual meeting of the Board of Trustees of the Carnegie Institution of Washington. It was subsequently requested as a loan exhibit by the Museum of Science and Industry (Rockefeller Center, New York City) and it was displayed there for about four months. During this time it was viewed by approximately 140,000 persons,

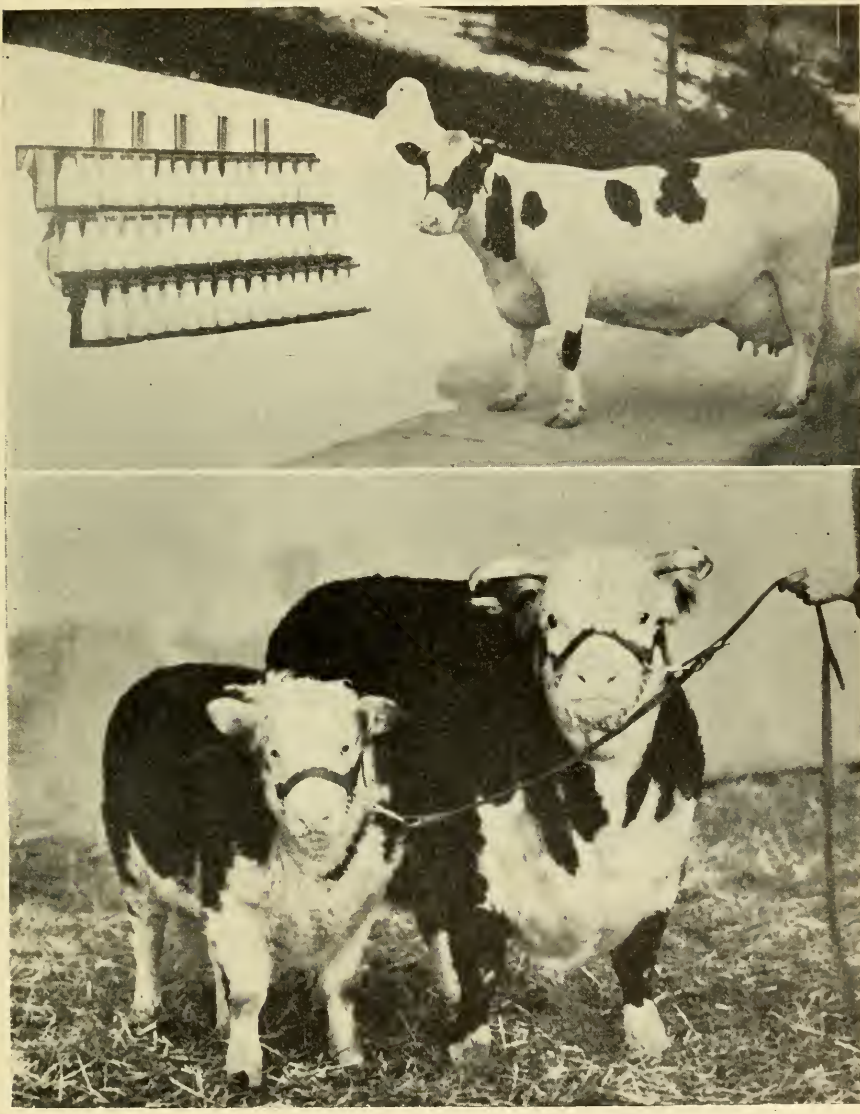

FIGURE 8. EXTREMES IN FUNCTION ADAPTATION ILLUSTRATED BY TWO CHAMPIONS WITH CONTRASTING ADAPTATIONS FOR THE USE OF FOOD ENERGY. ONE REPRESENTS SECRETION AND THE OTHER STORAGE

over 9000 of whom attended a total of 244 public lectures which briefly explained the subject.

Practical Significance of Metabolism Studies

Although clinical practice has given the term metabolism a familiar ring, its character and significance are not generally understood as yet except that somehow it relates to energy and is expressed as calories instead of B. T. U'S. Few for instance grasp the fact that energy performs the same general use in the animal as in a mechanical motor and that the mechanical motor is only a relatively crude imitation of the animal motor.

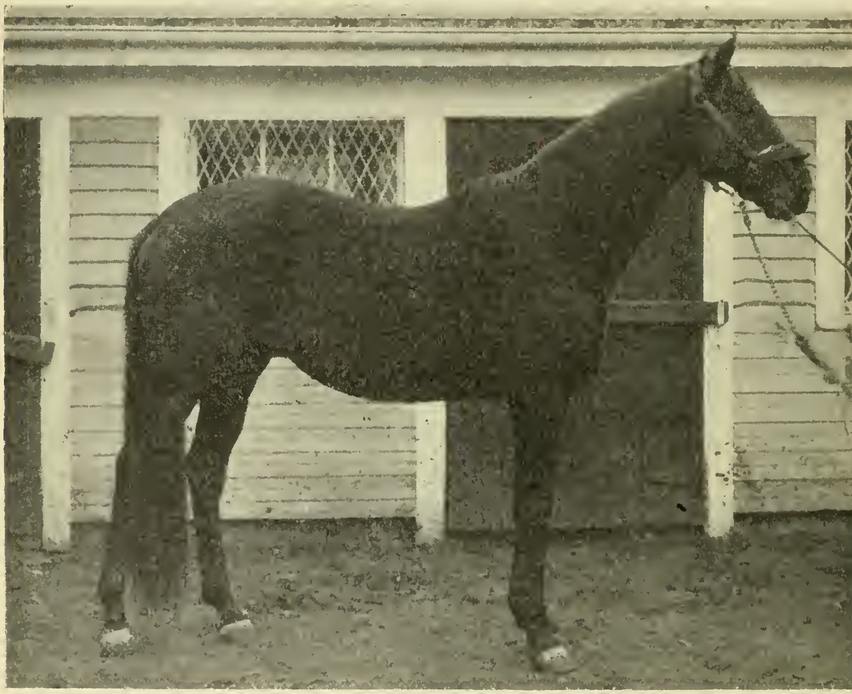

FIGURE 9. SUN GOD II, AN INTERNATIONAL TURF WINNER
He exemplifies speed and endurance, sudden application of great force, a large power plant, basal metabolism of 12,000 calories.

A brief practical explanation of the service of metabolism to the animal body can best be given by analogy. The animal body, like an internal combustion engine, is a transformer of energy from fuel (i.e. food in one case, gasoline in the other) to active power, or motion and heat. The provision for performing this and the processes are fundamentally similar; that is, the combustion chamber or mechanical cylinder is represented by the muscle cells, the carburetor supplying the oxygen necessary for combustion is represented by the lungs, the control of ignition rate is performed by the hormones secreted by the ductless glands, and the blood circulatory system serves as the supply line that carries the fuel (digested food) to the combustion chamber and removes the waste. (See Fig. 7).

Here the analogy ceases because the functions of the body are far more numerous and complicated than those of any mechanical device. For example, everyone knows that this biological engine cannot be started again if it is stopped. Hence the significant characteristic of the muscle cells is their constant activity, flexing and contracting rhythmically whether the individual is asleep or awake. They are oxidizing stored food but when food is not available they oxidize body substance to keep the process going, thus also producing heat. By this process the cell manifests the two characteristic expressions (motion and the production of heat) which we accept as evidence of life.

FIGURE 10. REVELATION, A DRAFT TYPE CHAMPION OF THE INTERNATIONAL LIVESTOCK EXPOSITION AT CHICAGO

He shows weight and power, slow action, smaller power plant, basal metabolism 8,800 calories.

During usual conditions when an animal burns food, combustion flares up temporarily with the result that the heat produced is much in excess of that due to the organic (hormone) stimulus. Hence it is the intensity of this internal organic urge conditioned by hormone stimulus to keep life processes going in the absence of food that represents the genetic adaptation of the animal motor.

The continuity of this self-expression of life processes by the protoplasmic cells collectively, this conversion or utilization of energy, is metabolism. When the body is relaxed and not actively digesting or absorbing food the collective activity of the cells represents basal metabolism which is minimum tempo at which this biological engine can function without stalling. The basal metabolism is therefore merely the persistent minimum effort necessary to keep alive. Biologically the energy expended in basal metabolism, or idling of the animal motor, can be regarded as the maintenance requirement. As a functional expression it also represents the internal adaptation of organs, glands, etc., for the potential conversion of energy, that is, the comparative "horsepower" rating of this biological motor.

This is illustrated in Fig. 6 by the contrast in internal adaptation to function as represented by the size of thoracic cavity or container of heart and lungs (i.e. power plant) in relation to external circumference and thickness of flesh.

FIGURE 11. EVEN SLOW PLODDING WORK INCREASES ENERGY EXPENDITURE TEN FOLD OVER RESTING

Basal metabolism or energy expenditure thus has physiological importance to the individual, but in domestic animals it contributes nothing to our own welfare. Economically its value is nil. From the economic point of view animal life really begins here with its innumerable activities. Categorically we let in the clutch on the idling motor, fuel (i. e. food) consumption goes up and the animal begins to carry out those economically important functions to which its internal adaptation is designed.

By selective breeding we have developed animals of many types, and with highly specialized functions far beyond those possessed by their feral ancestors.

In every class of farm livestock, even including poultry, we have thus created breeds with contrasting adaptations in regard to the use which they make of food energy. In the adaptation of these specialized functions for utilizing food energy they may be regarded as representing three general classes. The beef type stores energy as body tissue, the dairy type secretes it as milk, and the horse burns it up in work, either by a burst of muscular speed for short duration (as in a race) or in slow plodding all day effort of applying its weight in draft work.

Obviously the effect of selective breeding has been to redesign internal motor pattern to meet the requirements that exaggeration of function entails.

These experiments have shown that the genetic factor represents clearly an adaptation in metabolic activity to the particular function. Even with a similar caloric intake the energy conserving type becomes fleshy and the energy secreting type remains thin.

This is illustrated by the production record of two outstanding bovine examples of the result of selective breeding. This result presents an extreme hormone contrast in functional adaptation. One, the energy secreting type, with a high hormone stimulus produced an average of fifty quarts of milk for 365 consecutive days, the other, the energy conserving type, with a lower hormone stimulus, developed into a ton of beef. These of course were not experimental subjects so their basal metabolism was not measured. However, the experimental result of measuring the energy balance of two average purebred cows of the same breeds at moderate production and feeding indicated the same urge to fulfill the function to which the organism is adapted. In this instance the basal metabolism of the dairy cow or energy expending type was about 25 per cent greater than that of the beef cow or energy conserving type.

Muscular effort increases the energy expenditure enormously and as a result the working type is provided with a motor corresponding to the needs. Thus our experiments show that the horse has a higher basal metabolism than any other species so far measured, but even in this species there exists a difference according to the character of work performed. The race horse for example requires an internal adaptation for a greater momentary fuel consumption during a burst of speed than does a draft horse for slow plodding work, and this internal adaptation is reflected by a difference in basal metabolism.

Thus of two unusual type representatives, a thoroughbred race horse, and a purebred Percheron draft horse, whose basal metabolism we measured, the former had a basal heat production of 12000, the latter of 8800 calories.

The cost of work in terms of energy rises rapidly in proportion to the effort involved. The measurements which we have carried out with the horse along this line supply surprising results. From an energy expenditure of 750 calories (per hour) when standing quietly the output increased to three times that amount at a slow walk (no load), to four times at a fast walk and to seven times at a ten mile per hour trot. The same amount of energy (5100 calories) was spent to pull a 160 pound load at slow walk, but when the load was increased to 250 pounds the energy output jumped to 9000 calories.

The relative efficiency of horse and tractors has been frequently discussed but no such fundamental data of caloric cost had ever been ascertained for this species.

No attempt has so far been made to measure the energy expended during a race, or of the speed with which the energy output regains normality after exertion. The practical result of such study will probably supply us eventually with a yardstick of comparative endurance which is one of the first assets of a good horse.

We have also measured the comparative basal metabolism of sheep, goats, and pigs to determine their comparative energy requirements. Selective breeding has also had an effect in modifying, or as we call it improving, these species to a point where they offer some unique contrasts in food utilization and in their economic adaptation. Of these species, the pig is in a class by itself as it is capable of an extraordinary rate of growth. It can increase its weight a hundred fold during the first year as compared to about 15-fold for the sheep or from 5- to at most a 10-fold for the calf. Our data also show that the pig possesses an extraordinary superiority over other farm livestock in the relative proportion of the digestible food energy which it stores due in part to its labile adaptation to environmental conditions and probably to a low hormone activity, which results in a low basal energy requirement.

This study of the comparative basal metabolism of different species, and of types possessing different functional adaptation has supplied many new facts. The concept held for many years that the rate of metabolism, or basal heat production, is conditioned solely by the rate of heat loss to the environment, is untenable. It has been shown that basal metabolism is affected by seasonal influences and particularly by genetic factors which are essential to actuate the inherited (specialized) function to which the organism is adapted.

Publications

In addition to the progress reported year by year in the annual reports of this Station and in the Year Books of the Carnegie Institution of Washington the results of our investigation in nutrition and in breeding have been made public in the four large monographs, technical bulletins, the Journal of Agricultural Research, and through the medium of scientific societies in both this country and abroad. A number of popular bulletins on sheep breeding based largely on the general result of these researches were also prepared by E. G. Ritzman for publication by the New Hampshire Sheep Breeders' Association. The list is as follows—

Publications in Nutrition

TECHNICAL BULLETINS, N. H. AGRICULTURAL EXPERIMENT STATION

No. 16, April, 1920—A Respiration Chamber for Large Domestic Animals[1]
No. 26, June 1924—The Effect of Varying Feed Levels on the Physiological Economy of Steers.
No. 43, June, 1930—The Energy Metabolism of Sheep.
No. 45, April, 1931—The Heat Production of Sheep under Varying Conditions.
No. 52, June, 1932—An Automatic Method of Collecting Solid and Liquid Excreta from Cows in Digestion Balances.
No. 64, May, 1936—The Heat Production of the Sheep and Pig before and after Castration.
No. 66, July, 1936—Basal Metabolism of the Goat.
No. 75, June, 1941—Traits that Determine the Efficiency of the Pig as a Transformer of Energy.

[1] Also published in French: A. M. Leroy. Une chambre respiratoire pour animaux domestiques de grande taille. Bulletin de la Societie Scientifique D'Hygiene Alimentaire Vol. 19:500-523. 1921.

BULLETINS OF N. H. AGRICULTURAL EXPERIMENT STATION

No. 182, April, 1919—Cost of Raising Beef Cattle in New Hampshire.
No. 240, May, 1929—Simplified Technique and Apparatus for Measuring Energy Requirements of Cattle.

CIRCULARS OF N. H. AGRICULTURAL EXPERIMENT STATION

No. 32, April, 1930—Surface Area of Sheep.
No. 41, May, 1933—Studies of Feed Values of Early Hay.

ANNUAL REPORTS NEW HAMPSHIRE AGRL. EXPT. STA. 1919-1940.

MONOGRAPHS OF THE CARNEGIE INSTITUTION OF WASHINGTON

Publication No. 324—Undernutrition in Steers, Its Relation to Metabolism, Digestion, and Subsequent Realimentation, Benedict and Ritzman. 246 pages.
Publication No. 377—The Metabolism of the Fasting Steer, Benedict and Ritzman, 333 pages.
Publication No. 494—Nutritional Physiology of the Adult Ruminant, Ritzman and Benedict, 200 pages.

YEAR BOOKS OF THE CARNEGIE INSTITUTION OF WASHINGTON

No. 22, 1922-1923, pages 219-227
No. 23, 1923-1924, pages 115-119
No. 24, 1924-1925, pages 127-136
No. 25, 1925-1926, pages 139-146
No. 26, 1926-1927, pages 139-147
No. 27, 1927-1928, pages 153-165
No. 28, 1929, pages 147-159
No. 29, 1930, pages 183-196
No. 30, 1931, pages 223-238
No. 31, 1932, pages 173-182
No. 32, 1933,
No. 33, 1934, pages 159-169
No. 34, 1935, pages 65-74
No. 35, 1936, pages 70-80
No. 36, 1937, pages 76-84
No. 37, 1938, pages 329-331
No. 38, 1939, pages 295-297
No. 39, 1940, pages 256-259

PROCEEDINGS NATIONAL ACADEMY OF SCIENCE

Vol. 9, No. 1, p. 23-25, Jan. 1923. Undernutrition and its Influence on the Metabolic Plane of Steers.
Vol. 13, No. 3, p. 125-140, Mar., 1927. Fasting of Large Ruminants, Basal Metabolism of Steers, Metabolic Stimulus of Food in Case of Steers.
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