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THE ELEMENT OF UNCERTAINTY IN THE INTERPRETATION OF FEEDING EXPERIMENTS

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PART I. THE STATISTICAL INTERPRETATION OF FEEDING EXPERIMENTS

Introduction

Value of Feeding Experiments.—The purpose of the type of feeding experiment considered in this bulletin is the comparison of the fattening value of two or more systems of treatment of farm animals or of the fattening qualities of two or more groups of animals differing in age, breed, type, condition, or other particular. This comparison is made on the basis of the gains in weight recorded, the feed consumption, the results of the block test, and the economic considerations involved. Such an experiment is the most direct means of attacking many of the problems confronting the live-stock farmer. Our knowledge of the principles of animal nutrition is too fragmentary to enable us to foretell with certainty, except when greatly dissimilar, which of two rations, for instance, will produce the more rapid or the more economical gains in weight for a particular kind of farm animal, no matter how clearly defined or completely analyzed the rations may be. Actual experiment with those particular rations is generally essential to a satisfactory solution of the problem. However, the information thus obtained has at best a very limited application to other rations or other conditions, so that such feeding experiments ordinarily contribute little of fundamental importance to the science of animal nutrition.

Difficulties of Interpretation.—The plan of the ordinary feeding experiment, such as defined in the preceding paragraph, is simple, but when completed its results are often of ambiguous significance, and the problem of their rational interpretation is in any case worthy of the most careful attention. This is peculiarly tru of experiment station work, upon which recommendations to the farming community are made. The difficulty of interpreting the results of the feeding experiment may be diminished to a considerable extent by taking great care in the selection of experimental animals and by controlling experimental conditions as carefully as possible or practicable; but even after such precautions have been taken, a certain degree of ambiguity still attaches to the experimental results.

The ambiguity inherent in feeding experiments, and in fact in all experiments concerned with the functional activity of living organisms, is due to the impossibility of foretelling with certainty the precise result that would be obtained if the experiment were repeated as carefully as possible upon other similar animals or even upon the same lots of animals. This element of uncertainty in the interpretation of feeding trials is the more pronounced, of course, when attention is directed to the results that would be obtained by the practical farmer in following the recommendations of the experimentalist based upon an investigation conducted by the latter, because of the fact that the farmer in many cases cannot impose the precise experimental conditions required. Thus, an experiment station must be doubly cautious in advising its farming community as to the systems of feeding that are best to employ, since, with the most careful attention to details, a greater or less degree of uncertainty always exists as to whether essentially the same result would appear on repetition of the experiment. Furthermore, this uncertainty is always enhanced by the certainty that the farming community in general often cannot in practice follow instructions to the letter.

The publication of the results of a feeding experiment may be confined to a description of the experimental animals, the rations fed, and all other experimental conditions, and to a statement of the gains in live weight obtained, the changes in condition of the animals, the financial gains or losses, etc. "Such a statement is in itself valuable and not void of interest because it contains the description of a fact, but as long as this fact is not connected with other facts its statement is not so much knowledge as the material for the future acquisition of knowledge. On this ground one even cannot conclude that under similar conditions results will be obtained which resemble those of the first series of observations. It is, indeed, out of the question to reproduce exactly the same conditions, and, since one does not know anything about the conditions which necessitate the result, one cannot positively say that only the observed conditions are of importance and one must resign the hope to foretell future results. But the main interest of all investigations is to know whether the same, or at least similar results will be obtained in a future repetition of the observation. Before such a statement can be made it is necessary to form one's views about the causes which were at work to produce the first result."[a]

Factors Producing Gains in Weight.—In dealing with experimental observations on living organisms, such as observations on rates of gain in live weight of farm animals, one forms the hypothesis that the experimental results, *i. e.,* the gains in weight actually obtained, are due, in the first place, to a complex of conditions definitely imposed upon the subjects of the experiment and under relatively perfect control. These conditions consist, for instance, of the rations fed, the preparation of the rations, the method and times of feeding, the method of sheltering, weighing, and exercising the animals, the season in which the experiment is run, etc. If the feeding experiment be repeated, it is this complex of conditions that it is possible to maintain constant. In the second place, the gains in weight obtained must be considered as being influenced also by another group of conditions not under control. These conditions may be considered as consisting of the temperaments of the animals as evidenced in their differential physical activity, their feeding capacities, their physiological peculiarities, and all of the functional characteristics that render one animal distinct from another and are known collectively as its *individuality.* Besides the individualities of the experimental animals, there must be included in this second group of causal conditions the environmental conditions not under control, such as the weather, and even the personality of the attendant. Such uncontrolled conditions cannot be kept constant, of course, from one experiment to another, but are necessarily variable. Therefore, they constitute the element of uncertainty in the full interpretation of the results of feeding experiments. In order to deal with these variable conditions in foretelling the result of repeating such an experiment, we merely assume that their influence on the rate of gain in live weight is perfectly *random,* showing no recognizable law or regularity except in a large series of observations. As Urban aptly says, "We base our expectation that a repetition of the series of experiments will give similar results on the identity of the conditions which we know and on the supposition of the random character of the influences which we do not know."

The Problem to be Studied.—It is the purpose of this section of the bulletin to consider the element of uncertainty in the interpretation of the results of feeding experiments due to these variable, uncontrolled, and largely unknown experimental conditions, and to propose methods of dealing with the question in a systematic and rational manner, so that the sphere of uncertainty

[a]F. M. Urban, Exp. Stud. in Psych. and Ped., III, "The Application of Statistical Methods to the Problems of Psychophysics," p. 19. Phila., 1908.

surrounding the conclusions based on experimental results will be reduced to a minimum and be defined as clearly as possible. The methods proposed have been employed in other and closely related fields of research and, in fact, have already been applied in a brief manner to one of the many problems connected with feeding experiments, by Wood and Stratton,[a] and later by Robinson and Halnan,[b] of Cambridge University.

A feeding experiment involves not only a record and interpretation of the feed consumption and the gains of each lot, but also a statement of the cost of the experimental animals and of the feeds consumed as compared with a statement of the price realized on the animals of each lot when sold. The question of the relative emphasis to be placed on these two subdivisions of the subject matter of a feeding experiment is of importance. In view of the fact that the feed consumption and the resulting gains of a given lot of animals on a given ration determine the final condition of the animals and afford the basis for the economic considerations involved in a feeding experiment, and in view of the fact that "conditions as to market price of feeding and fat cattle and cost of feeds have never been identical during any two consecutive years and seldom more than similar at irregular intervals,"[c] it is obvious that the most valuable data of a feeding experiment are the data concerning the feed consumption and the rapidity of gain of the class of farm animals from which the experimental animals were drawn. B. E. Carmichael takes substantially the same position in the following quotation:

"The author is thoroughly convinced that too important a place is often given to the *cost* of gains when discussing the results of a feeding experiment, thus rendering more probable a wrong understanding by the student or feeder. When feeders and experimenters think, reckon, and write concerning feeding experiments with *amount* of feed and *rate* and *extent* of gain in live weight, *rather than with cost* of feed, animals, and gains and *net profit* from the operation as the factors for comparisons, it will be reasonable to expect more intelligent selection of rations and consequently fewer failures to secure satisfactory returns for feed and labor required to conduct feeding operations.

"The writer would not be understood as saying that a financial statement is of no value or that nothing should be said concerning the cost of gains. On the contrary, each has a value, but it is believed that in either case the value is far less important than is the matter of the amount of feed required to produce a given gain, on account of the sudden and wide variation in price that may occur."[d]

The feed consumption in feeding experiments, according to the ordinary practice, is determined for the entire lot rather than for the individual animals, and such total data are not susceptible

[a]Journ. Agr. Sci., vol. 3, pp. 417-440. 1908-10. See also T. B. Wood, Journ. Board Agr., London, Sup. 7, 1911, Nov., pp. 32-37.

[b]Journ. Agr. Sci., vol. 5, pp. 48-51. October, 1912.

[c]Herbert W. Mumford, Ill. Agr. Exp. Sta., Bul. 90, p. 203.

[d]Ohio Agr. Exp. Sta., Bul. 187, pp. 18 and 19.

to treatment by the methods to be outlined below. In this bulletin, therefore, attention is confined to the gains in weights obtained in feeding experiments and to the methods of comparing adequately the gains of two or more lots of animals, since in many experiments individual gains are reported.

General Method of Solution.—The problem of the feeding experiment that is considered in this section of the bulletin is the comparison of a number of gains in weight made by animals in one lot, treated alike as far as practicable, with a number of gains in weight made by animals in another lot, treated alike, but in one particular treated differently from the animals of the first lot, the object of the comparison being to determine whether the one difference in treatment between the two lots has produced a difference in the rate of gain in weight. This comparison may be most effectually made by considering the two series of gains separately at first, with the idea of describing each adequately, but with as few terms as possible, and then comparing the two abbreviated descriptions.

THE FREQUENCY DISTRIBUTION AND THE AVERAGE[a]

In describing the gains made by a group of animals, the total gain of the group is often taken, but for comparative purposes it is almost universally considered that it is better to reduce this total gain to a *per capita* basis, and hence it is generally the case that the common average or arithmetic mean of the individual gains of a lot is the one value taken as descriptive of the lot.

When a chemist runs a series of atomic weight determinations upon a chemical element, and subsequently takes the average of his results, this average has a perfectly definite physical significance, *i. e.,* it is the best approximation obtainable to the actual atomic weight of the element. However, the case is quite different when the investigator in animal nutrition averages the gains in weight made by a group of similarly treated animals during the same period of time. Strictly speaking, there is nothing here that can be called a "true value" to be obtained from a set of values diverging from it as the result of errors of observation. The distinction between the two cases is well brought out by Edgeworth when he says that *observations,* such as those of the chemist, "are different copies of the same original," while *statistics,* such as those of gains in weight of a lot of animals, "are different originals affording one generic portrait."

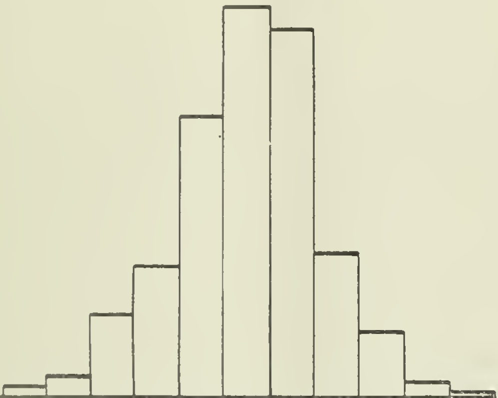
The meaning of the average of a set of statistics may be considered in the following way: It is conceivable that the aggregate

[a]In the following discussion, "average" refers to the arithmetic mean.

of the directly imposed experimental conditions under which the gains in weight were made, operated in the production of a *typical* gain, from which the individual gains diverge as the result of the casual or random sources of variation, and the average gain may be considered as the best approximation to this *type.*

The Frequency Distribution.—In considering this conception of the average gain in weight of farm animals treated in a similar manner, it is necessary to investigate the *frequency distribution* of such gains. Suppose a large number of animals, say several hundred, were treated alike as far as possible with regard to feed, shelter, etc., and suppose the average daily gain in weight for each animal be determined for a considerable period of time, say one hundred days. Suppose the daily gains thus obtained be grouped into class intervals of 0.1 lb. and the number of gains occurring within each class interval be noted. The series of numbers thus obtained is known as a *frequency distribution,* since it gives the frequency with which gains of any given magnitude occur. There are, of course, no data in existence of the gains in weight made by several hundred animals treated alike at the same place and during the same time. Therefore, in obtaining such frequency distributions an indirect method has been employed.

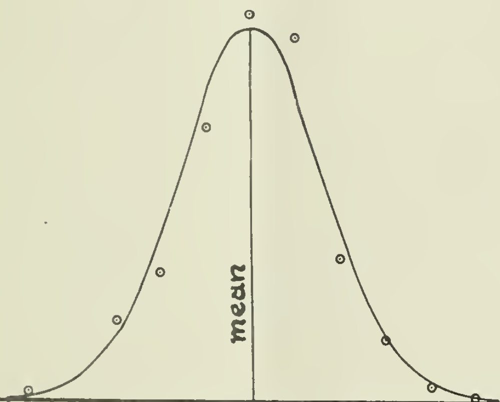
In obtaining the numbers upon which Fig. 1 of the chart is based—this figure being a graphical representation of the frequency distribution of the daily gains in weight of 498 sheep—the average daily gains made by 46 lots of sheep were taken, the lots varying in size from 8 to 16 sheep. The lots were treated in different ways, of course, and at different stations during different periods of time. In combining the different gains for the purpose of forming one distribution, it was desired to eliminate the variation due to differences in feed and other definite factors, and to retain only that variation due entirely to the casual factors, such as individuality and imperfectly controlled conditions. In accomplishing this object, the average daily gain in weight of the entire group of 498 sheep was obtained and found to be 0.3485 lb. Next, the gains in each of the 46 lots were changed, or *transmuted,* by addition or subtraction so that the average daily gains of the various lots were made identical and approximately equal to 0.3485 lb. Thus, the first lot so treated consisted of 10 sheep with an average daily gain of 0.283 lb. By adding to each of the ten gains in the lot the difference between 0.283 lb. and 0.348 lb., which is equal to 0.065 lb., the desired change was accomplished. For another lot of ten animals with an average daily gain of 0.413 lb., 0.065 lb. was subtracted from each of the individual gains. By thus making the average gains of the 46 lots identical without disturbing the variation within the lots, it was believed that the influence of the dif-



Class values	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60
Frequencies	3	7	27	44	92	129	121	48	21	5	1

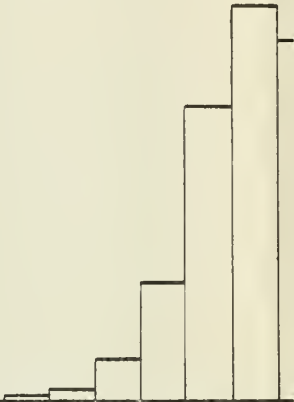
FIG. 1

Frequency Distribution of the Daily Gains in Weight of 498 Sheep.



Class values	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60
Frequencies	1.0	5.8	22.1	57.2	101.4	122.7	101.4	57.2	22.1	5.8	1.0

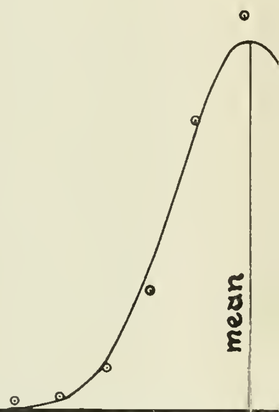
FIG. 2



Class values	.75	1.00	1.25	1.50	1.75	2.00	2
Frequencies	1	2	7	20	48	65	[illegible]

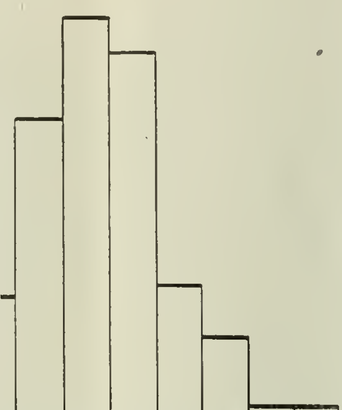
FIG. 3

Frequency Distribution
Gains in Weight of 241



Class values	.75	1.00	1.25	1.50	1.75	2.00	2
Frequencies	0.3	1.8	8.0	23.7	46.8	61.2	5

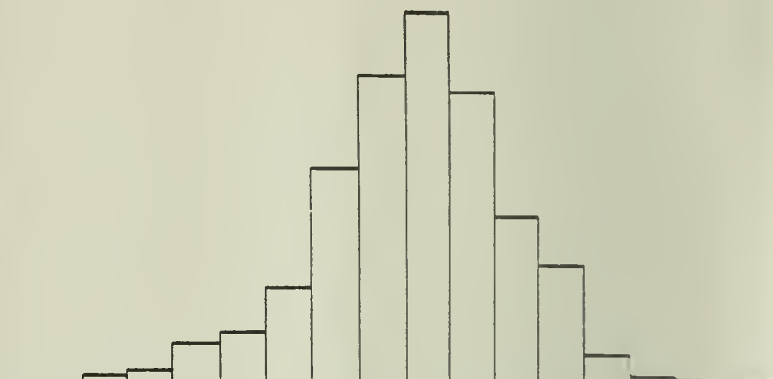
FIG. 4



Class values	0	1.75	2.00	2.25	2.50	2.75	3.00	3.25
Frequencies	)	48	65	59	22	13	3	2

FIG. 3

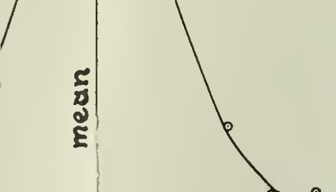
ribution of the Daily
of 241 Steers.



Class values	.60	.70	.80	.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00	2.
Frequencies	3	4	11	14.5	26	57	80.5	97	76.5	45.5	32.5	7.5	2.5	1.5	1	

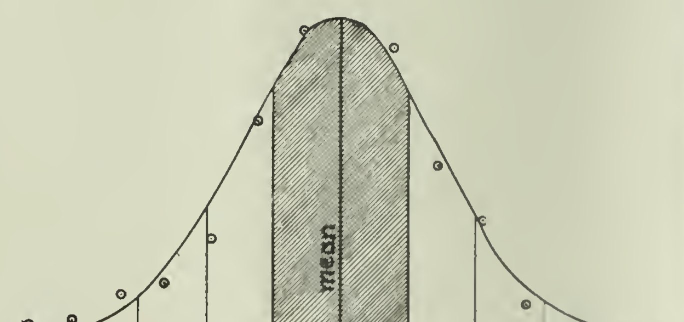
FIG. 5

Frequency Distribution of the Daily Gains in Weight of 461 Pigs.



Class values	0	1.75	2.00	2.25	2.50	2.75	3.00	3.25
Frequencies	.7	46.8	61.2	53.2	30.7	11.8	3.0	0.5

FIG. 4



Class values	.60	.70	.80	.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
Frequencies	0.7	2.6	7.8	18.9	37.4	60.2	78.7	83.4	71.8	50.4	28.7	13.2	5.0	1.5	0.4

FIG. 6

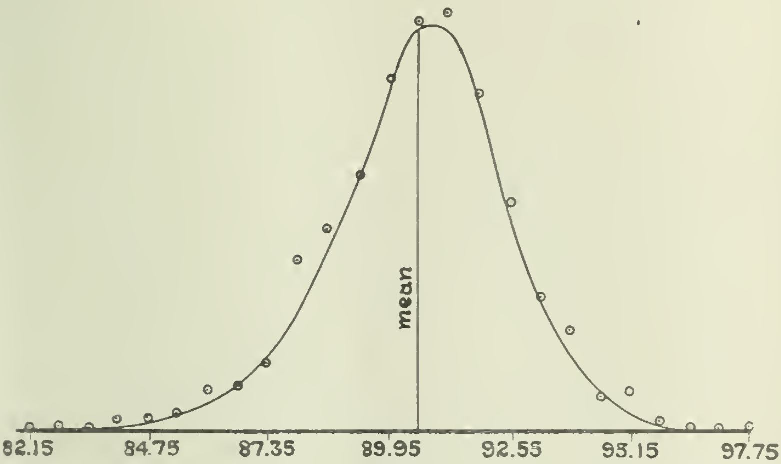


FIG. 7

Frequency Distribution of the Coefficients of Digestibility of the Protein of a Normal Mixed Diet, Obtained from 1153 Observations on 23 Men.

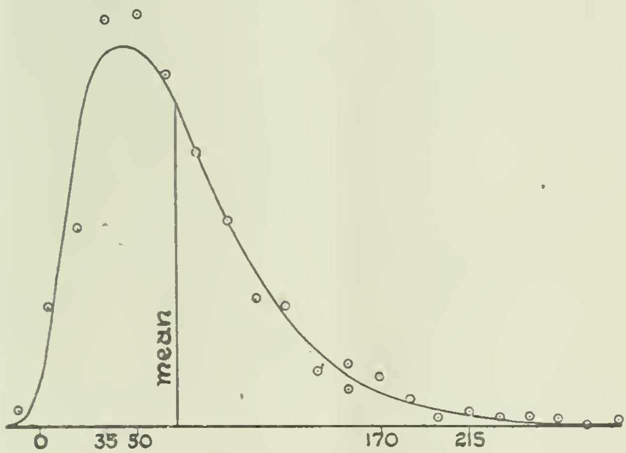


FIG. 8

Frequency Distribution of the Daily Excretion of Indican in the Urine, Obtained from 814 Observations on 11 Men.

ferent experimental conditions among the lots was eliminated as far as possible, while the influence of the casual factors represented by the variation within the lots was preserved intact. The 498 gains thus transmuted were used in obtaining Fig. 1.

In this distribution the class interval chosen was 0.05 lb., as is indicated by the first row of figures at the base of the diagram. The second row of figures gives the *frequencies* of the different classes. Thus, the number 129 in the middle compartment indicates that 129 of the 498 daily gains in weight (transmuted according to the above scheme) fell within the interval 0.325 to 0.375 lb., the number directly above, *i. e.,* 0.35, being the mid-value of this class. The frequency distribution represented by this second row of numbers is graphically illustrated by the superimposed diagram, which is known as a *histogram.* Along the base of this histogram, equal spaces are marked off representing the equal class divisions. On each space a rectangle is erected, the height of which is proportional to the frequency of the respective class; or, preferably, since the gains must be considered as being continuously distributed along the base line or scale and merely summated at equal, convenient, arbitrary intervals, the *areas* of the rectangles should be considered as representing frequency. Figs. 3 and 5 represent the frequency distributions of the daily gains in weight of 241 steers and 461 pigs, respectively, and have been constructed from transmuted values in the same way as Fig. 1.

The Normal Frequency Curve.—It will be seen from all three distributions that the frequencies start at zero, rise rather regularly to a maximum, and decrease regularly to zero again, the rates of increase and of decrease being appreciably similar. This is well shown in Figs. 2, 4, and 6. In these figures a curve of a definite character, represented by a definite equation, and known as the *normal frequency curve,* has been fitted to the three distributions. The base lines of these figures have been divided into the same equal divisions representing the same classes as the figures directly above. The closeness of the fit is indicated graphically by the circled points placed at distances above the centers of the class intervals proportionate to their actual frequencies as given in the figures immediately above, and numerically by the frequency values given in the second row of figures below. These frequency values give areas beneath the curve between ordinates erected at the class limits. Thus, the value 122.7 in the second row below the center of Fig. 2 gives the area bounded by the curve, the base line, and the ordinates erected at 0.325 and 0.375 lb. on the horizontal scale, and corresponds exactly to the value 129 given in Fig. 1. The closeness of fit of these three curves is apparently as satisfactory as could be desired.

Perhaps the most important fact disclosed by these frequency distributions is that variations in rate of gain in weight due to uncontrolled experimental conditions, while exhibiting no regularity and no conformance to law as regards frequency of occurrence in the small experiment, actually *do* exhibit a regularity in the long run and actually *do* conform to a law that may be considered as being approximately represented by the mathematical definition of the frequency curve satisfactorily fitting the distribution, *i. e.*, the normal law of frequency in the cases under discussion. This tendency of the casual variations in gain in weight observed within a lot of similarly treated animals to exhibit frequencies of occurrence in the long run in conformity to a mathematically defined law is at the basis of all attempts to predict the results of future repetition of feeding experiments by finding the probability that an average lot gain or the difference between two average lot gains will lie between any assigned limits. The law defining the frequency of occurrence of casual variations is simply a mathematical expression by which the probability of the occurrence of a given gain in weight is obtained by finding the extent of its deviation from the average gain.

The Average as a Type.—Returning to the conception of the average gain in weight as a *type* which tends to be set up by the definite experimental conditions deliberately imposed, and which is only incompletely realized by reason of the numerous casual factors which are beyond control, it seems that in the frequency distributions such a type would be the position on the horizontal scale of the ordinate passing thru the summit of the frequency curve. This is the value of greatest frequency, the value more often realized than any other under conditions of like control. In Figs. 2, 4, and 6, ordinates are erected at points on the base lines corresponding to the arithmetic means of the gains in weight, and it will be seen that the means of the distributions may be regarded as actually being the points of greatest frequency, or at least very good approximations to such points.

From a study of these distributions, it may be considered that a typical gain in weight exists within the lot, and that the arithmetic mean of the individual gains is as good an approximation to this type as can be readily obtained. In defining this typical gain to which the arithmetic mean approximates, we may say that it is the gain that would be realized by each animal in the lot if no such thing as individuality existed and if all experimental conditions were under complete control and were kept constant for all animals.

It may be said in passing, however, that the conception of the arithmetic mean as an approximation to a type does not apply to all distributions. Thus, Fig. 7 gives the frequency curve of the coefficients of digestibility of the protein of a mixed normal diet from 1153 observations on 23 men.[a] In this case the mean is distinctly situated to the left of the maximum ordinate, due to the peculiar asymmetry of the curve. This condition may be considered as existing in all cases of distribution of percentages where the limiting percent is 100 and the typical or *modal* percent is very near this limit. Whatever considerable variation occurs in the percentage, therefore, must naturally draw out the distribution to a greater extent below the type, or, as it is technically called, the *mode,* than above it. In Fig. 8 is shown another case of asymmetry. This figure gives the frequency curve of the daily excretion of indican in the urine, the data for which were obtained by Folin from 814 observations on 11 men during the course of his experiment to determine the physiological effect of saccharin.[b] Here the lower physical limit of the distribution is, of course, zero, and since the typical value, or the mode, occurs near this limit, and since the variability is rather extreme, the distribution is drawn out above the mode.

The Average as a Descriptive Value.—A second conception of the arithmetic mean of a series of gains in weight made by a lot of uniformly treated animals, is merely that of a *discriptive value,* a representative gain used in place of the whole series of gains, the best representative perhaps of the series. Edgeworth describes it as: "that quantity which, if we must in practice put one quantity for many, minimizes the error unavoidably attending such practice."[c] It must be admitted, however, that if the best that can be said of a mean is that it is merely a descriptive value, it lacks much that is desirable. It has no *physical* meaning such as is possessed by an average that coincides with the mode. It can be defined only by reciting its method of calculation, and not by describing any characteristics that it necessarily possesses. It must be regarded simply as the result of a mathematical calculation leading to a value occupying an intermediate position in the series, whose principal claim to consideration is that it is easily obtained and is almost universally used, rightly or otherwise. Furthermore, the calculation of the arithmetic mean, leading as it does to a value such that the sum of the differences between it and all values below it is equal to the sum of the differences between it and all values above it, is most significant only when the value desired is the mid-value of a symmetrical distribution, and therefore where asymmetry distinctly exists, the arithmetic mean cannot but suffer a loss

[a] These data were obtained by the Division of Animal Nutrition of the Department of Animal Husbandry of this station.

[b] U. S. Department of Agriculture, Report No. 94. 1911.

[c] Edgeworth, Trans. Cambridge Phil. Soc., vol. 14.

of significance. If, for instance, a chemical method of analysis were such that errors in defect of the true value were distinctly and decidedly more frequent and more important than errors in excess, it is evident that the process of taking an arithmetic mean of a number of results obtained by such a method would necessarily be looked upon as leading more often than not to a result less than the desired value.

VARIATION AND ITS MEASUREMENT

In calculating the average gain exhibited by a lot of similarly treated animals, a more or less satisfactory measure is obtained of the influence of the deliberately imposed conditions upon the rate of growth. The incidental and uncontrolled experimental conditions, constituting all individual and environmental factors that have not been kept constant thruout the lot, find direct and complete expression in the *variation*, or *dispersion*, of the individual gains. Hence a measure of the variation of the gains within the lot is a measure of the influence of the uncontrolled factors in the experiment, which always render more or less ambiguous the conclusions ultimately deduced. Hence, also, such a measure is another value descriptive of a series of gains in weight obtained under similar conditions. In fact, so far as rate of growth is concerned, the average lot gain, and a good measure of the variation of gains within the lot, sufficiently describe for all ordinary comparative purposes the response of the animals in the lot to the experimental conditions.

In obtaining a measure of the variation or the dispersion within the lot, it is obviously necessary to have at hand the gains of the individual animals. The frequent practice, in weighing up lots, of obtaining only the total weight per lot, so that only the total gain per lot for the experiment is finally available, renders all study of dispersion within the lots impossible; for, while the arithmetic mean of the individual gains in weight is obtainable directly from the total gain, any measure of dispersion must take into consideration the individual gains and any adequate measure of dispersion must take into consideration all of the individual gains.

The Range of Observations.—The simplest measure of dispersion and the one most commonly used is the *range* of observations actually obtained, such range being the difference between the minimum and the maximum values. However, it has very little to commend it, in spite of its rather general use, aside from the ease of its calculation. Obviously, one of the properties of a good measure of dispersion is that it have as high a degree of stability as possible as we pass from one lot of animals to other and other similarly treated lots. Consider, for instance, a large number of lots of steers that have been similarly treated for the same period of time, each lot, say, containing ten steers. It seems evident that that measure of the dispersion of the individual gains in weight is best which is the most constant from lot to lot, since the same uncontrolled factors to which are due the variation within the lots have influenced each and every lot. But the range from the minimum to the maximum gain in a lot is directly affected by the extreme and unusual gains which may have been obtained, the very gains whose influence should be minimized because of their infrequent occurrence and non-typical character. Furthermore, supposing these lots of steers that are under consideration are not of the same size, it is evident that the range of dispersion within the lots will in general increase with the size of the lot, since the steers exhibiting extremely high or extremely low gains will be found more frequently in the larger than in the smaller lots. Thus, the range between the highest and the lowest gains in a lot is of little value for comparative purposes, since, like the total gain, it depends in part upon the size of the lot; but, unlike the total gain, the influence of the size of the lot cannot be eliminated by a simple division by the number in the lot, or in fact, by any other reasonably simple mathematical process

The Standard Deviation.—Obviously, a good measure of dispersion must take into consideration each and every individual gain obtained; otherwise it really is not a characteristic of the whole series of gains and is unduly influenced by the extreme gains. Perhaps the first method that occurs to one of involving all gains in a measure of their dispersion is to take the average deviation of each of the gains from their mean, paying no regard, of course, to the position of the gain—whether above or below the mean. In fact, this is an excellent measure of dispersion that is sometimes used and is known as the *average deviation.* The measure of dispersion in most common use, however, is obtained by squaring all deviations of individual gains from the average, adding, dividing by the number of gains, and extracting the square root of the quotient. This is known as the *standard deviation,* or the *root-mean-square deviation from the mean.* While the standard deviation is much more difficult of calculation, it possesses several advantages over the average deviation,[a] and is in more general use.

THE SIGNIFICANCE OF AN AVERAGE AND ITS PROBABLE ERROR

The possession of an adequate measure of variation at once leads to the problem of determining to what extent variation with-

[a]For a very good discussion of the average deviation and the standard deviation, see G. U. Yule: "An Introduction to the Theory of Statistics," chap. viii. London: Chas. Griffin & Co., Ltd. 1911.

in the lot vitiates conclusions based upon average lot gains. The average lot gain and the standard deviation of the individual gains sufficiently describe the lot for all ordinary comparative purposes, and the question now at issue is how these two descriptive terms can be used to render any subsequent comparison the most efficacious. As a matter of fact, the average gain or the total gain of a similarly treated lot of animals is a very deceptive quantity unless its exact *significance* is quantitatively defined by some additional term. An average gain should be thought of, not so much as an isolated point in the scale of measurement, but rather as the mid-value of an interval such that there is a definite probability that upon repetition of the experiment the average gain so obtained will fall within it. Such an interval is defined by the *probable error* of the average; and the probability that repetition of the experiment will yield an average within the limits of this probable error is exactly one-half. Raymond Pearl, of the Maine Experiment Station, who is applying biometric methods to problems of agricultural science, insists that "an experiment which takes no account of the 'probable error' of the results reached is inadequate and as likely as not to lead to incorrect conclusions."[a]

Similarly, Wood and Stratton emphasize strongly the advisability and, in fact, the necessity of allowing for errors of sampling incurred in the selection of animals for experiment. The following quotation is especially significant: "With the great growth of interest among the farming community and the increasing tendency of the farmer to take note of the work of the experimentalist and to act upon it, it is becoming increasingly important that due caution should be exercised by experimenters in interpreting their results before laying them before the agricultural public."[b]

Since an attempt to allow for experimental error in the interpretation of average lot gains is not effective unless the individual gains have been obtained, it is obviously important, in conducting a feeding trial, to ascertain individual behavior—the reaction of each animal to the experimental conditions imposed. Important as this condition is, it is too frequently disregarded in experiment station work. The collection and publication of individual data is too often thought to have little or no bearing on the problem of the experiment and consequently to be a waste of energy and space; and yet by the neglect of this one condition, the investigator throws away the only opportunity of adequately analyzing his data.

The Standard Deviation of an Average.—The element of uncertainty in the interpretation of an average gain in weight for a

[a]Scientia, vol. 10 (1911), p. 106.

[b]Journ. Agr. Sci., vol. 3, pp. 417-440. 1908-10.

lot of animals is due to the fact that successive lots treated similarly for a given period will necessarily give different average gains in weight. An arithmetic mean of a series of gains in weight must be considered as possessing a variability, just as is the case with the individual gains, due to uncontrolled experimental conditions; and, since these uncontrolled experimental conditions find direct expression in the variability of gains within the lot, it follows that the variability of an average gain bears a definite relation to the variability of individual gains. Obviously, the variability of an average gain decreases as the size of the lot increases, the main reason for increasing the size of a lot being, in fact, to render the average gain more significant. It may be shown, however, that the variability of an average gain does not decrease *directly* as the number of animals in the lot increases, *but only as the square root of this number* increases.[a] In other words, *the presumptive standard deviation of an average gain of a lot is equal to the standard deviation of the gains within the lot divided by the square root of their number.*

The Frequency Distribution of an Average.—It may further be shown that the variation to which a mean gain in weight is subjected as successive samples of animals are taken and treated experimentally is such that the distribution of means tends to assume the *normal* form, definable by the *normal frequency curve*,[b] such as that shown in Fig. 6 of the chart. In fact, whether the original values from which a mean is derived are so distributed or not, it may be shown that the distribution of means tends strongly to assume the normal form. Now, in conceiving of the frequency distribution which would be exhibited by a particular average gain obtained experimentally if the experiment should be repeated a large number of times, obviously the best value to assume for the maximum point in the distribution, the point of greatest frequency, is the actual average gain obtained, since the one experiment actually performed has indicated that this is the most probable value that would be obtained upon repetition.

The Probable Error of an Average.—Let the normal curve in Fig. 6 of the chart represent the presumptive distribution of the average gain of a given lot of animals. The mid-ordinate of the curve we will assume to be located at this mean value. Now, in defining the significance of such a mean value, the following procedure is the customary and perhaps the most natural one to pursue. Divide the area under the curve into two equal parts, one part symmetrically including the maximum ordinate of the curve.

[a]Yule: "Theory of Statistics," p. 340.

[b]See Henderson: "Frequency Curves and Moments." Trans. Actuarial Soc. of Amer., vol. 8, pp. 30-42.

This has been done in the figure, and that half of the area situated at the center of the distribution is indicated by cross-hatching. Now, since, as explained above, areas under a frequency curve represent frequencies, it may be said that upon continued repetition of the experiment, as many average lot gains will fall within the shaded area as without. Expressed in other terms, the odds in favor of obtaining a second average gain within the shaded area, or without, for that matter, are 1 to 1. The distance on the horizontal scale from the center of the distribution to the ordinate on either side defining the shaded area is known as the *probable error of the mean,* so that the probable error may be said *to define an interval, symmetrically including the average, such that the odds are exactly even that a second average resulting upon repetition of the experiment will fall within it.* One of the properties of the normal frequency curve is that the probable error of the mean is obtainable directly from the standard deviation of the mean by simply multiplying by the factor 0.6745,[a] from which it follows that *the probable error of an average lot gain in weight is equal to the standard deviation of the average multiplied by 0.6745, or is equal to the standard deviation of the individual gains within the lot divided by the square root of their number and multiplied by the factor 0.6745.*[b]

A very good statement of the relation between the three *statistical constants* thus far discussed is given by H. L. Rietz in his Appendix to Eugene Davenport's "Principles of Breeding." Rietz says: "In describing a frequency distribution, the average gives absolutely no idea as to whether deviations are large or small,—nothing in regard to the spread of the distribution. It is the object of the 'standard deviation' to be descriptive of this variability, and it is the object of the so-called 'probable error' to indicate what confidence is to be placed in statistical results." The description of a series of gains made by a lot of similarly treated experimental animals should be thought of as a more or less complete and satisfactory description of the frequency distribution of gains of which the particular series experimentally obtained is a random sample.

The Limits of Practical Certainty.—The ordinates situated at distances from the center of the curve of two and three times the probable error are also indicated in Fig. 6. The first pair of ordinates include nine-elevenths of the area of the curve, or the ratio of the area within the ordinates to the area without is 4.5 to 1;

[a]Yule: "Theory of Statistics," pp. 305-307.

[b]The probable error of the mean may be expressed mathematically by the formula $E_m = 0.6745 \frac{\sigma}{\sqrt{n}}$ where σ is the standard deviation of the original observations and n is their number.

from which it follows that the odds of obtaining a second average gain within a distance of twice the probable error from the average actually obtained are 4.5 to 1. Similarly, for a distance of three times the probable error, the odds are about 21 to 1, for four times the probable error, 142 to 1, for five times the probable error, 1310 to 1, etc.[a] Since there are no definite limits to a distribution of this kind, the occurrence of average gains upon repetition of the experiment extremely removed from the average gain actually obtained, which is represented by the mid-ordinate of the curve, cannot be said to be impossible, but only extremely improbable. It becomes necessary, therefore, in assigning the significance of an average lot gain, to decide upon some value which, when added to and subtracted from the average gain, defines an interval such that the average gain obtained upon repeating the experiment is practically certain to fall within it. Wood and Stratton have recommended that for data obtained from agricultural experiments that pair of ordinates situated equidistant from the mid-ordinate of the frequency curve and removed from it to such a distance that the area between them and the curve constitutes 30/31 of the total area under the curve, are good limiting values for use. This merely amounts to assuming that when the odds are 30 or more to 1 that an event will happen, we are practically certain that it will happen. For a normal distribution, which, as has been seen, an average lot gain tends to assume, a value 3.17 times the probable error, or, roughly, 3 times the probable error, constitutes the limiting value recommended by Wood and Stratton. The requirement of odds of at least 30 to 1 that a feeding experiment upon repetition will duplicate the results actually obtained, before definite conclusions be drawn from it and definite recommendations be made to the farmer, seems reasonable and, judging from the current practice of the investigators in various fields employing these methods, is not by any means severe. Thus, Davenport and Rietz, in Bulletin 119 of this station, say: "It will be noticed that by the time we have made an allowance of three or four times the probable error we have reached a chance which amounts to practical certainty and even 21 to 1 involves far less chance than *is involved in most business transactions.*"

The merit of such methods as these for the interpretation of feeding trials consists largely of the fact (1) that they are perfectly systematic, (2) that the argument leading from the original individual data to the resulting conclusions is unbroken and capable of being expressed definitely, and (3) that after it is de-

[a]C. B. Davenport: "Statistical Methods," p. 14. New York. John Wiley & Sons, 2nd rev. ed. 1904.

cided that the methods are applicable, the personal judgment of the investigator, which is so liable to introduce bias into the interpretation, is practically eliminated.

ILLUSTRATIONS OF THE USE OF THE PROBABLE ERROR

In illustrating the use of the probable error we will first consider an experiment published in Bulletin 71 of the South Dakota Station, the object of which was to compare the value of speltz and barley as a single grain ration for fattening sheep. The two lots consisted of 12 animals each. Lot I, fed speltz, made an average gain during the 105 days of the experiment of 25.0 lbs. per sheep. The standard deviation of the gains in this lot was 9.44 lbs. From these figures, the best estimate we can make of the standard deviation that would be exhibited by the average gain if the experiment were repeated a large number of times is 9.44 lbs. divided by $\sqrt{12}$ (there being 12 sheep in the lot), which is equal to 2.73 lbs. Since the distribution of such a series of average gains would be of the normal type, the probable error of the average gain obtained in this experiment is equal to its standard deviation, 2.73 lbs., multiplied by the factor 0.6745, the required product being 1.8 lbs. The average gain with its probable error is ordinarily written 25.0 ± 1.8 lbs., and the whole expression means that the odds are exactly even that if the experiment were repeated with 12 other sheep fed a grain ration of speltz and treated in all other ways as far as possible the same as were the sheep in this experiment, the mean gain for the lot would fall within the interval $25.0-1.8$ lbs.$=23.2$ lbs., and $25.0+1.8$ lbs.$=26.8$ lbs. Similarly the odds are 30 to 1 that this second average gain would fall within the interval $25.0\pm(3.17\times 1.8)$ lbs., that is, somewhere between 19.3 lbs and 30.7 lbs. Thus, while the average gain actually obtained was 25.0 lbs., and while this is the most probable average gain that would be obtained upon repetition of the experiment, we can say with reasonable certainty only that a second average gain would fall somewhere between 19.3 and 30.7 lbs. Thus, the element of uncertainty resulting from the meaningless fluctuations in the gains of the individual sheep due to the individuality of the animals and other uncontrolled experimental conditions, has been fairly definitely and reasonably defined for this lot of animals.

Lot II, fed a grain ration of barley, yielded an average gain of 37.9 lbs., the standard deviation of the individual gains being 8.23 lbs. Proceeding as above, the probable error of this average gain will be found to be 1.6 lbs., so that we are practically certain that a second average gain which would result from repeating the experiment on other sheep, would fall within the interval $37.9\pm$

(3.17×1.6) lbs., namely, between the limits 32.8 lbs. and 43.0 lbs.

Therefore, since we are practically certain that any random sample of 12 sheep selected as were the sheep of this experiment and treated as was Lot I, would exhibit an average gain in 105 days between 19.3 and 30.7 lbs., and that any similarly selected sample of 12 sheep treated as was Lot II would show an average gain in 105 days between 32.8 lbs. and 43.0 lbs., it is obvious that we may feel sure that the one deliberate difference in treatment between Lots I and II, *i. e.*, the difference in grain ration, does influence the gain in weight of sheep, barley tending to produce a better gain than speltz under the feeding conditions of this experiment. A more systematic way of settling the question, however, is to take the difference in average gain between the two lots, *i.e.*, 12.9 lbs., and find its probable error. It may be shown that the presumptive variability or standard deviation that would be exhibited by a difference between two averages if the experiment were repeated over and over again, is equal to the square root of the sum of the squares of the standard deviations of both averages,[a] and consequently the probable error of a difference bears a like relation to the probable errors of the two averages. According to this formula, the probable error of the difference under consideration is 2.4 lbs., so that we may feel certain that upon repetition, the excess of gain of the barley lot over that of the speltz lot would be within the limits 12.9±(3.17×2.4) lbs., that is, between 5.3 and 20.5 lbs. The average difference, 12.9 lbs., is 5.4 times its probable error, and the odds that the excess average gain of Lot II over that of Lot I would fall between 0 and 25.8 lbs. are over 7000 to 1.

In Bulletin 64 of the Pennsylvania Station is reported an experiment on steers, one of the purposes of which was to compare the gains made by steers fed during the winter in a barn with those made by steers fed in an open shed adjoining an open yard. The lots contained 12 steers each and were treated alike except as regards shelter. Lot I, fed in a barn, showed an average gain in 126 days of 267.7±8.8 lbs., and Lot II, fed in an open shed, a gain of 247.7±7.4 lbs. The difference in gain between the two lots was 19.0±11.5 lbs. Since this difference is less than twice its probable error, it may well have resulted from the casual factors producing variation within the lot.

In the 16th Annual Report of the Wisconsin Station, the results of an experiment to determine the comparative value of rape and clover for growing young pigs is reported. Each lot of pigs contained 21 animals. During an experimental period of 56 days,

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[a]Yule: "Theory of Statistics," pp. 207-208.

Lot I, which was pastured on rape, gained 71.0 ± 1.4 lbs., and Lot II, pastured on clover, 68.3 ± 1.3 lbs., the difference in favor of Lot I being 2.7 ± 1.9 lbs. The odds are only 2 to 1 that upon repetition of the experiment the lot pastured on rape would exhibit a gain between 0 and 5.4 lbs. above that of the lot pastured on clover, and it may be shown by taking the ratio of the difference in gain to its standard deviation and using tables of the normal probability integral,[a] that the odds are only 5 to 1 that under the conditions of this experiment rape-pastured pigs would again exhibit a greater average gain than clover-pastured pigs. Thus, the data when analyzed by the method under discussion hardly warrant a definite conclusion.

A Probability Method for Small Lots of Animals

While the calculation of probable errors and the use of tables of normal probability integrals is the best method available, and is undoubtedly a good method for precise definition of the element of uncertainty inherent in the interpretation of averages when the number of animals per lot is large, when the number is ten or less, a probability table compiled by "Student" and published in Biometrika[b] for 1908 may better be used for this purpose. In the article in which the table occurs, "Student" considers the distribution of means of small samples and finds certain irregularities which gradually disappear as the size of the sample increases. These discrepancies between the theory of large samples and the theory of small samples are such that by the application of the ordinary theory which has been described above, to small samples, *i. e.,* samples of ten or less, the odds obtained that repetition will result in a certain way are greater than the data actually justify. The methods of analysis described in this article should commend themselves highly to the investigator who is compelled for practical reasons to employ small lots of animals.

[a] C. B. Davenport: "Statistical Methods," p. 119.

[b] Page 1.

PART II. A STATISTICAL STUDY OF VARIATION IN THE GAINS IN WEIGHT OF FARM ANIMALS UNDER LIKE CONDITIONS

Introduction

In the preceding section of this bulletin, it is shown that an important factor contributing to the element of uncertainty in the interpretation of feeding trials consists of individual differences in the reaction of experimental animals to environmental conditions and of the unavoidable differences in environmental conditions to which the different experimental animals are subjected. It is further shown that such a factor of uncertainty can be handled satisfactorily by the ordinary statistical methods,—standard deviations and probable errors, as well as average gains in weight, being calculated for the different lots of animals in a feeding experiment.

With the advent of an adequate quantitative measure of variation in the gains in weight of animals upon like rations and under similar experimental conditions, the possibility presents itself of solving many problems intimately concerned with the methods of conducting feeding experiments and with the improvement of such methods. Other problems possessing a more general significance are also brought within reach of definite solution by the use of statistical measures of variation.

This section of the bulletin treats of the extent of variation in gain in weight within the lot and upon what this variation depends. Also, the question of the reduction of such variation receives attention. Finally, consideration is given to the possibility that other than casual sources of variation in gain in weight are concerned in the ambiguity attaching to experimental conclusions as ordinarily formulated.

The material for the following investigation was gathered largely from experiment station work in this country, tho some valuable assistance was received from similar work in Canada and England. In thus utilizing experimental results collected by many different investigators at widely varying localities for the purpose of solving diverse problems in live-stock feeding, many difficulties were encountered in adapting such a heterogeneous mass of data to the solution of a few related problems, the existence of which was in no case recognized when the experiments were planned and undertaken. The facts or suggestions finally elicited, however, are perhaps the more valuable because of the richness and heterogeneity of the results upon which they are based.

J. B. Lawes on Variation.—The existence of extreme variation among the gains in weight obtained within similarly treated lots of animals has very frequently been the occasion for comment in experiment station literature. One of the best discussions on this subject that we have been able to find is that of J. B. Lawes, occurring in the course of a report of investigations on the comparative fattening qualities of sheep conducted at the Rothamsted Station, England, about sixty years ago. Speaking of the selection of the 40 Hampshire and 40 Sussex wethers under investigation, Lawes says:

"It is perhaps seldom that animals have been drawn for purposes of experiment with more care than in the instances of which the foregoing tables [giving the weights and gains of the sheep] record the results, yet we have scarcely a sheep in either breed which does not give twice, thrice, or more times as great an increase in gross live weight at one period, as at another of equal length; whilst taking the entire period of the experiment, we have nearly double the increase with some animals as with others by their side, and having ostensibly the same description and qualities of food provided.

"The variation in the apparent rate of gain of the same animal at different times, is largely due to the difference in the amounts of the matters of the food retained within the animal at the different times of weighing, and to obviate error from this cause we have only to extend our experiments over a sufficient length of time, and to be careful, as far as possible, always to weigh the animals at the same period of the day, and under similar circumstances as regards their hours of feeding.

"With respect to the difference of result shown by different animals, having professedly the same allowance of food, much of it is doubtless due to distinct constitutional tendency to fatten or otherwise; yet in some cases it no doubt depends upon a real difference in the food consumed by individual animals, for it is impossible to secure for each its due share of the several foods supplied; and wherever there are many animals kept and fed together, there are always some who exercise a kind of mastery over the rest, and if they do not eat more food altogether than is allotted to them, they will at least take more of the best of it than is their share, and thus reduce the fair allowance to all the rest. By this cause, indeed, it is not improbable that the proper feeding and increase of some animals well adapted for it may be prevented; though in so far as these differences are really due to the quantities of feed consumed by different individuals, it is obvious that the true relation of food to increase will be less misstated by the gross numerical results of feeding experiments, than would be the case were the irregularites entirely owing to varying constitutional capabilities of the different animals to grow or fatten upon the same food.

"But whatever be the causes of these variations, the figures in the tables show that, notwithstanding the careful selection of the animals, we have among the Hampshire sheep a difference in their average weekly gain of from about 3¾ lbs. to little more than 2 lbs.; and among the forty Sussex sheep, of from little more than 2½ lbs. to less than 1½ lbs. Indeed, the tenor of all published results on feeding seems to show that these fluctuations and variations are the rule and not the exception; and the fact of them, therefore, should lead us to great caution in drawing nice conclusions from experiments made with but a small number of animals, and extending only over a short period of time."[a]

The Coefficient of Variation.—As is shown in the first section of this bulletin, the standard deviation, or root-mean-square deviation from the arithmetic mean, is a good measure of variation for some purpose, *e.g.*, for gauging the value of the arithmetic mean as an approximation to the typical gain in live weight under certain defi-

[a]Journ. Roy. Agr. Soc. of England, vol. 12, pp. 419-420. 1851.

nite experimental conditions, or, as some prefer to consider it, for gauging the value of the mean as a quantity descriptive of a given series of gains in weight obtained under similar conditions, or, again, for measuring the *significance* of a mean gain in weight.

For extensive comparison, however, the standard deviation is inadequate, since, in the first place, it depends upon the units of weight employed, and, in the second place, it depends in some measure upon the mean value itself. Thus, a lot of 19 pigs gained an average of 35.74 lbs. in four weeks, and of 77.11 lbs. in eight weeks. The standard deviation of the 19 individual gains at the end of four weeks was 5.31 lbs., and at the end of eight weeks, 11.28 lbs. In view of the great disparity between the corresponding average gains, the question whether the 19 pigs exhibited gains more variable at the end of four weeks than at the end of eight weeks, cannot be settled in fairness by comparing simply the two standard deviations. For the fairest comparison it is customary to convert the standard deviations into percentages based upon their respective averages. For example, 5.31 constitutes 14.86 percent of 35.74, and 11.28 constitutes 14.63 percent of 77.11; from which it follows that the variability for the two periods figured in this manner was practically identical. The percentages thus obtained, *i.e.*, 14.86 and 14.63, are known *as coefficients of variation*, or *coefficients of variability*.

Again, consider a comparison as to variability of gain among lots of different species of animals. Consider, for instance, (1) a lot of 9 cockerels, (2) a lot of 16 sheep, (3) a lot of 21 pigs, and (4) a lot of 15 steers, concerning which the following statistical data have been collected:

Lot	Average daily gain	Standard deviation	Coefficient of variation
1	.589 oz.	.119 oz.	20.20
2	.350 lb.	.0451 lb.	12.89
3	1.22 lb.	.157 lb.	12.86
4	2.53 lb.	.242 lb.	9.56

In such cases as the above, the only feasible method of comparison is to consider the coefficients of variation.

COEFFICIENTS OF VARIATION ORDINARILY OBTAINED IN FEEDING EXPERIMENTS

Results of Wood and Stratton.—It is a matter of some interest to study the variation in gain in weight, or the *experimental error*, ordinarily existing within the lot for the different kinds of farm animals. The only published investigations of this nature that we are aware of are those of Wood and Stratton and of Robinson and Halnan referred to at the beginning of this bulletin. As the result of nine experiments on the fattening of cattle performed at Cambridge and involving 90 animals, Wood and Stratton found an average coefficient of variation of 21.20. Five similar experiments performed in Scotland and involving 50 animals gave an average coefficient of 20.75, while two cattle-feeding experiments performed in this country, involving 40 animals, yielded an average coefficient of variation of 20.31. Finally, seven experiments performed at Norfolk on the fattening of sheep, involving 100 animals, gave an average coefficient of 21.21. These four coefficients, three obtained with cattle and one with sheep, exhibit a remarkable agreement and would seem to indicate that for these two kinds of animals the percentage variability as regards gain in weight for animals within the lot is substantially the same.

Results of Robinson and Halnan.—As the result of a statistical analysis of three feeding experiments, Robinson and Halnan conclude that "the probable error of one animal in a pig-feeding experiment is in the region of 10 percent of the average live-weight increase."[a] This is equivalent to asserting that the coefficient of variation of gains in weight in pig-feeding experiments is about 15, a value considerably lower than the coefficients of Wood and Stratton for sheep and cattle.

Results Obtained from American Experiments.—Results which we have obtained from experiment station work performed in this country entirely are slightly different from those just quoted. From the results of sixteen experiments on the feeding of sheep,[b] involving 803 animals divided into 80 lots of 5 to 16 animals each, we found the average coefficient of variation of the 80 coefficients calculated, to be 21.63, a figure comparing favorably with the average coefficient of 21.20 obtained by Wood and Stratton for sheep.

Eighteen experiments on steers,[c] involving 449 animals divided into 50 lots of 5 to 15 animals each, yielded an average coefficient of variation of 16.73. This is considerably lower than the three averages for steers obtained by Wood and Stratton, *i. e.*, 21.20, 20.75, and 20.31.

From seventeen experiments on swine,[d] involving 507 pigs divided into 49 lots of 5 to 23 pigs each, an average coefficient of 17.12 was obtained. This coefficient agrees well with that obtained for steers, *i. e.*, 16.73, but is somewhat higher than that found by Robinson and Halnan for swine.

[a]Loc. cit.

[b]See Appendix, pages 558 to 560.

[c]See Appendix, pages 563 to 564.

[d]See Appendix, pages 567 to 569.

The coefficients here reported would appear to indicate that the variability of gains in weights for steers and for swine are substantially the same, whereas the variability for sheep is distinctly higher.

Results Obtained at Woburn and Rothamsted.—Experiments performed at the Woburn Experimental Farm and at the Rothamsted Station[a] tend to substantiate the conclusion that as a general rule sheep give more variable gains than steers. Eight experiments performed on sheep at the Woburn Experimental Farm, involving 375 animals divided into 25 lots of 10 to 24 animals each, gave an average coefficient of variation of 20.80. If five experiments performed at the Rothamsted Station, involving 316 sheep divided into 15 lots of 5 to 46 animals each,[a] be included, an average coefficient of 20.40 results. Nine experiments on steers performed at Woburn, involving 22 lots of 4 steers each and 2 lots of 6 steers each, *i. e.,* a total of 100 steers, gave an average coefficient of variation of 18.15, over 2 percent lower than the two coefficients for sheep given above.

Discrepancies Among Coefficients.—Upon reference to the Appendix, which gives in tabular form all of the data upon which the above discussion is based, it will be seen that the percentage variability of the individual lots varies in a remarkable manner. This is shown by the following frequency distributions of the coefficients of variation of the various lots of animals, including both English and American experiments.

Kind of animal	Class intervals									
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
Sheep	1	5	23	36	27	12	9	3	0	1
Swine	0	7	16	13	8	3	0	1	0	1
Steers	0	12	17	24	13	3	1	2	0	0

Extreme coefficients not included in the above table are: for sheep, 58.21 for a lot of 11 animals, 55.33 for a lot of 10 animals, and 76.9 for a lot of 5 animals; for steers, 51.90 for a lot of 4 animals. The three distributions tend to confirm the conclusion that sheep in general exhibit greater variability as regards fattening qualities than do either steers or swine.

It is worthy of remark that this extreme variability exhibited by coefficients calculated from data obtained from many separate lots of animals treated differently at different localities and at different times, is to be expected, not only from the heterogeneity of

[a]See Appendix, pages 561-562 and 565-566.

the data, but also in large part from the mere size of the coefficients obtained. Thus, according to Pearson, the standard deviation of a coefficient of variation C, may be represented by the formula

$$\sigma_c = \frac{C}{\sqrt{2n}} \left[1 + 2 \left(\frac{C}{100} \right)^2 \right]^{1/2};$$

from which it follows that σ_c increases as C increases, n being the number of observations from which C is calculated. Thus, suppose that a lot of 15 sheep exhibits a series of gains in live weight whose variability is measured by a coefficient of 20. Then if successive series of sheep taken 15 to a lot were treated in the same manner, the best estimate we could make of the standard deviation of the coefficients of variation obtained, using only the data of the first series, would be

$$\sigma_c = \frac{20}{\sqrt{30}} \left[1 + 2 \left(\frac{20}{100} \right)^2 \right]^{1/2} = 3.79.$$

Taking the probable error of C as 0.6745 σ_c and multiplying by 3.17,[a] we define an interval symmetrically including the coefficient 20 such that the odds are 30 to 1 that a second coefficient obtained from a second lot of 15 sheep would fall within it. Thus, we are practically certain only that a second lot of sheep would exhibit a coefficient falling within the limits 20±8.1, *i. e.*, between 11.9 and 28.1.

Meaning of Such Discrepancies.—It is because of the large probable errors attaching to coefficients of 15 to 20 that it is so difficult to demonstrate that a given ration or other system of treatment is capable of producing more (or less) uniform gains than a second ration or other treatment. It is no exaggeration to say that a single experiment with lots of the moderate size ordinarily employed can shed practically no light upon a question of this kind, no matter how extreme the difference in variation between lots, except in conjunction with other experiments of a like nature.

The point under discussion is worthy of illustration. Consider the results of two experiments conducted by W. L. Carlyle at the Wisconsin Station to determine the relative value of rape and clover pasture for fattening pigs.[b] The lots of pigs employed contained 19 animals each in the first experiment and 21 animals each in the second. In the first experiment, the coefficient of variation of the gains in weight of Lot I, allowed to run on rape pasture, was 15.50, while that of Lot II, turned out on clover pasture, was

[a]See page 477.

[b]15th and 16th Annual Reports Wis. Sta.

28.03. One might conclude from this experiment that rape pasture tended to produce more uniform gains than clover pasture. In the second experiment, however, the lot on rape pasture gave a coefficient of variation of 13.23, while the lot on clover pasture gave a coefficient of only 12.88.

Number of Animals per Lot Required in Feeding Experiments

Statistical theory is capable of attacking directly a problem of considerable importance to the technic of feeding experiments, *i. e.,* the number of animals that should be included in the lots of a feeding experiment. The calculations upon which Table 1, giving the results of a statistical study of this problem, is based are given in the Appendix.[a] The number of animals required to demonstrate satisfactorily the significance of various percentage differences in average gain in weight between two lots of animals, for sheep and for pigs and steers, is given in this table, the supposition being, as the evidence seems to indicate, that in general, in experiments on sheep more animals are required per lot than in experiments on swine and steers. The few data that we have collected concerning the variability of the gains in weight of poultry are quite comparable with those for swine and steers, indicating that the same number of animals per lot are required for the former as for the latter.

It will be seen from Table 1 that only a moderate number of animals are required per lot except for differences of less than 12.5

Table 1.—Number of Animals per Lot Required to Demonstrate the Significance of Various Percentage Differences Between Average Lot Gains

For experiments on sheep		For experiments on steers and swine	
Percentage difference between average lot gains	Number of animals per lot required	Percentage difference between average lot gains	Number of animals per lot required
50	2	50	1
40	2	40	2
30	4	30	3
20	8	20	5
17.5	10	17.5	7
15	14	15	9
12.5	20	12.5	13
10	31	10	20
7.5	54	7.5	36
5	121	5	80
2.5	482	2.5	317

[a] See pages 571 to 572.

to 15 percent between lots. For differences of less than 12.5 to 15 percent the number of animals required increases at a very rapid rate.

Advantages of Large Lots of Animals.—In order to appreciate the significance of Table 1, it is necessary to form some idea of the percentage differences ordinarily obtained between lots of animals treated differently. In the case of rations markedly different in nutritive value, such as corn meal alone and corn meal supplemented by meat meal, shorts, middlings, tankage, etc., in swine experiments, differences between average lot gains may run as high as 95 to 100 percent. Experiments comparing the relative efficiency of alfalfa, timothy, and clover hay, or of some of the more common grains, or feeding on pasture and in dry lot, in the production of gains in weight, may yield differences of 15 to 50 percent between lots. However, such cases as those just cited are exceptional. In the common run of feeding trials, the purpose is to determine the relative efficiency of two rations of approximately equal value, so that differences of more than 10 to 15 percent between lots are not to be expected. Consequently, according to the best information available, the lots of animals used should contain at least 10 to 14 animals, if definite information is to be derived from the experiment. In fact, for differences as low as 10 percent between lots, 25 to 30 animals are required.[a]

Such a large number of animals is rarely used and is perhaps prohibitive for most experiments. However, when working with animals whose feeding capacities and other individual characteristics are so variable, and when, in general, experimental conditions are under such loose control that the standard deviation of gains within the lot averages 17 to 21 percent of the average lot gain, the point to insist upon is that the results of single experiments with four or five animals are in general practically worthless except in conjunction with other experiments performed under the same conditions. This is the conclusion to which Wood and Stratton have come, and it seems to be inevitable, at least until some method of lowering this extreme variability is discovered.

In the course of the elaborate experiments performed at the Rothamsted Station on the comparative fattening qualities of different breeds of sheep, J. B. Lawes again and again calls attention to the variability in fattening qualities exhibited by sheep under

[a]These estimates of the number of animals per lot required in order to obtain definite information concerning a problem in animal feeding, relate to the feeding experiment as ordinarily run, in which no particular effort is made to reduce the experimental error. When such effort is made in an effective manner, perhaps according to the suggestions hereinafter outlined, the above estimates may be reduced to a greater or less extent.

supposedly like conditions and selected with the utmost care. Thus, in his investigation of the Cotswold breed, he says, in speaking of the table giving the gains in weight per four weeks and for the entire experiment of each of the 46 wethers:

"This table brings prominently to our view the point to which we have so often called attention, namely, the great variation in the rate of gain of the same animal during different consecutive periods and of different animals of the same breed, however carefully selected, and having ostensibly the same description and qualities of food. This point we feel it is important to insist upon so often, as showing the uselessness of comparative experiments on feeding, unless both conducted with a large number of animals, and extended over a considerable period of time, so as to eliminate, as far as possible, the effects of the various sources of irregularity which we have before pointed out."[a]

The same warning is given in the investigation of Leicester and crossbred lambs. We wish to emphasize this attitude of Lawes as being assumed over half a century ago by a man of undoubted authority in such matters, as the result of an extensive experience in the fattening of sheep and of other farm animals. It is evidently an attitude necessarily assumed by the careful observer in practical animal husbandry, as well as by the statistical investigator after analyzing by methods at present peculiarly his own the wealth of data which experiment stations everywhere have rendered accessible to him.

The necessity of employing large lots of animals in demonstrating the relative efficiency of two treatments of approximately equal value, for instance two treatments capable of producing a 10-percent difference in gain in live weight between two lots of animals, is capable of illustration in another and perhaps more effective way. Assuming an equal percentage variability of gains in the two lots, each of which contains 10 animals, this percentage variability must be no higher than 12.06 in order to set up odds of at least 30 to 1, that is, in order to adequately prove any difference whatever in efficiency between two experimental treatments capable of effecting a 10-percent difference in gain. Considering the American experiments only, of the 80 lots of sheep whose coefficients of variation were determined, only 11 exhibited a variability as low as this; of the 49 lots of pigs only 8 possessed a coefficient of 12.06 or less; of the 50 lots of steers only 9 gave coefficients as low as or lower than 12.06. With 14 animals to the lot, a coefficient of variation for each lot at least as low as 14.23 is necessary. Fifteen of the 80 lots of sheep, 19 of the 49 lots of pigs, and 15 of the 50 lots of steers possessed coefficients of variation as low as or lower than 14.23. With 16 animals to the lot, a coefficient of variation for each lot of at most 15.26 is required. Sixteen of the 80 lots of sheep, 24 of the 49 lots of pigs, and 19 of the 50 lots of steers possessed coefficients of variation as low as or lower than this.

[a]Journ. Roy. Agr. Soc. of England, vol. 13, p. 182. 1852.

SIZE OF GAINS AND THEIR VARIABILITY

From inspection of the data given in the Appendix, one receives the impression that in general, for the same feeding experiment, there is a tendency for the variability of gains within the lot to correlate itself with the average gain, low average gains being in general associated with high variabilities. The detailed data are so heterogeneous as to render any systematic study of this question impossible. However, confining ourselves to those experiments in which the lots consist of at least 10 animals and the differences among average lot gains are large, we will consider only those results capable of affording the most decisive evidence either one way or the other.

Evidence for Sheep.—Considering the feeding experiments with sheep[a] first, Experiment 1 offers little evidence either one way or the other, the gains for most lots being quite similar. However, Lot I, with the lowest average gain (32.9 lbs.) exhibits the highest coefficient of variation (25.08); while Lot III, with the highest average gain (41.3 lbs.) possesses a coefficient of variation of only 17.31. The standard deviations of these two lots stand in the same relation to each other. In Experiment 4, Lot I (10 sheep) shows an average gain of 31.3 lbs., a standard deviation of 4.80 lbs., and a coefficient of variation of 15.34; Lot II (10 sheep) shows an average gain of 23.4 lbs., a standard deviation of 7.79 lbs., and a coefficient of variation of 33.29. Thus, in this case the lot giving the lower average gain exhibits the higher absolute and percentage variability, the differences being very marked.

In Experiment 5, Lots Ia, IIa, and IIIa were under experiment in the fall of 1908, while Lots Ib, IIb, and IIIb were under experiment in the fall of 1909, the lots designated by the same Roman numeral receiving similar rations. It will be seen from page 558 of the Appendix, that much better gains were obtained in 1908 than in 1909, even after reduction to a daily basis; also, that the variability of gains is greater for the year giving the poorer gains (1909). Furthermore, on comparing Lot IIIa with Lots Ia and IIa, Lot IIIa is seen to have the greatest average gain and the smallest coefficient of variation. Similarly, on comparing Lot IIIb with Lots Ib and IIb, Lot IIIb is seen to possess the greatest average gain and the least absolute and percentage variability.

In Experiment 6, it will be noted that Lots I and III, with the lowest average gains, exhibit the highest absolute and percentage variability. Lot I, Experiment 7, shows an average gain of 25.0 lbs. in 105 days, and a standard deviation of 9.44, *i. e.,* 37.77 per-

[a]See Appendix, pages 558 to 562.

cent of the mean. Lot II exhibits an average daily gain of 37.9, a standard deviation of 8.23, and a coefficient of variation of 21.70. In Experiment 8, Lots Ia and IIa before weaning exhibit much better average gains than after weaning. The results in the latter case are recorded under Lots Ib and IIb. The percentage variability before weaning is correspondingly less than that after weaning.

We shall not attempt an analysis of Experiment 9 because the lots are so small, but from a cursory glance at the results for the four lots before and after weaning it will be seen that they agree admirably with the theory that the better gains are also in general the more uniform gains.

As further support for this conclusion, we cite Experiments 13, 17, 18, 20, 23, and 24 of the Appendix.

Evidence for Swine.—The experiments on swine[a] do not afford very strong confirmation of the theory under consideration, it must be admitted. This is due in large part to the fact that in many of the swine experiments the lots made similar gains, and that in many experiments small lots of animals were employed, —conditions unfavorable to the solution of the problem at hand. In Experiment 62, tho the lots were small, the inverse correlation between average gain and variability for the six lots is very evident. In Experiments 63 and 64, with 8 and 9 animals to the lot, the evidence is more or less contradictory. In Experiment 65, the data are very irregular, tho they fall in with the theory after a fashion. Thus, the average coefficient of variability for the three lots giving the three lowest average gains is 37.9; for the three lots giving the next lowest gains, 16.8; for the three lots giving the next lowest gains, 15.8; and for the lot giving the highest gain, 13.5. In Experiments 66 and 69 the evidence is contradictory, while in Experiments 67 and 68, it is favorable to the theory. In Experiment 77, the evidence is contradictory.

Evidence for Steers.—For steers,[b] conditions are about the same as for swine. We will not consider the Pennsylvania experiments (35, 36, 37, 38, 39, 41, and 42), since in all of them the two lots gave very similar average gains in weight. The most comprehensive single steer experiment the data for which are given in the Appendix, is No. 43, an experiment by H. W. Mumford performed at the Michigan Station. In this experiment the correlation between average daily gain per lot and the coefficient of variation, while far from perfect, is quite perceptible. The two largest coefficients obtained are those for Lots IX and X, exhibiting the

[a]See Appendix, pages 567 to 569.

[b]See Appendix, pages 563 to 566.

two smallest average gains, while the smallest coefficient is that of Lot VII, exhibiting the largest average gain. Arranging the lots in groups of two in the order of increasing average lot gains, the average coefficients of variation per group run as follows: 24.15, 16.40, 15.83, 17.00, and 14.84.

Evidence for Poultry.—Considering next the poultry experiments,[a] aside from Experiment 78, in which the results are very irregular, probably because the lots were composed of different breeds, and Experiment 84, in which there was only one lot, all show a greater absolute and percentage variability for the lot exhibiting the lower average gain. The unanimity exhibited by these five experiments is quite remarkable.

Summary of Evidence.—The preponderance of evidence thus favors the conclusion that good gains are in general uniform gains, and that in any experiment involving two or more lots of animals there will be more or less close correlation between average lot gains and the corresponding coefficients of variation, such that large values of the former will in general be associated with small values of the latter. While the evidence that we have presented in support of this view is more convincing for sheep and poultry than for steers and swine, the distinction is more apparent than real. As explained above, the particular sheep and poultry experiments cited are more favorable to a solution of the problem than the steer and swine experiments. The conclusion of this section may be stated in other words, *i. e.,* it appears that experimental conditions favorable to growth and fattening are favorable to uniformity of individual gains.

REDUCTION OF THE EXPERIMENTAL ERROR IN FEEDING EXPERIMENTS

The question whether the extreme variability of gains in weight ordinarily encountered in feeding experiments, constituting the experimental error of such investigations, can be reduced without diminishing the significance of experiment station work, is a legitimate object for discussion and investigation. As the result of a single careful experiment on four steers, Wood and Stratton conclude that there is no way of surmounting the difficulty caused by the extreme variability of gain in weight of farm animals and that "the requisite precision in feeding trials can only be obtained by increase of numbers, or if that is impossible, repetition of the experiment." We are of the opinion that such a sweeping conclusion as this is not based upon sound and sufficient evidence. The results of our studies considered in the following pages are not in harmony with such a conclusion.

[a]See Appendix, page 570.

In fact, three experiments on swine (76, 77, 78) conducted by one of the Canadian experiment stations seem to present evidence in direct contradiction to the conclusion of Wood and Stratton. These experiments involve 1 lot of 5 pigs, 5 lots of 6 pigs, and 4 lots of 10 pigs. The coefficients of variation of the gains produced are remarkably, and with one exception, uniformly low, averaging only 10.98. Only one of the 10 lots possesses a coefficient as high or higher than the average for the experiments on swine performed in this country, *i. e.*, 17.12. The reports of these experiments are too meager to enable one to tell what feature or features of experimental control are responsible for this low variability, but it seems that here, at least, a relatively high precision in feeding trials has been attained with only moderately large lots of animals.

(*a*) *Importance of Reducing the Experimental Error*

The importance to the technic of feeding experiments of some method of increasing the uniformity of gains within the lot as the period of observation increases should not be underestimated. The difference between the fattening qualities of two lots of animals selected differently, or between two systems of treatment, is expressed fairly well as a percentage difference rather than a difference of so many pounds or ounces. The statement that Ration A differs in fattening qualities from Ration B to the extent of x pounds has no meaning whatever; the statement that Ration A differs from Ration B to the extent of x pounds in y days, or of x pounds per day, is perfectly definite and involves all necessary information; but the statement that Ration A is x percent better as regards fattening qualities than Ration B is less cumbersome and more intelligible than the latter statement, while containing all necessary information. It is a perfectly legitimate assumption, until proof to the contrary is presented, that the percentage difference between two rations tends to remain constant thruout a feeding experiment. Now, it may be shown that the smaller the coefficient of variation of the gains in weight within a lot, other things being equal, the smaller the minimum percentage difference between the average gain for the lot and the average gain for a second lot that can be definitely traced to the difference in treatment or the difference in make-up between the two lots.[a] Hence the value of legitimately reducing the coefficient of variation of gains is obvious.

We will illustrate the point with the data from one of the Rothamsted experiments given in Table 7, *e. g.*, the data for the lot of 40 Sussex wethers. If this experiment had closed at the end of 4 weeks, the final coefficient of variation of the 40 total

[a] See Appendix, pages 571 to 572.

gains in weight would have been 30.32. If another lot of 40 Sussex wethers had been under observation for the same period of time and had also exhibited a variation of 30.32 percent, on some other ration we will say, then the smallest difference in fattening qualities between the two rations that could be detected with reasonable certainty would be a difference of 12.5 percent; that is, a difference between the two average lot gains of 12.5 percent is the smallest difference that could set up odds of 30 to 1 that the difference in ration was actually concerned in the difference in gain. If this experiment had ended at the end of 8 weeks, this minimal difference between average lot gains would have been reduced to 9.5 percent; at the end of 12 weeks it would have been 7.2 percent; at the end of 16 weeks, 6.2 percent; and at the end of 20 weeks, 5.6 percent. We see, therefore, that during the course of this experiment, which was so conducted that the individual gains were becoming more and more uniform, the average lot gain became much more efficient as a comparative value and much more representative of the experimental conditions whose influence on the fattening of sheep it is supposed to measure.

To illustrate further the great practical value of definite methods of reducing experimental error, we will consider the statistical data of four experiments with poultry performed by F. T. Shutt of the Central Experiment Farm, Canada.

Experiments 79, 81, and 82 were performed in 1901-02, and Experiment 83 in 1904-05. As far as the meager reports of the experiments indicate, the feed in all lots was given to the fowls "in such quantity as was immediately consumed." In the first three experiments, no tendency for gains to become more uniform is evident. In fact, in Experiment 81 the contrary tendency may be seen. In Experiment 83, however, the gains in each lot regularly increase in uniformity to a very marked degree. The ration in this experiment was not very different from that of Experiments 79 and 81. In the latter, the ration consisted of ground oats, 4 parts, ground barley, 3 parts, and meat meal, 1 part, made into a mash with skim milk. In the former, the ration was ground oats, 3 parts, and ground barley, 2 parts, also mixed with skim milk. It would obviously have been to the advantage of Experiments 79, 81, and 82 if they had been conducted as was Experiment 83, tho just wherein Experiment 83 differed essentially from the others, one cannot discover from the report. Perhaps the difference would have been evident only upon careful investigation, for instance of the quantities of feed consumed during each week of the experiment.

The comment of Shutt upon the variability of the gains observed in his several lots of fowls is of interest: "What we may term individualism is as strong among fowls as in other classes

TABLE 2.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF POULTRY

(All weights expressed in ounces)

Total gain	Statistical data of total gains in weight			Statistical data of total gains in weight		
	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
	Lot A. 6 Barred Plymouth Rock Cockerels (79)			Lot B. 6 Barred Plymouth Rock Cockerels (79)		
In 1 week	8.50	2.813	33.09	12.92	1.742	13.43
In 2 weeks	11.75	5.611	47.75	20.08	3.469	17.28
In 3 weeks	17.58	7.219	41.06	30.08	4.936	16.41
In 4 weeks	17.33	9.754	56.28	34.92	6.147	17.60
In 5 weeks	22.58	11.081	49.07	40.75	6.836	16.78
In 6 weeks	26.67	8.280	31.05	44.00	7.047	16.02
	Lot I. 6 Barred Plymouth Rock Cockerels (81)			Lot II. 6 Barred Plymouth Rock Cockerels (81)		
In 1 week	15.42	2.129	13.81	11.58	2.506	21.64
In 2 weeks	26.17	1.771	6.77	18.50	4.481	24.22
In 3 weeks	31.17	2.054	6.59	23.25	4.625	19.89
In 4 weeks	40.00	3.582	8.95	30.50	6.760	22.16
In 5 weeks	44.25	4.171	9.43	35.42	10.34	29.20
In 6 weeks	49.17	4.561	9.28	38.92	10.53	27.05
	Pen I. 6 Barred Plymouth Rock Cockerels (82)			Pen II. 6 Barred Plymouth Rock Cockerels (82)		
In 1 week	9.67	3.544	36.65	11.58	4.649	40.15
In 2 weeks	14.75	6.300	42.71	17.25	6.156	35.69
In 3 weeks	21.33	5.080	23.82	23.25	7.052	30.33
In 4 weeks	28.25	8.240	29.17	28.75	10.09	35.09
In 5 weeks	36.08	9.684	26.84	30.42	10.98	36.09
In 6 weeks	41.58	9.400	22.61	35.08	11.54	32.89
	Pen I. 8 Barred Plymouth Rock Cockerels (83)			Pen II. 8 Barred Plymouth Rock Cockerels (83)		
In 1 week	4.87	2.976	61.11	6.37	2.690	42.23
In 2 weeks	10.12	3.060	30.24	12.87	2.848	22.13
In 3 weeks	19.87	3.756	18.90	21.12	2.571	12.17
In 4 weeks	27.75	4.493	16.19	30.37	3.239	10.67
In 5 weeks	34.12	5.160	15.12	36.00	2.646	7.35

of live stock. Vitality, constitutional vigor, and ability to digest and assimilate food are not meted out alike to all, and tho there is no apparent cause, lack of thrift is not uncommonly to be observed in some members of a hatch." This belief, which is strikingly confirmed by the statistical study we have made of some of Shutt's experiments, is undoubtedly at the basis of the general practice of the chemistry and poultry divisions of the Central Experimental Farm, of presenting individual data in all feeding experiments on fowls and in all experiments to determine the effect of different methods of poultry management on egg production. It is to be regretted that this practice is so unusual among investigators of the problems of poultry management, since it has so much in its favor in rendering the results of experiments more intelligible and less ambiguous.

(*b*) *Selection of Animals as Regards Age, Breed and Type, Sex, and Previous Treatment*

In securing the greatest possible uniformity of gains within the lot in feeding experiments, obviously the first care should be in the selection of the animals.

Age.—That animals at different ages exhibit different fattening qualities, needs no demonstration, and the necessity of including only animals of approximately the same age in an experimental lot is pretty generally recognized.

Breed and Type.—That different breeds of the same species of animals behave differently on the same rations is undisputed in some cases, while in all cases it is a possibility, if not a probability, in the absence of definite evidence to the contrary. These differences are to be expected more especially when the breeds differ in general type. Thus, in the case of steers, the dairy and beef types, in the case of swine, the lard and bacon types, and in the case of sheep, the mutton and wool types, may be supposed to differ most markedly in fattening qualities.

In the case of sheep, the extensive breed tests conducted at the Iowa Station by Wilson and Curtiss[a] and the extensive experiments of J. B. Lawes at Rothamsted (27, 28, 29) leave no doubt that breed differences as regards rate of growth do exist.

In the case of steers, the evidence for the existence of breed difference is apparently not so convincing, or at least not so generally recognized. Thus, W. A. Henry says: "So far as the data go, we have no evidence that beef-bred animals make more rapid growth than do others."[b] H. P. Armsby is inclined to the same

[a]Iowa Agr. Exp. Sta., Buls. 33 and 35.

[b]Feeds and Feeding, 11th ed., 1911, p. 329.

opinion.[a] While we have not made an extensive study of the literature, some experiments that we have reviewed indicate in no uncertain fashion that different breeds, especially when of different types, may exhibit different fattening qualities under the same conditions. An extensive experiment by H. W. Mumford of this station[b] presents indisputable evidence to this effect. The object of the investigation was a comparison of the six standard grades of feeding steers as regards their fattening qualities. Each lot consisted of 16 steers of the same grade. A very complete description of the lots is given in the original bulletin. However, we shall give only a brief resumé, more especially of the characteristics of the lots as regards their breeding.

Of Lot 1, containing the fancy selected feeders, Mumford says: "They contained nearly 100 percent of the blood of the improved beef breeds. The dams were high-grade Shorthorn cows and the sire a registered Hereford." Lot 2, containing choice feeders, were high-grade Shorthorns. In Lot 3, containing the good feeders, beef blood still predominated. Concerning Lot 4, the medium feeders, the author says: "It should be said that this lot did not contain a steer that failed to show evidence of improved beef blood, altho the predominating blood seemed to be native or unimproved, with occasionally a dash of the blood of some one of the dairy breeds." Lot 5, the common feeders, "showed but a very small percentage of beef blood. Native and unimproved blood predominated." Lot 6, the inferior feeders, "showed no evidences of beef blood and every evidence of being scrubs."

During a feeding period of 179 days, these lots exhibited the following average daily gains in weight: Lot 1, 2.570 lbs.; Lot 2, 2.543 lbs.; Lot 3, 2.341 lbs.; Lot 4, 2.128 lbs.; Lot 5, 2.207 lbs.; and Lot 6, 1.950 lbs. While complete individual data are not given, thus precluding a complete analysis of the significance of average lot differences, there can be no reasonable doubt, from a study of these averages, that the infusion of beef blood tended strongly to accelerate the rate of gain of the better grade steers.

While the data of the above experiment indicate that breeds of different general types may differ in fattening qualities, some data presented by Curtiss before the Ames Graduate School during the summer session of 1910,[c] indicate that decided, tho slight, differences in rapidity of gains exist even among breeds of the general beef type.

[a] U. S. Dept. Agr., Bur. An. Ind., Bul. 108, pp. 29 and 44. 1908.

[b] Ill. Agr. Exp. Sta., Bul. 90.

[c] See E. Harrison and J. A. S. Watson: "Correlations between Conformation and the Production of Beef in Beef Cattle, etc." Thesis for the M.S. degree, Iowa State College, 1911.

In the case of swine, the evidence is unmistakable that at least some breeds can be differentiated from each other as regards fattening qualities. Here again breed differences are the more marked when accompanied by differences in general type. Apparently these differences are not at all constant, but vary with the rations fed or with the conditions of feeding; that is, in some experiments one breed may show a marked superiority over another, while in another experiment, in which other rations are used or other conditions obtain, the relation found in the first case may be reversed. As an illustration of this point, we shall first cite an experiment by W. A. Henry of the Wisconsin Station on two lots of 12 pigs each.[a] The total gains made by the individual pigs at the end of 12 weeks on a ration of corn and wheat middlings, and the breed and sex to which each pig belonged, are summarized in Table 3.

TABLE 3.—TOTAL GAINS IN WEIGHT OF TWO LOTS OF PIGS, WITH BREED AND SEX OF INDIVIDUALS

No. of pig	Lot I			Lot II		
	Breed	Sex	Gain	Breed	Sex	Gain
1	Grade Berkshire	barrow	92	Grade Berkshire	barrow	133
2	Grade Berkshire	sow	77	Grade Berkshire	sow	95
3	Poland-China	barrow	29	Poland-China	sow	55
4	Grade Berkshire	sow	103	Grade Berkshire	barrow	98
5	Berkshire	barrow	60	Poland-China	barrow	64
6	Grade Berkshire	barrow	80	Grade Berkshire	sow	113
7	Yorkshire	sow	80	Poland-China	barrow	30
8	Berk. razorback	sow	71	Pol.-Chin. raz'b.	sow	98
9	Pol.-Chin. raz'b.	barrow	84	Berk. razorback	sow	75
10	Berkshire	sow	87	Yorkshire	sow	81
11	Poland-China	sow	71	Berk. razorback	barrow	109
12	Poland-China	barrow	59.	Berkshire	sow	87

It will be noticed, especially in the case of Lot II, that the Poland-China pigs did very poorly. As Henry says: "The Poland-China hogs proved unsatisfactory feeders, showing losses at the weighing period on several occasions. Towards the last they became lame and their conditions may be characterized as 'broken down.' As they had received the same treatment at all times as the others, we cannot offer any explanation excepting that they were weaker animals generally."

An Iowa experiment on the feeding of corn and supplementary feeds to pigs (65) affords data concerning the differential fattening qualities of different breeds of pigs. Each lot consisted of 9 or 10 pigs and of representatives of 4 or 5 breeds. The gains of the

[a]18th Annual Report of the Wisconsin Station. 1901.

pigs of the various breeds as regards their position above or below the mean gain of their respective lots are given in Table 4.

The data in this table are of interest, not so much by reason of what they prove as regards the relative fattening qualities of different breeds of swine, but by reason of what they suggest. In

TABLE 4.—DATA CONCERNING THE GAINS IN WEIGHT OF TEN LOTS OF PIGS AND THEIR RELATION TO THE BREED OF THE PIGS

No. of lot	Average gain for lot	Lot ration	Pigs giving gains *above* the respective lot average	Pigs giving gains *below* the respective lot average
I	103.4	Corn meal, timothy pasture	3 York-Durocs 1 Poland-China 2 Berkshires 1 Yorkshire	1 Poland-China 2 Berkshires
II	125.5	Corn meal 2 pts., shorts 1 pt., timothy pasture	2 York-Durocs 1 Poland-China 2 Berkshires 1 Yorkshire	1 York-Duroc 2 Poland-Chinas 1 Berkshire
III	133.2	Corn meal 1 pt., shorts 1 pt., timothy pasture	1 York-Duroc 1 Berkshire 3 Poland-Chinas 1 Yorkshire	2 York-Durocs 2 Berkshires
IV	140.9	Corn meal 5 pts., meat meal 1 pt., timothy pasture	3 York-Durocs 2 Poland-Chinas 1 Yorkshire	3 Berkshires
V	153.9	Corn meal 5 pts., tankage 1 pt., timothy pasture	2 York-Durocs 2 Poland-Chinas 1 Yorkshire	1 York-Duroc 1 Poland-China 3 Berkshires
VI	133.7	Corn meal, clover pasture	3 York-Durocs 1 Poland-China 2 Berkshires 1 Yorkshire	1 York-Duroc 1 Poland-China 1 Berkshire
VII	90.9	Corn meal 2 pts., shorts 1 pt., in dry lot	1 York-Duroc 1 Poland-China 2 Berkshires	2 York-Durocs 1 Poland-China 2 Berkshires 1 Yorkshire
VIII	100.2	Corn meal 1 pt., shorts 1 pt., in dry lot	1 Poland-China 1 Berkshire 3 York-Durocs	1 Poland-China 3 Berkshires 1 Yorkshire
IX	121.8	Corn meal 5 pts., meat meal 1 pt., in dry lot	2 York-Durocs 2 Poland-Chinas	1 York-Duroc 3 Berkshires 1 Yorkshire 1 Tamworth
X	102.5	Corn meal 5 pts., tankage 1 pt., in dry lot	3 York-Durocs 3 Poland-Chinas 1 Tamworth	3 Berkshires 1 Yorkshire

some cases the suggestion is accompanied by a considerable probability, tho with such few and heterogeneous data that whatever interpretation is attempted must be couched in very moderate language.

It will be noticed that each lot contained a Yorkshire pig. In the first six lots, the Yorkshire pigs exhibit gains above, and generally considerably above, their respective lot averages. In the last four lots, however, the Yorkshire pigs exhibit gains far below their respective lot averages. It will be noticed that the first six lots were turned out on pasture, while the last four lots were confined in dry lots. The evidence is very suggestive, therefore, that the advantage of pasture over dry lot is much more marked in the case of Yorkshire pigs, as representatives of the bacon type perhaps, than in the case of the other breeds experimented upon.

It will also be noticed that the Berkshire pigs exhibit gains both above and below the average in Lots I, II, III, VI, VII, and VIII. In Lots IV, V, IX, and X, however, the Berkshires consistently show gains below the average, and, as the original data indicate, far below the average; in short, the Berkshire gains in Lots IV, IX, and X are the lowest gains in the lots, and in Lot V, the three Berkshires exhibit the two lowest and the fourth lowest gains in the lot. These four lots are the lots in which the corn meal was supplemented by meat meal and tankage, two of the lots being turned out on pasture and two being confined in dry lots. The behavior of the Berkshire pigs seems to be specific and to distinguish these representatives of the Berkshire breed sharply from the representatives of the other breeds.

An extensive breed test on swine, extending over three years, was conducted at the Iowa station by Curtiss and Craig.[a] The rations in the three experiments differed to a greater or less extent. A summary of the results obtained after the pigs were weaned is given in Table 5.

TABLE 5.—BREED TEST AT THE IOWA EXPERIMENT STATION

First experiment: 92 days		Second experiment: 153 days		Third experiment: 165 days	
Breed	Av. daily gain	Breed	Av. daily gain	Breed	Av. daily gain
10 Duroc-Jerseys	.90	9 Yorkshires	1.16	5 Yorkshires	1.16
6 Yorkshires	.80	9 Duroc-Jerseys	1.10	10 Berkshires	1.04
7 Tamworths	.77	10 Berkshires	1.03	8 Tamworths	1.03
10 Chester-Whites	.74	10 Chester-Whites	1.01	10 Poland-Chinas	.97
7 Crossbreds	.73	10 Tamworths	1.00	10 Duroc-Jerseys	.95
5 Poland-Chinas	.72	8 Poland-Chinas	1.00	9 Chester-Whites	.93
10 Berkshires	.68				

[a]Iowa Agr. Exp. Sta., Bul. 48. 1900.

The rank of the different breeds as regards average daily gain is quite different in the three experiments, possibly because of the different rations used. The experiments agree, however, in several particulars, *e. g.*, in attributing to the Yorkshire breed a general superiority, and to the Chester-White and Poland-China breeds a general inferiority. It may be shown that with a variability in the Duroc-Jersey and Berkshire lots as high as 33 percent, the odds are 30 to 1 that the former breed possesses greater fattening powers than the latter under the particular conditions that obtained in the first experiment.

For other experimental data on breed tests with swine, the reader is referred to Bulletin 47 of the U. S. Dept. of Agr., Bureau of Animal Industry, by Rommel.

As further evidence on the question under discussion, we wish to cite a few experiments in which each lot consists of a separate litter. Some statistical data on these experiments are given in Table 6.

TABLE 6.—VARIABILITY OF GAINS FOR LOTS OF PIGS, EACH LOT CONSISTING OF A SINGLE LITTER

Reference	No. of pigs in litter	Length of experment in days	Statistical data of total gains in weight		
			Mean	Standard deviation	Coefficient of variation
Wis. 7th Ann. Rpt.[a]	7	119	64.33	7.09	11.02
	8	119	86.74	13.73	15.83
	7	119	70.91	9.43	13.30
	7	119	65.06	6.69	10.29
Mich. Bul. 138[a]....	8	119	104.60	9.77	9.34
	9	119	83.55	4.11	4.92
Wis. Bul. 104[b].....	10	56	53.3	6.25	11.73
	10	56	24.0	4.58	19.08
	5	56	37.6	3.44	9.15
	6	56	45.3	7.25	16.00
	8	56	50.5	8.56	16.95
	9	56	33.0	6.32	19.15
	7	56	51.3	5.00	9.75
	6	56	38.0	2.77	7.30
	8	56	46.0	6.76	14.70
	5	56	49.2	7.11	14.45
	5	56	31.4	6.25	19.90
	5	56	57.6	6.67	11.58
Total	130				
Average					13.00

[a]Pigs observed from birth.

[b]Pigs observed from weaning time.

The coefficients of variation of the gains made by these 18 litters are in general comparatively low. In only 3 litters is the coefficient of variation greater than the average coefficient for pigs as indicated by the American feeding experiments reviewed, *i. e.*, 17.12. It is interesting to note, in view of what has been said above as regards the relation between the size of gains and their variability, that the three litters exhibiting the three highest coefficients of variation of the 18 coefficients exhibit also the three lowest average lot gains obtained in the Wisconsin experiment. The average coefficient of variation for the 18 litters is more than 4 percent lower than the general average for American swine experiments, indicating with a high degree of probability the advantageous effect of the rigorous selection of experimental animals as regards breed, type, age, and ancestry.

As regards the relative fattening qualities of the different breeds of poultry, we shall simply refer the reader to an extensive investigation of this question conducted at the Central Experimental Farm and reported by Frank T. Shutt.[a] Nine different breeds were under investigation, and while some were quite similar in fattening qualities, some were either markedly superior or markedly inferior to others.

It is difficult to reconcile such unequivocal evidence as appears to exist as regards the differential fattening qualities of different breeds of animals with the cautious statements often made by authorities on the fattening of farm animals. We believe the explanation lies in the method ordinarily used in collecting data for the solution of the question. The ordinary method of solving the question of whether breed is a factor in determining the rate of growth is open to considerable objection. The indiscriminate averaging together of a large number of experiments cannot be expected to bring out any differential effect of breed. It may, in fact, actually obscure all such effects, since it is highly probable (in some cases actually demonstrated) that the effect of breed on growth and fattening is a function of the ration fed as well as of other experimental conditions. The Kansas Station has shown, for instance, that scrub or native steers do much better than Shorthorn steers when turned out on poor pasture, because of their better foraging ability, which is a distinctive characteristic of the unimproved cattle of Kansas; whereas, in the fattening pen, the Shorthorn steers possess a more or less distinct advantage.[b] Similarly, the typical bacon hog ordinarily has the advantage over the lard hog when turned out on pasture, while when fed in dry lot his more restless temperament and his ability to get around better put him at a disadvantage. An interesting illustration of this fact is the behavior of the Yorkshire pigs in the Iowa experiment discussed above (page 500). Therefore, the averaging of the results

[a]Canadian Experimental Farms, Report for 1902, pp. 219-222.

[b]Kan. Agr. Exp. Sta., Bul. 51. 1895.

of experiments in which the conditions are not strictly comparable tends to obscure any effect of breed, some experiments compensating for the advantage or disadvantage given to certain breeds by other experiments. The best method of attacking the problem, therefore, is the detailed study of individual experiments.

It may be concluded on first thought that while different breeds may react differently to any given ration, the disadvantage accruing from this fact may be counteracted by balancing lots carefully, *i.e.,* by including the same number of each breed in each lot. Furthermore, it seems to be the opinion of some that by including different breeds in the same lot the experiment acquires a more general significance and the conclusions of the experiment have a more general application. As a matter of fact, as we shall show, this greater generality does not at all result from a loose selection of animals. Such selection simply renders the results of the experiment more ambiguous.

In demonstrating this fact, we shall first consider an experiment by Henry of the Wisconsin Station on 2 lots of 12 pigs each, the data of which are given in Table 3. The pigs of Lot II gained, on an average per head, over 22 lbs. more than the pigs of Lot I. It may be supposed, on first thought, that the conclusion that corn meal, which was fed to Lot II, is better for fattening swine than whole corn, which was fed to Lot I, applies to all the breeds of pigs experimented upon, *i. e.,* grade Berkshires, Poland-Chinas, Berkshires, Berkshire razorbacks, Poland-China razorbacks, and Yorkshires. An analysis of the individual data reveals a very different state of affairs. The four grade Berkshires of Lot I gained, on an average, 86.5 lbs., and the four grade Berkshires of Lot II, 109.8 lbs.; the three Poland-Chinas of Lot I gained 53.0 lbs., on an average, while those of Lot II gained only 49.7 lbs.; the two Berkshires of Lot I gained 60 and 87 lbs. respectively, while the one Berkshire of Lot II gained 87 lbs.; the one Berkshire razorback of Lot I gained 71 lbs., and the two pigs of the same breeding in Lot II gained 75 and 109 lbs., respectively; the Yorkshire pig in Lot I gained 80 lbs., and the Yorkshire in Lot II, 81 lbs.; the Poland-China razorback of Lot I gained 84 lbs., and that of Lot II, 98 lbs.

In summing up such evidence as this, *no certain conclusion applying to any one breed of animals can be deduced.* A fairly high degree of probability has been established that for grade Berkshires corn meal is better than whole corn, tho one grade Berkshire in Lot I, fed whole corn, gained more than two in Lot II, fed corn meal. For Poland-China pigs, however, the opposite conclusion is more applicable. The Berkshire pig in Lot II exhibited a gain identical with that of one of the Berkshires in Lot I. The Yorkshire in Lot II gained only 1 lb. more than the Yorkshire in

Lot I. The Berkshire razorback of Lot I gained only 4 lbs. less than one of the Berkshire razorbacks of Lot II, while the difference between the gains of the two Poland-China razorbacks was much less than half the difference between the gains exhibited by the two Berkshire razorbacks of Lot II fed on the same ration. Evidently the generality of the conclusion deduced from such heterogeneous experimental results has not been extended in the slightest by including such different breeds in the same lot. Only a confusing ambiguity has resulted, so that one is not by any means certain that the conclusion applies to any of the breeds.

Many instances of the marked disadvantages of including several breeds in the same lot may be seen in the Iowa experiment of Kennedy and Robbins, the data of which are given in Table 4. Thus, consider Lots IX and X, the average gains for which were 121.8 lbs. and 102.5 lbs., respectively. The three Yorkshire-Durocs of Lot IX gained 116.7, 122.0, and 155.0 lbs., respectively, and the three pigs of the same breed in Lot X gained 129.3, 108.3, and 123.0 lbs. It would be difficult indeed to differentiate these two lots of Yorkshire-Duroc pigs. The two Poland-Chinas of Lot IX gained 152.7 and 125.7 lbs., while the two Poland-Chinas of Lot X gained 165.0 and 140.0 lbs. Here also differentiation is impossible. The Berkshires of Lot IX made gains of 113.7, 101.7, and 101.0 lbs., and the Berkshires of Lot X made gains of 35.0, 26.7, and 61.7 lbs. Apparently with this breed there is a sharp differentiation between lots. The Yorkshire pig of Lot IX gained 107.7 lbs., and the Yorkshire of Lot X, 64.3 lbs. The Tamworth of Lot IX gained 121.7 lbs., and the Tamworth of Lot X, 171.7 lbs. On such detailed analysis of Lots IX and X as the above, the avoidable ambiguity due to differential breed characteristics is plainly revealed.

We are firmly of the opinion that *from every standpoint the inclusion of different breeds and types in the same lot of experimental animals is a bad practice, possessing no redeeming feature.*

Sex.—The evidence concerning the effect of sex on fattening qualities seems to indicate quite clearly that the castrated male gains faster than the female of the same species and breed.

In the case of sheep, the evidence for this statement is very convincing. Carmichael[a] found in 3 lots of sheep, each containing 22 wethers and 22 ewes, that the wethers, on an average, made 10 percent greater gains than the ewes. Thus, the average daily gains at the end of 117 days were 0.218 and 0.233 lb. for the ewes and wethers, respectively, of Lot I; 0.210 and 0.231 lb. for the ewes and wethers of Lot II; and 0.212 and 0.239 lb. for the ewes and wethers of Lot IV. Curtiss and Wilson[b] found the average daily

[a]Ohio Agr. Exp. Sta., Bul. 187. 1907.
[b]Iowa Agr. Exp. Sta., Bul. 35. 1897.

gains for a lot of 9 Shropshire wethers during a feeding period of 106 days to be as follows: 0.43 lb. from September 16 to 30, 0.44 lb. for October, 0.30 lb. for November, and 0.28 lb. for December. A lot of 10 Shropshire ewes on the same ration made the following average daily gains for the same periods: 0.48, 0.32, 0.25, and 0.26 lb., respectively. The lambs in each lot were fed to their full capacity of the grain mixture used, and of roots and hay. The ewe lambs, however, were the lighter eaters. They took on fat rapidly and were more nearly finished during the latter part of the experiment than the other lots, which consisted of wether lambs. According to the authors, "This distinction between the sexes has been observed in all of the experiments made at this station, including both cattle and sheep." J. B. Lawes, in an experiment covering a period of 140 days (29), found an average gain of 44.50 lbs. for a lot of 40 crossbred wether lambs, and an average gain of 42.50 lbs. for a lot of 40 crossbred ewe lambs, the breeding being the same. The ration was oil meal, chaffed clover hay, and roots, and was fed to the two lots in the same quantities per 100 lbs. live weight. The fact that the difference between the gains of ewe and of wether lambs in this experiment is small is probably due to the method of apportioning the ration.

W. L. Carlyle, experimenting with two lots of lambs before and after weaning (8), reports the individual gains. In Lot I, the average gain of the 10 ewes during the 10 weeks before weaning was 33.50 lbs., and that of the 7 wethers during the same period, 39.12 lbs. During the 10 weeks after weaning, the average gain of the ewes was 23.40 lbs., and that of the wethers, 26.86 lbs. In Lot II, before weaning, the average gain of the 13 ewes was 35.70 lbs., and that of the 4 wethers, 40.00 lbs. After weaning, the average gain of the ewes was 22.77 lbs., and that of the wethers, 16.00 lbs. W. C. Coffey (3) experimented on three lots of lambs of different ages, there being 10 lambs to the lot. The lambs were under observation for 98 days. In Lot I, the 5 ewes gained an average of 25.1 lbs., and the 5 wethers, an average of 31.5 lbs. In Lot II, the 6 ewes gained an average of 25.1 lbs., and the 4 wethers, an average of 38.4 lbs. In Lot III, the 5 ewes gained an average of 29.5 lbs., and the 5 wethers, an average of 33.7 lbs.

As regards pigs, the evidence on the whole favors the view that barrows gain faster than sows under the same conditions. Table 7 contains data pertinent to the question at issue.

Carlyle's experiments present contradictory evidence. His lots contained various breeds of pigs. A possible explanation, therefore, is that there were more sows than barrows of the breeds that gained the faster. His experiment, however, is not reported in sufficient detail to test the correctness of this view. Nevertheless, the table supports the view that barrows are in general better gainers than sows.

TABLE 7.—THE RELATIVE FATTENING QUALITIES OF BARROWS AND SOWS
(All weights expressed in pounds)

Reference No.	Length of experim'nt in days	No. of lot	Barrows		Sows	
			No.	Average total gain	No.	Average total gain
Henry's Experiments						
59	84	I	10	117.6	9	106.7
59	84	II	10	112.3	9	112.1
66	98	I	10	118.1	4	97.5
66	98	II	7	147.6	7	129.3
67	70	I	4	140.2	5	134.8
68	70	I	6	78.0	4	80.0
68	70	II	5	113.0	5	102.2
70	84	I	7	100.5	5	100.2
70	84	II	9	112.7	3	94.7
71	84	I	4	115.0	1	89.0[a]
72	91	I	4	133.0	2	104.5
72	91	II	4	158.2	2	138.0
Carlyle's Experiments						
58	63	I	11	52.6	8	58.0
58	63	II	12	43.0	7	60.8
60	56	I	11	70.4	10	71.8
60	56	II	11	69.0	10	67.6
Experiment of Kennedy and Robbins						
65	112	I	5	99.0	5	107.8
65	112	II	5	135.8	5	115.0
65	112	III	5	137.8	5	128.6
65	112	IV	4	155.2	5	129.4
65	112	V	5	161.6	5	146.2
65	112	VI	6	133.5	4	133.5
65	112	VII	5	110.6	5	71.4
65	112	VIII	5	102.6	5	97.6
65	112	IX	5	135.6	5	108.4
65	112	X	6	103.5	4	101.0

[a]This was the lowest gain in the lot.

That cockerels are much more easily fattened than pullets is a matter of common knowledge with poultrymen. The experiments of Shutt (78, 84) afford good evidence of the correctness of this statement.

In view of such evidence as the above, indicating differential fattening qualities of the sexes, *it is obviously bad practice to include the two in the same experimental lot.*

Previous Treatment.—The differential effect of different previous treatments of farm animals as regards their fattening powers is well known. For instance, given two steers of the same age and breed, one of which has been wintered on a liberal ration and the other on a maintenance ration, the latter will in general take on fat more readily and economically than the former in a subsequent feeding period. Therefore, if animals are selected for experimental purposes from different herds and different localities, a preliminary feeding period of considerable length, during which all animals are fed alike, is a wise precautionary measure to insure the requisite homogeneity within lots.

Conclusion.—There is no advantage or necessity of introducing such avoidable factors of heterogeneity as age, breed and type, sex, and previous treatment into experimental lots. Nothing is gained by so doing and much is sacrificed. The sources of variation, or heterogeneity, whose elimination is a veritable problem, are not these gross factors, but the factors of individuality and uncontrolled experimental conditions. The influence of these factors, under the best of conditions, is considerable, and to superimpose other variable but avoidable factors of variation upon these is inexcusable.

(*c*) *Changes in Variability of Gains During the Course of a Feeding Experiment*

By a judicious selection of animals as regards age, breed and type, sex, and previous treatment, thus removing obvious heterogeneity from within the lot, the uniformity of individual experimental results will be enhanced in a perfectly legitimate manner. The question then presents itself whether any changes occur in the variability of gains during the course of a feeding experiment and upon what these changes depend. We have found, from a rather extensive analysis of the results of feeding experiments in which the animals were weighed periodically while under observation, that in some experiments the percentage variability of the gains of animals within the lot decreased more or less regularly as the experiment progressed, while in other experiments no such tendency was evident. It is obviously advantageous to decrease wherever possible and practicable the coefficient of variation of gains in the several experimental lots, because the smaller these coefficients the smaller is the experimental error and the more surely can a given percentage difference between average lot gains be demonstrated as causally connected with differences in experimental conditions.[a]

Rothamsted Experiments with Sheep.—As illustrations of experiments in which the percentage variability of individual gains within the lot decreased as the experiment progressed, we shall first cite the experiments of J. B. Lawes of the Rothamsted Station, England (see Table 8). These experiments are peculiarly suitable for our purposes, in view of the large lots of animals used and the care with which the experimental conditions were controlled.

A well-marked decrease in the percentage variability of the gains in weight secured is evident in each of the above lots of sheep. The feed for all lots was of the same description, namely, oilcake and chaffed clover hay as dry foods, given in fixed quantities, and

[a]See formula on page 572 of the Appendix. Also pages 493-496.

TABLE 8.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF SIX LOTS OF SHEEP, AND TOTAL FEED CONSUMPTION PER CAPITA PER DAY FOR SUCCEEDING FOUR-WEEK PERIODS

(All weights expressed in pounds)

Total gain	Statistical data of total gains in weight			Average consumption of feed per capita per day for succeeding 4-week periods		
	Mean	Standard deviation	Coefficient of variation	Oil cake	Clover hay	Swedes
Lot of 40 Sussex Wethers (27)						
In 4 weeks...	10.07	3.364	33.40	.777	.777	9.86
In 8 weeks...	16.82	4.549	27.04	.777	.777	9.62
In 12 weeks...	22.12	5.026	22.72	.777	.777	9.99
In 16 weeks...	30.32	5.556	18.32	.777	.777	10.86
In 20 weeks...	35.15	6.910	19.66	.777	.777	11.00
In 24 weeks...	46.30	6.334	13.68	1.143	1.000	14.13
In 26 weeks...	52.72	7.183	13.62	1.143[a]	1.000[a]	13.64[a]
Lot of 40 Hampshire Wethers (27)						
In 4 weeks...	10.72	3.981	37.14	1.000	1.000	12.50
In 8 weeks...	20.35	4.902	24.09	1.000	1.000	12.22
In 12 weeks...	29.90	6.674	22.32	1.000	1.000	13.82
In 16 weeks...	41.02	8.822	21.51	1.000	1.000	16.45
In 20 weeks...	52.59	10.980	20.88	1.000	1.000	16.32
In 24 weeks...	62.79	10.880	17.33	1.500	1.000	19.30
In 26 weeks...	70.12	10.810	15.41	1.500[a]	1.000[a]	16.04[a]
Lot of 46 Cotswold Wethers (28)						
In 4 weeks...	14.46	3.338	23.09	1.000	1.000	14.33
In 8 weeks...	27.15	5.853	21.56	1.000	1.000	13.66
In 12 weeks...	40.57	7.131	17.58	1.000	1.000	17.62
In 16 weeks...	51.10	8.421	16.48	1.375	1.000	16.69
In 20 weeks[b]...	63.89	9.990	15.64	1.393	.929	18.58
Lot of 40 Leicester Wethers (29)						
In 4 weeks...	7.50	3.017	40.23	.799	.799	10.02
In 8 weeks...	11.00	6.012	54.65	.799	.799	9.23
In 12 weeks...	23.42	6.822	29.13	.799	.799	11.51
In 16 weeks...	34.67	8.329	24.02	.799	.799	14.29
In 20 weeks...	44.57	9.526	21.37	1.000	.799	14.80
Lot of 40 Crossbred Wethers (Sussex-Down Ewe, Leicester Ram) (29)						
In 4 weeks...	8.75	2.653	30.32	.799	.799	9.79
In 8 weeks...	15.65	3.575	22.84	.799	.799	9.08
In 12 weeks...	25.22	4.379	17.36	.799	.799	11.24
In 16 weeks...	37.20	5.573	14.98	.799	.799	14.23
In 20 weeks...	44.50	6.052	13.60	1.000	.799	14.87
Lot of 40 Crossbred Ewes (Sussex-Down Ewe, Leicester Ram) (29)						
In 4 weeks...	7.47	2.976	39.84	.750	.750	9.47
In 8 weeks...	13.22	3.443	26.04	.750	.750	8.61
In 12 weeks...	24.10	4.188	17.38	.750	.750	10.87
In 16 weeks...	34.10	4.460	13.08	.750	.750	13.09
In 20 weeks...	42.50	5.572	13.11	1.000	.799	13.69

[a]This is a 2-week instead of a 4-week period.

[b]Lacking 2 days.

swedes given *ad libitum*. The dry foods were allotted according to the average initial weights of the lots, the oilcake being increased by one-half toward the conclusion of the experiment. It will be noted from the table that excepting the second 4-week period, the quantities of swedes consumed increased in general for all lots.

Woburn Experiments with Sheep.—Another good illustration of the tendency for gains to become more uniform as the experiment progresses, is afforded by an experiment performed at the Woburn Experimental Farm, England, in 1892, a statistical resumé of which is given in Table 9.

Table 9.—Change in Variability of Total Gains in Weight of Three Lots of Sheep (23)

(All weights expressed in pounds)

Total gain	Statistical data of total gains in weight		
	Mean	Standard deviation	Coefficient of variation
Lot I. 24 Hampshire Tegs			
In 36 days	19.25	3.192	16.58
In 65 days	30.42	4.690	15.42
In 93 days	49.25	6.050	12.28
Lot II. 24 Hampshire Tegs			
In 36 days	18.00	3.894	21.63
In 65 days	26.42	6.204	23.48
In 93 days	41.96	7.727	18.42
Lot III. 24 Hampshire Tegs			
In 36 days	15.79	3.807	24.11
In 65 days	26.33	4.210	15.99
In 93 days	43.87	5.652	12.88

At the beginning of the experiment, each lot received ½ lb. of concentrates per head per day, Lot I receiving ½ lb. of linseed cake, Lot II, ¼ lb. of linseed cake and ¼ lb. of barley, and Lot III, ¼ lb. of linseed cake, 1/6 lb. of barley, and 1/12 lb. of malt. At the beginning of the second period, the concentrate ration was increased to ¾ lb., and at the beginning of the third period, to 1 lb. Swedes and clover-hay chaff were given *ad libitum* to all lots. A distinct tendency for the gains to become more uniform is evident.

A third illustration of this tendency from another experiment performed at the Woburn Station by J. A. Voelcker, is given in Table 10. The sheep used were Hampshire-Downs with a slight cross of Oxford. The experiment started November 30. All lots received at the beginning ½ lb. of linseed cake per head daily; this was increased on February 6 to ¾ lb. All lots received swedes or mangels *ad libitum*, Lot I received oat-straw chaff, and

TABLE 10.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF FOUR LOTS OF SHEEP (21)

(All weights expressed in pounds)

Total gains	Statistical data of total gains in weight					
	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
	Lot I. 15 Sheep			Lot III. 15 Sheep		
In 50 days....	21.67	6.294	29.05	24.13	4.631	19.19
In 98 days....	40.73	5.650	13.87	42.47	5.690	13.40
	Lot II. 15 Sheep			Lot IV. 15 Sheep		
In 50 days....	21.27	5.893	27.71	25.27	3.549	14.04
In 98 days....	41.67	7.578	18.19	44.80	7.608	16.98

Lot II, meadow-hay chaff, *ad libitum*. Lot III received oat-straw and meadow-hay chaff *ad libitum* in equal parts, well mixed. Lot IV received mixed grain, about ⅓ lb. per head per day thruout the experiment. In the words of Voelcker, "There is very little doubt that the sheep would have taken a considerably larger amount of dried grains had they been allowed it, but this could not have been economical." Lot I ate the most roots, Lot II, the next, and Lot IV, the least. The latter lot was the only one that did not exhibit increasing uniformity of gains as the experiment progressed. The following statement in the report of this experiment is of interest: "The losses and inequalities generally found in feeding a number of sheep during a winter were, mainly owing to the very open character of the weather, very small."

Iowa Experiment with Pigs.—A lot of 24 pigs in an experiment at the Iowa Station carried out by L. G. Michael and W. J. Kennedy (61) exhibited gains which became more and more uniform as the experiment progressed, as the data in Table 11 testify.

TABLE 11.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF A LOT OF TWENTY-FOUR PIGS (61)

(All weights expressed in pounds)

Total gain	Statistical data of total gains in weight			Corn consumed per head per day for successive periods
	Mean	Standard deviation	Coefficient of variation	
In 10 days..........	3.46	3.93	113.60	3.85
In 20 days..........	15.87	3.54	22.31	4.84
In 30 days..........	22.58	4.15	18.39	4.85
In 40 days..........	35.33	3.71	10.50	5.27
In 48 days (23 pigs)	43.57	4.00	9.18	5.22
In 55 days (23 pigs)	49.70	4.40	8.85	5.29

The pigs in this experiment all received the same amount of feed thruout the experiment, being fed individually. The ration was corn alone and corn supplemented by various stock foods; hence the low gains. Since the stock foods apparently had no differential effect and did not produce gains significantly different from corn alone, all of the data are treated together instead of in four lots. The corn ration was increased from time to time as the experiment progressed.

Michigan Experiment with Pigs.—C. D. Smith reports a feeding experiment on 2 lots of pigs under observation from birth.[a] On an increasing ration, the variability of gains decreased during 17 weeks of the experiment. The statistical data of this investigation are given in Table 5 of the Appendix.[b]

Illinois Experiment with Steers.—In Bulletin 103 of the Illinois Station, H. W. Mumford reports the results of an experiment on 10 lots of high-grade Shorthorn steers, the lots consisting of 10 or 15 steers each. The statistical data for the first 16 weeks and the total 22 weeks are given in Table 12. In this table it will be noticed that the average daily gain per steer, instead of the average total gain per steer, is considered. It may be easily shown that

TABLE 12.—CHANGE IN VARIABILITY OF AVERAGE DAILY GAINS IN WEIGHT OF TEN LOTS OF SHORTHORN STEERS (43)

(All weights expressed in pounds)

Average daily gain per steer	Statistical data of daily gains in weight					
	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
	Lot I. 10 Steers			Lot IV. 15 Steers		
In 16 weeks...	2.481	.512	20.64	2.321	.473	20.38
In 22 weeks...	2.486	.354	14.24	2.412	.385	15.96
	Lot II. 15 Steers			Lot VII. 15 Steers		
In 16 weeks...	2.535	.636	25.09	2.353	.524	22.27
In 22 weeks...	2.499	.503	20.13	2.534	.242	9.55
	Lot III. 15 Steers			Lot VIII. 10 Steers		
In 16 weeks...	2.072	.497	23.99	1.972	.350	17.75
In 22 weeks...	2.181	.415	19.03	2.106	.290	13.77
	Lot IV. 15 Steers			Lot IX. 10 Steers		
In 16 weeks...	2.353	.437	18.58	2.026	.652	32.18
In 22 weeks...	2.473	.489	19.77	2.025	.431	21.28
	Lot V. 15 Steers			Lot X. 10 Steers		
In 16 weeks...	2.266	.375	16.55	1.920	.640	33.33
In 22 weeks...	2.470	.388	15.71	1.995	.539	27.02

[a]Mich. Agr. Exp. Sta., Bul. 138. 1896.

[b]See page 573.

the coefficient of variation of gains reduced to the daily basis is the same as the coefficient of variation of the original total gains.

In each lot, with the exception of Lot IV, the gains for the 22-week period were more uniform than the gains for the 16-week period. The quantities of feed consumed by the lots were changed as the experiment progressed, the concentrates in general being increased and the roughages decreased.

Canadian Experiment with Steers.—At the Nappan, Nova Scotia, Station, R. Robertson ran an experiment on 3 lots of 8 Shorthorn steers for 135 days. The statistical data for periods of 15 days are given in Table 13.

In each of the above three lots of steers, it is evident that there was a pronounced tendency for the gains to become more uniform as the experiment progressed. It is of interest to note that the high coefficients for all lots for the first 15-day period are probably connected with the fact that in this experiment, contrary to ordinary practice, a preliminary feeding period was not included. All lots were fed alike, as far as possible, for the entire experiment. The concentrates in the ration (mixed meals) were regularly increased from start to finish, while the hay (or straw) and succulent feeds (roots and ensilage) were decreased.

Summary of the Evidence.—The experimental data presented in Tables 8 to 13 inclusive are sufficient to show that in some cases, at least, feeding experiments may be so conducted that the percentage variation of gains within the lot will decrease as the period of observation increases. As to whether this decrease would continue indefinitely or would stop with some minimum coefficient, the data cited can offer no conclusive verdict. It is evident, however, that the increase in the uniformity of lot gains is ordinarily the most rapid in the early periods of the experiment, while in the closing periods of the experiment in most cases the change in the coefficient of variation is gradual. In fact, in some of the cases cited, the coefficient was practically constant for the last two or three periods. From such facts we are inclined to believe, therefore, that the coefficient of variation of lot gains cannot be reduced beyond a certain minimum characteristic of the experimental conditions and of the sample of animals under observation.

(*d*) *Effect of Change of Ration on Variability of Gains*

Illinois Experiment with Sheep.—Many of the feeding experiments whose results we have submitted to a statistical analysis either have failed utterly to exhibit any progressive change in the coefficient of variation of gains within lots, or have exhibited only slight reductions, generally in the fore part of the experiment. We shall consider, first, in this connection, some unpublished data on

TABLE 13.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF THREE LOTS OF SHORTHORN STEERS (48)

(All weights expressed in pounds)

Total gain	Statistical data of total gains in weight								
	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
	Lot I. 8 Shorthorn Steers			Lot II. 8 Shorthorn Steers			Lot III. 8 Shorthorn Steers		
In 15 days	33.7	13.63	40.39	43.1	23.31	54.06	33.1	14.99	45.26
In 30 days	73.7	17.99	24.39	83.2	16.94	20.35	70.0	14.79	21.13
In 45 days	134.4	19.75	14.69	113.1	27.03	23.90	99.3	11.30	11.37
In 60 days	168.7	24.72	14.65	158.1	32.78	20.73	143.7	30.47	21.20
In 75 days	215.0	24.37	11.34	188.1	29.25	15.55	175.6	27.32	15.56
In 90 days	256.2	24.15	9.43	214.4	27.93	13.03	205.6	24.68	12.00
In 105 days	282.5	25.74	9.11	248.7	34.25	13.77	227.5	25.12	11.04
In 120 days	308.1	26.21	8.51	268.1	38.72	14.44	255.6	28.27	11.06
In 135 days	330.6	29.26	8.85	285.6	32.25	11.29	278.1	24.61	8.85

lamb feeding collected by this station. Three lots of 7 lambs each were under observation for 24 weeks. A statistical resumé of the experiment, as far as the gains in weight and the feed consumed are concerned, is given in Table 14.

TABLE 14.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF THREE LOTS OF LAMBS, AND TOTAL FEED CONSUMPTION PER LOT PER PERIOD[a]

(Gains in weight expressed in pounds: feed consumed expressed in kilograms)

Total gain	Statistical data of total gains in weight			Total consumption of feed per lot per 4-week period		
	Mean	Standard deviation	Coefficient of variation	Alfalfa hay	Corn meal	Oil meal
Lot I. 7 Lambs						
In 4 weeks....	10.93	2.162	19.78	156.4	82.5	5.41
In 8 weeks....	20.00	2.000	10.00	155.5	96.0	5.06
In 12 weeks....	29.86	1.619	5.42	144.6	108.7	5.72
In 16 weeks....	38.50	1.615	4.19	125.2	118.8	6.25
In 20 weeks....	45.53	3.963	8.70	119.2	120.4	6.33
In 24 weeks....	54.00	3.093	5.73	117.6	117.2	6.16
Lot II. 7 Lambs						
In 4 weeks....	13.64	3.248	23.81	166.7	66.2	23.5
In 8 weeks....	22.79	3.853	16.91	173.8	79.1	26.6
In 12 weeks....	33.86	4.307	12.72	159.7	88.8	29.8
In 16 weeks....	42.29	6.702	15.85	138.3	97.8	32.5
In 20 weeks....	49.39	8.371	16.95	119.3	102.8	34.3
In 24 weeks....	60.50	9.464	15.64	124.1	103.0	34.3
Lot III. 7 Lambs						
In 4 weeks....	12.79	1.870	14.62	177.3	48.4	48.4
In 8 weeks....	23.29	2.801	12.03	182.6	56.2	56.2
In 12 weeks....	32.07	2.692	8.39	163.8	62.3	62.3
In 16 weeks....	42.93	2.744	6.39	150.9	68.4	68.4
In 20 weeks....	50.40	4.045	8.03	139.1	73.0	73.0
In 24 weeks....	61.36	3.758	6.12	137.0	72.6	72.6

[a]Unpublished data from the Ill. Agr. Exp. Sta. H. S. Grindley, W. C. Coffey, and A. D. Emmett, with the co-operation of W. E. Carroll and Sleeter Bull.

It will be noticed that in all three lots a decrease in the coefficient of variation occurred for the first three or four periods only. An examination of the quantities of feed consumed per period is, we believe, suggestive of an explanation. We have tabulated this information in the last three columns of the table, the weights of feeds being given in kilograms.

It will be seen that the alfalfa hay consumed in general decreased for all lots from the first to the last period, the most notable exceptions being slight increases for Lots II and III from the first to the second 4-week periods. The corn meal and oil meal in general were increased rather steadily from the first to the fourth period.

From the fourth to the fifth period only a slight increase in the consumption of these feeds occurred in Lots I and II, tho in Lot III there was a more marked increase. During the fifth and sixth periods the consumption of all feeds was practically constant.

Comparing these changes in feed consumption with the corresponding changes in the percentage variability of gains in weight, one is inclined to the opinion that an increasing feed consumption is in general accompanied by an increasing uniformity of gains within the lot as measured by the coefficient of variation, while a constant or decreasing feed consumption is in general accompanied by a constant or decreasing uniformity of gains. This conclusion is not incompatible with the experiments above cited, tho in the latter, at times, a constant feed consumption was accompanied by an increasing uniformity of gains. Also, the conclusion reached above, that within any experiment the lots making the best gains generally exhibit the most uniform gains, falls in line with this conception, which may be restated in the proposition that conditions favorable to good gains are also favorable to uniform gains. It is probable that other factors than change in ration enter into the question. Possibly the relation of the feed consumption to the bodily requirements is also concerned in the changes in variability of the gains in weight, a liberal feed consumption, possibly, being conducive to an increasing uniformity of gains. Other factors, such as changes in the weather conditions, very probably exert an effect (see page 523).

Wisconsin Experiments with Swine.—We wish to consider next two experiments conducted at the Wisconsin Station by W. L. Carlyle in 1897 and 1898. The object was to compare rape and clover pasture for fattening swine. Corn meal and shorts or middlings were given as supplementary feeds. The average total gains, standard deviations, and coefficients of variation, as well as the total consumption of supplementary feeds per lot per period, are given in Table 15.

In the experiment of 1897, the consumption of corn meal and shorts varied only within narrow limits for 8 weeks and was the same for the two lots. However, in the case of Lot I the coefficient of variation decreases almost continuously from period to period, while in the case of Lot II no consistent change is evident. In looking for an explanation of this difference between the two lots, the description given of the rape and clover pastures is suggestive: "The rape was quite immature when the experiment began and as a consequence it steadily improved in quality, while the clover was better when the experiment began than it was later." Apparently, for Lot I the pasturage was more palatable and was more voraciously eaten as the experiment progressed, while for Lot II, the

TABLE 15.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF FOUR LOTS OF PIGS, AND TOTAL FEED CONSUMPTION PER LOT PER PERIOD (58, 60)

(All weights expressed in pounds.)

Total gain	Statistical data of total gains in weight			Feed consumption per period	
	Mean	Standard deviation	Coefficient of variation	Corn meal	Shorts or middlings
Lot I. 19 Pigs on Rape Pasture (1897)					
In 2 weeks..............	12.26	3.242	26.44	590	295
In 4 weeks..............	22.21	3.915	17.63	560	280
In 6 weeks..............	35.26	6.640	18.83	627	313
In 8 weeks..............	47.11	7.933	16.84	630	315
In 9 weeks..............	54.89	8.509	15.50	315	157
Lot II. 19 Pigs on Clover Pasture (1897)					
In 2 weeks..............	10.11	3.837	37.95	590	295
In 4 weeks..............	19.95	7.937	39.78	560	280
In 6 weeks..............	38.05	10.831	28.46	627	313
In 8 weeks..............	45.47	14.711	32.35	630	315
In 9 weeks..............	49.53	13.885	28.03	315	157
Lot I. 21 Pigs on Rape Pasture (1898)					
In 2 weeks..............	20.43	3.320	16.25	650	325
In 4 weeks..............	37.62	4.402	11.70	770	385
In 6 weeks..............	54.47	6.751	12.39	910	455
In 8 weeks..............	71.05	9.400	13.23	980	490
Lot II. 21 Pigs on Clover Pasture (1898)					
In 2 weeks..............	16.52	2.570	15.56	650	325
In 4 weeks..............	33.43	5.114	15.30	770	385
In 6 weeks..............	50.48	6.814	13.50	910	455
In 8 weeks..............	68.33	8.800	12.88	980	490

reverse was true; for this reason, probably, there was an increasing uniformity of gains in Lot I but not in Lot II.

The experiment of 1898 affords an interesting confirmation of this view. Here both lots received the same quantities of corn meal and middlings, the consumption of these concentrates increasing as the experiment progressed. In this case, however, the clover-pasture lot (II) exhibited a regularly increasing uniformity of gains, while the rape-pasture lot, except for an initial increase from the first to the second period, exhibited a decreasing uniformity of gains. Again referring to the description of the pasturage, we find that "When the pigs were first put on the rape it was in prime condition for them, whereas later it became more ripe and woody and they did not relish nor eat it as they did at first. The clover, on the contrary, was somewhat parched and dry when the experiment began, but grew very succulent and tender as the fall rains came on."

Henry's Experiments at Wisconsin with Pigs.—We shall cite next several experiments performed at the Wisconsin Station by W. A. Henry and associates. The experiments are representative of a series extending over ten years, the purpose of which was to determine the value of whole corn as compared with corn meal as the main portion of the ration for fattening pigs. The statistical data of the first experiment which we shall consider are given in Table 16.

TABLE 16.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF TWO LOTS OF PIGS, AND TOTAL FEED CONSUMPTION PER LOT PER WEEK (59)

(All weights expressed in pounds)

Total gain	Statistical data of total gains in weight			Feed consumption per week	
	Mean	Standard deviation	Coefficient of variation	Corn	Wheat middlings
Lot I. 19 Pigs (Whole Corn)					
In 1 week	8.37	2.65	31.66	490	245
In 2 weeks	20.05	2.72	13.57	560	280
In 3 weeks	30.26	5.24	17.32	630	315
In 4 weeks	35.74	5.31	14.87	560	280
In 5 weeks	45.89	6.77	14.75	560	280
In 6 weeks	58.16	8.74	15.03	616	308
In 7 weeks	69.63	11.88	17.06	616	308
In 8 weeks	77.11	11.28	14.62	616	308
In 9 weeks	87.05	12.26	14.09	616	308
In 10 weeks	96.26	14.82	15.40	616	308
In 11 weeks	102.40	14.38	14.05	616	308
In 12 weeks	112.40	16.02	14.25	588	294
Lot II. 19 Pigs (Corn Meal)					
In 1 week	8.37	2.75	32.90	490	245
In 2 weeks	19.26	4.41	22.90	560	280
In 3 weeks	28.95	4.15	14.33	630	315
In 4 weeks	35.16	5.70	16.23	560	280
In 5 weeks	44.53	7.01	15.73	560	280
In 6 weeks	56.47	8.14	14.41	616	308
In 7 weeks	67.37	8.87	13.17	616	308
In 8 weeks	76.42	10.63	13.91	616	308
In 9 weeks	89.21	10.18	11.41	644	322
In 10 weeks	97.16	11.61	11.95	644	322
In 11 weeks	101.30	13.99	13.81	644	322
In 12 weeks	112.20	14.82	13.21	616	308

In Lot I, from the 6th week to the 12th the ration was practically constant and consequently the coefficient of variation of the total gains in weight produced shows no tendency to consistently decrease as the period of observation increases. In fact, from the 2d to the 12th week the coefficients vary within relatively narrow limits.

The coefficients of variation of gains in weight for Lot II conform more closely to the changes in the quantity of feed consumed. The continuous increase in the latter during the first 3 weeks is associated with a continuous decrease in the coefficient of variation.

The decrease in feeds during the 4th week produced an increase in the coefficient. No change in feed during the 5th week accompanied a slight decrease in the coefficient. A large increase in feed intake at the beginning of the 6th week produced a reduction in the coefficient. A constant intake for the next two weeks was accompanied by a further decrease in the coefficient, followed by an increase. An increase in feed intake at the beginning of the 9th week occasioned a marked decrease in the coefficient. The constant feed intake of the next two weeks apparently effected first a gradual increase and then a marked increase in the coefficient of variation. The decrease in feed intake at the beginning of the 12th week was accompanied by a slight decrease in the coefficient of variation, this effect being anomalous.

The second experiment of this series, which we have subjected to a statistical study, gave the data contained in Table 17.

TABLE 17.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF TWO LOTS OF PIGS, AND TOTAL FEED CONSUMPTION PER LOT PER WEEK[a]

(All weights expressed in pounds)

Total gain	Statistical data of total gains in weight			Total feed consumption per week	
	Mean	Standard deviation	Coefficient of variation	Corn	Middlings
Lot I. 12 Pigs (Whole Corn)					
In 1 week	14.92	5.19	34.79	285	142
In 2 weeks	19.67	4.50	22.86	320	160
In 3 weeks	28.58	4.27	14.94	326	163
In 4 weeks	34.33	5.44	15.84	340	170
In 5 weeks	46.67	6.86	14.70	325	163
In 6 weeks	49.58	9.85	19.87	308	154
In 7 weeks	53.00	8.20	15.47	290	145
In 8 weeks	57.58	9.06	15.73	288	144
In 9 weeks	62.83	11.97	19.05	284	142
In 10 weeks	66.08	15.42	23.34	252	126
In 11 weeks	69.33	16.25	23.44	260	130
In 12 weeks	74.42	18.20	24.45	226	113
Lot II. 12 Pigs (Corn Meal)					
In 1 week	14.00	2.45	17.50	293	146
In 2 weeks	18.50	3.55	19.17	340	170
In 3 weeks	29.12	4.40	15.12	350	175
In 4 weeks	39.83	6.22	15.61	360	178
In 5 weeks	50.58	8.67	17.15	361	181
In 6 weeks	58.42	10.50	17.97	356	178
In 7 weeks	61.00	10.93	17.90	317	159
In 8 weeks	66.00	13.63	20.65	312	156
In 9 weeks	71.17	14.27	20.05	302	151
In 10 weeks	76.75	18.18	23.69	302	151
In 11 weeks	80.67	22.21	27.53	308	154
In 12 weeks	86.50	26.71	30.88	230	115

[a]Wis. Agr. Exp. Sta., 18th Annual Report. 1901.

After an initial increase for the first 4 or 5 weeks, the ration decreased fairly regularly to the end of the experiment. In both lots, the increase in ration was accompanied by a decrease in percentage variability of gains in weight, while the decrease in ration from the 4th or 5th week occasioned an increase in variability that, in Lot II at least, became more and more pronounced as the experiment progressed, so that in Lot I the variability of the gains for the entire experiment was larger than the variability of the gains for the first 2 weeks, while in Lot II the unique condition of much more variable gains at the end than at the beginning of the experiment, resulted.

Four more of the experiments of Henry and associates have been subjected to an analysis similar to the above. The statistical data for these are included in Tables 6 to 9, inclusive, of the Appendix.[a] In some of the lots in these investigations the correlation between change in ration and change in the percentage variability of gains is very evident.

Of these experiments, only Experiment 32 calls for special comment. In this experiment, altho the ration increased more or less regularly from the beginning to the end, the coefficient of variation of the gains in weight of both lots decreased to a minimum and then abruptly increased and remained at the higher level for the rest of the experiment. It is obvious that this is hardly to be expected from the experiments thus far reviewed and from the conclusions we have thus far developed of the effect of change of ration upon change of variability of gains. The calculations contained in Table 18 afford a more or less satisfactory explanation of these exceptional changes in the coefficient of variation.

For the purpose of measuring most effectively the changes instituted in the rations, the quantities of the different feeds consumed per week have been converted into Scandinavian feed units. One feed unit, according to this system, is equal to 1 lb. of standard grain, such as corn, or its equivalent in feeding value. According to this system, in the case of pigs, 1 lb. of corn is equivalent to 1.2 lbs. of shorts or middlings, and to 6.0 lbs. of skim milk. On reference to Table 9[b] of the Appendix it will be seen that in Lot II the coefficient of variation decreases for 5 weeks and then abruptly increases during the 6th week. In Lot I, the decrease continues for 4 weeks, but an increase occurs during the 5th as well as the 6th week. Referring now to Table 18, it will be seen that the number of feed units per 100 lbs. live weight remains at a comparatively high level in both lots for the first 5 weeks, and then

[a]See pages 574 to 577.

[b]See page 577.

TABLE 18.—RELATION OF FEED TO BODY WEIGHT IN EXPERIMENT 32

	Lot I			Lot II		
	Total feed units per lot	Total weight of lot,[a] lbs.	Feed units per 100 lbs. live weight	Total feed units per lot	Total weight of lot,[a] lbs.	Feed units per 100 lbs. live weight
1st week	257	815	31.5	263	822	32.2
2d week	265	891	29.7	273	883	30.9
3d week	314	977	32.1	330	964	34.2
4th week	318	1072	29.7	323	1069	30.2
5th week	359	1172	30.6	373	1177	31.7
6th week	326	1308	24.9	370	1318	28.1
7th week	339	1369	24.8	394	1396	28.2
8th week	369	1494	24.7	416	1528	27.2
9th week	397	1552	25.6	448	1623	27.6
10th week	437	1672	26.1	470	1743	27.0
11th week	455	1798	25.3	500	1862	26.9
12th week	474	1903	24.9	525	2011	26.1

[a]That is, the total weight of the lot at the beginning of the week.

assumes a lower level rather suddenly during the 6th week. Furthermore, in Lot I this lower level is maintained till the end of the experiment, while in Lot II further decreases occur. Turning again to Table 9 of the Appendix, it will be seen that in Lot I, from the 6th week to the end of the experiment, the coefficient of variation maintains practically the same level, while in Lot II, a notable increase occurs at the beginning of the 8th week, coincident with a decrease of one unit in the number of feed units per 100 lbs. live weight, establishing a higher percentage variability for the rest of the experiment.

Whether this correlation is really significant or is simply a more or less remarkable coincidence, we are not prepared to say definitely. It is at least highly suggestive. If significant, it would indicate that the effect of change of ration on change of variability of gains is modified by the relation between ration and body weight or ration and nutritive requirements.

Wisconsin Experiment with Lambs.—An experiment performed at the Wisconsin Station by W. L. Carlyle is of considerable interest in this connection. Two lots of lambs, 17 in a lot, were fed for 10 weeks before and 10 weeks after weaning. The lambs in Lot I were fed coarsely ground corn, while those in Lot II received coarsely ground peas. Before weaning, the lambs in both lots had all the grain they would eat. After weaning, they were limited to about ½ lb. per capita per day. The statistical data concerning the total gains in weight every two weeks thruout the experiment, and the total quantities of grain consumed per lot per period of two weeks, are given in Table 19.

TABLE 19.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF TWO LOTS OF LAMBS, AND TOTAL GRAIN CONSUMPTION PER LOT PER PERIOD

(All weights expressed in pounds)

Total gain	Statistical data of the total gains in weight			Corn meal or pea meal eaten per 2 weeks	Statistical data of the total gains in weight			Corn meal or pea meal eaten per 2 weeks
	Mean	Standard deviation	Coefficient of variation		Mean	Standard deviation	Coefficient of variation	
	Lot I. 17 Lambs: Before Weaning				Lot II. 17 Lambs: Before Weaning			
In 2 weeks	8.41	1.717	20.42	34	7.29	2.163	29.67	69
In 4 weeks	16.06	1.798	11.19	79	16.18	3.110	19.22	98
In 6 weeks	23.88	2.470	10.34	101	25.35	4.324	17.06	106
In 8 weeks	31.24	3.334	10.67	136	31.12	5.098	16.38	158
In 10 weeks	35.82	4.076	11.38	187	36.71	5.686	15.49	124
	Lot I. 17 Lambs: After Weaning				Lot II. 17 Lambs: After Weaning			
In 12 weeks	39.71	5.432	13.68	189	39.12	6.048	15.46	189
In 14 weeks	44.71	6.124	13.70	173	43.71	7.069	16.17	173
In 16 weeks	51.24	7.075	13.81	170	49.29	8.093	16.42	170
In 18 weeks	57.18	8.298	14.51	179	55.12	7.828	14.20	168
In 20 weeks	60.65	8.331	13.74	179	57.88	7.600	13.13	168

Before weaning, the variability of gains decreased continuously in Lot II, while in Lot I, after an initial marked decrease, it remained practically constant. The explanation of this difference in behavior is not obvious from the data at hand. Possibly the marked increase in the consumption of corn by Lot I from the first to the second period reduced the variability of the gains to its characteristic minimum, which subsequent feeding could not reduce; or possibly the explanation of the difference is to be found in the different quantities of milk obtained from the dams in the two lots.

At the time of weaning, however, the change in variability of the two lots is perfectly intelligible according to the theory under investigation, *i.e.,* that an increasing feed consumption (within certain limits at least) tends to produce more uniform gains, while a constant or decreasing feed consumption tends to produce less uniform gains. By reference to the table, it is evident that in the case of Lot I at weaning the grain ration was unaltered. The withdrawal of milk from the ration therefore occasioned an increase in the coefficient of variation. In the case of Lot II, the withdrawal of milk was accompanied by a compensating increase in the consumption of grain, and the coefficient of variation remained practically unaltered.

Pennsylvania Experiments with Steers.—We shall next consider two experiments on steers performed at the Pennsylvania Station by Mairs and Risser, a statistical resumé of which is given in Table 20.

In the first of these two experiments, the mixed meal in the ration was increased for the first 6 or 8 weeks, the clover hay varied only within narrow limits, while the corn stover was decreased. The variability of the gains in each of the two lots decreased for the first two or three periods, and then remained practically constant. In the second experiment, the mixed meal was increased continuously from the first of the experiment to the sixth or seventh period, after which a slight decrease occurred. The corn stover in Lot I was consumed in rather constant quantities, until the last period, when a decrease occurred. In Lot II, a more or less regular decrease occurred from start to finish. The quantity of clover hay consumed in both lots was fairly constant. It will be seen that the rations of this experiment, especially that of Lot I, increased in general as the experiment progressed. Consequently, the variability of gains in both lots decreased progressively from start to finish, the decrease being more noticeable in Lot I.

Woburn Experiments with Sheep.—The last experiment that we shall consider is one performed by Voelcker at the Woburn Experimental Farm in 1895-6 on sheep. The data are given in Table 21.

The ration in general was increased at times as the experiment progressed. In no lot, however, is there a very decided tendency

TABLE 20.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF TWO LOTS OF STEERS, AND TOTAL FEED CONSUMPTION PER LOT PER PERIOD

(All weights expressed in pounds)

Total gain	Statistical data of total gains			Total feed consumption by 2-week periods		
	Mean	Standard deviation	Coefficient of variation	Clover hay	Corn stover	Mixed meal
Lot I. 12 Steers (35)						
In 2 weeks...	16.6	6.30	38.02	984	748	1825
In 4 weeks...	51.4	9.67	18.81	1147	812	2467
In 6 weeks...	98.4	14.90	15.14	971	678	2769
In 8 weeks...	113.3	17.71	15.63	1098	767	2909
In 10 weeks...	148.4	25.01	16.85	1016	589	2950
In 12 weeks...	166.8	23.48	14.08	1025	648	3023
In 14 weeks...	201.5	32.20	15.98	1023	617	3199
In 16 weeks...	230.4	41.90	18.19	1050	563	2980
In 18 weeks...	269.3	43.48	16.15	1050	533	2930
Lot II. 12 Steers (35)						
In 2 weeks...	9.1	15.13	166.60	1020	848	1921
In 4 weeks...	49.7	11.20	22.51	1134	953	2464
In 6 weeks...	81.0	15.75	19.44	964	786	2941
In 8 weeks...	111.7	21.05	18.84	1079	847	3122
In 10 weeks...	134.8	21.78	16.16	1058	672	2968
In 12 weeks...	160.7	29.03	18.07	1029	651	3088
In 14 weeks...	188.6	31.00	16.44	1019	619	3134
In 16 weeks...	210.0	33.97	16.18	1041	447	2912
In 18 weeks...	247.7	38.18	15.41	993	528	2802
Lot I. 12 Steers (36)						
In 18 days...	13.2	10.43	78.72			
In 32 days...	55.1	17.67	32.08	1084	821	2367
In 46 days...	84.6	23.33	27.58	1042	840	2872
In 60 days...	115.9	24.34	21.00	1134	827	3038
In 74 days...	149.2	30.25	20.27	988	798	3118
In 88 days...	184.4	38.06	20.64	1030	850	3298
In 102 days...	208.9	37.17	17.79	1130	804	3339
In 116 days...	228.7	40.62	17.76	1105	605	3231
Lot II. 12 Steers (36)						
In 18 days...	34.1	19.17	56.25			
In 32 days...	73.0	21.08	28.88	1043	895	2485
In 46 days...	95.4	30.39	31.85	1091	811	2882
In 60 days...	128.2	33.36	26.02	1079	759	3061
In 74 days...	156.4	34.80	22.25	958	659	3093
In 88 days...	180.4	41.18	22.83	1028	795	3232
In 102 days...	203.4	44.14	21.70	1137	390	3224
In 116 days...	226.9	41.92	18.48	1053	491	3141

for the gains to become more uniform after the first 63 days; in one lot (III) the coefficient of variation at the end of 63 days is practically the same as that at the end of 87 days, while in one lot (I) it is less. The explanation of this state of affairs we believe is to be found in the weather conditions at the time of the experiment, which are described by Voelcker as follows:

"The winter of 1895-6 will long be remembered as one of an altogether exceptional character, if 'winter' indeed it could be called. Though there was an almost entire absence of frost, yet from the commencement until the middle

TABLE 21.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF FOUR LOTS OF SHEEP (22)

(All weights expressed in pounds)

Total gains	Statistical data of total gains in weight					
	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
	Lot I. 15 Sheep			Lot III. 14 Sheep		
In 34 days....	15.27	6.248	40.92	15.07	8.311	55.15
In 63 days....	25.87	7.957	30.76	24.36	8.217	33.73
In 87 days....	31.53	10.020	31.78	27.36	9.216	33.68
	Lot II. 15 Sheep			Lot IV. 13 Sheep		
In 34 days....	15.07	4.074	27.03	18.46	7.812	42.32
In 63 days....	25.20	6.524	25.89	28.31	9.738	34.40
In 87 days....	29.07	6.424	22.10	30.07	8.922	29.67

of January cold winds were very prevalent, together with a continual dampness and general 'mugginess' of atmosphere, this weather proving very trying for sheep, and in the neighborhood of the Woburn farm flockmasters lost several of their sheep. * * * Nor did our experiments fare any better, for in all we lost six sheep."

That the weather conditions were unfavorable to fattening is suggested by the average daily gains per sheep for the three periods of the experiment. The first period was 34 days in length, the second, 29, and the third, 24. For Lot I, these three averages are, respectively, 0.449, 0.366, and 0.236 lb.; Lot II, 0.443, 0.349, and 0.161 lb.; and Lot III, 0.543, 0.340, and 0.074 lb.

Conclusions.—In the above presentation of experimental data concerning the change in variability of gains in weight within the lot as the period of observation increases, no attempt to select experiments favorable to any particular theory, or to discard any experiments except those whose data were too incomplete for advantageous study, has been made. The data given in Tables 8 to 21 inclusive represent practically all the data of this nature that we have thus far collected. There is every reason for believing, therefore, that the conclusions to which they lead are unbiased and have a general application.

It is evident, however, that no single explanation can apply to the change in variability in all the experiments reviewed. The factors involved are evidently numerous, and in many cases even the chief factors cannot be detected, either because the experimental conditions were not described in sufficient detail, or because the lots were so small that the casual fluctuations in any statistical constant, such as a coefficient of variation, incident to all feeding trials, obscured progressive changes.

We believe, however, that a general statement may be made that will sum up in a satisfactory manner the chief indications of the several experiments just studied. *It seems probable that conditions* *favorable to growth or fattening in general are favorable to uniform rates of growth or fattening within a group of animals.*

As a first corollary to this rule: *Given two groups of animals under different conditions, that group growing or fattening at the more rapid rate will, in general, tend to exhibit the more uniform gains, uniformity being measured on the percentage scale.*

Considering next groups of animals under changing conditions, it follows that *if change in ration, weather, or other conditions is resulting continually in conditions more favorable to growth or fattening, the gains within the group will tend to become more and more uniform.* The full significance of this corollary is not at once evident. Consider the ration of experimental animals, for instance. The feed requirement of animals per individual increases during the course of a feeding experiment with increasing age and body weight. Therefore, a constant ration thruout an experiment results, not in equally favorable conditions for growth or fattening for successive periods, but in progressively less favorable conditions, tho the rate of this change may be gradual. Hence we have found in the above study that a constant ration is often accompanied by a decreasing uniformity of gains, tho the decrease may be slight and may be deferred. Often a constant ration is accompanied by no progressive change in the uniformity of gains, especially if the period during which the ration remains constant is short, the change from favorable to less favorable conditions being too slight to produce any noticeable effect upon the coefficient of variation. One would expect the latter state of affairs to occur with mature rather than with immature animals. Similarly, an increasing ration does not necessarily mean continually more favorable conditions, unless the increase keeps pace with the increasing requirements.

The above conclusions are merely tentative and may be modified by further investigation. In fact, the experimental data we have considered indicate certain minor exceptions. In the first place, it seems that no matter what the ration be or what changes in the ration be instituted, the gains at the very beginning of an experiment are generally extremely variable, and the extreme variability undergoes a considerable decrease in a very short time. This may be the result of a general change in ration made a short time before the experiment started and of a comparatively rapid adaptation of the animals to this change. Again, for any given group of animals and any given set of experimental conditions, there seems to be a minimum variability characteristic of the particular experimental conditions and the particular animals selected for experimental purposes, beyond which it is impossible to go no matter how increasingly favorable the feeding or other conditions may be made. Further, a general impression we have received from the above study is that the rate of decrease of the coefficient of variability under favorable fattening conditions becomes gradually less as this minimum is approached.

It appears that the effect of changes in experimental conditions on the variability of gains is more pronounced and more noticeable in the case of sheep than in the case of either steers or swine. This would indicate that sheep are more susceptible to such changes than other farm animals, a conclusion that probably embodies the consensus of opinion of investigators of the feed requirements and capacities of farm animals.

(e) *Physiological Selection of Animals For Feeding Experiments*

In considering other methods of conducting feeding experiments than those above discussed, the object of which is to secure more uniform behavior of the individual experimental animals, or, in other words, to reduce the *experimental error,* we shall investigate a plan the essence of which is the selection for experiment of only those animals that in the course of a preliminary feeding period have proved to be functionally similar. This plan is apparently in vogue at several stations in one modified form or another. The most forceful arguments in its favor are its simplicity and a feeling that is difficult to evade that it is necessarily very effective in reducing to a minimum the effect of individuality.

It is desired, for instance, to undertake an experiment with the purpose of comparing the fattening value of two rations. For practical reasons, we will say, it has been decided to use two lots of ten animals each. From the station herd, thirty animals, say, of uniform age, breed, sex, and general appearance are selected. These thirty animals are put on a uniform ration for a period of two to four weeks, or thereabouts. At the end of this preliminary period, the individual gains made by the animals are consulted, and those twenty animals are picked for the experiment whose gains cluster closest about the average gain for the lot. During this preliminary period, these twenty animals have behaved very similarly so far as the rate of fattening is concerned, and it is assumed that they will continue on similar behavior during the experiment proper. This procedure may be modified as follows: Instead of putting the original thirty animals on a uniform ration, they may be divided into two lots of fifteen each, and these two lots may be put on the two rations that are to be investigated. After several weeks the ten animals of each lot that have made the most representative gains are selected and the experiment is continued on these animals only. This latter procedure has the advantage over the former in that it need not be assumed that because animals gain at a similar rate on one ration, they will do so on another. We are assuming merely that they will continue to gain uniformly on the same ration.

By this selection of animals, which we will call a *physiological selection,* we are presumably excluding abnormal individuals from the experiment as well as securing a lot of animals in which individuality is reduced to within satisfactory limits.

Theoretical Considerations.—We feel that there are certain theoretical objections to such a physiological selection of experimental animals. Assuming that the selection is effective in lowering variability, it seems far from improbable that the arbitrary selection of animals made after the preliminary test[a] will detract from the value of the subsequent experiment to the practical farmer, since the animals actually experimented upon cannot be regarded as a random sample nor even as a sample that the farmer could approximately duplicate. The experimental animals have been drawn from a class that cannot be defined. Suppose in the preliminary test we decide to exclude from further experiment all animals that have not made an average daily gain of at least a certain magnitude, which we shall arbitrarily agree upon, and all animals that have made greater average daily gains than another arbitrary magnitude. Does this constitute a practicable definition of the class of animals from which we have selected the animals for our experiment? Can we say that the conclusions ultimately drawn from the experiment apply to animals of a certain species gaining between *a* and *b* pounds per day under such and such conditions? We hardly think so. If there is anything that the collection of individual data from time to time during a feeding trial shows, it is this,—that under the same experimental conditions the same animals will unaccountably change in weight in a very irregular manner, now losing in weight or showing very poor gains for days at a time and subsequently exhibiting phenomenal gains, so that animals cannot be classified even approximately by the gaining qualities exhibited during a brief preliminary test. The exclusion of "abnormal" individuals, *i.e.*, individuals in a pathological condition due to constitutional defects, disease, etc., from a feeding experiment is perfectly legitimate, but we doubt whether anyone is competent to pick out "abnormal" individuals after such a test on the basis of gains in weight. Certainly exceptional functional characteristics are no sure indices to abnormal functional characteristics, and the exclusion of individuals exhibiting rather exceptional

[a]The objection of course, is not directed at the preliminary period as such, but at the practice of utilizing this period for the physiological selection of animals. As has been shown above, the preliminary feeding period is a very necessary accessory to the experiment proper.

functioning for the purpose of securing an artificially homogeneous lot will result in an unfair test of the problem which it is desired to solve.

Does Physiological Selection Eliminate Poor Gainers?—The objections to such a physiological selection of animals for feeding experiments as that described above are not all theoretical. It may be attacked on the ground of its efficacy in accomplishing the purposes which it is supposed to serve. In testing such efficacy we know of no more suitable data than those collected by J. B. Lawes at the Rothamsted Station. The six lots of sheep that Lawes experimented with contained 40 to 46 animals each. The individual gains for every four weeks of the experiment were carefully determined and reported. Suppose we consider the first four weeks of each experiment as a preliminary test for the purpose of affording a basis for a physiological selection of the animals. On the basis of the gains obtained during this first four-week period, we shall divide each of the six lots of sheep into sub-lots, or groups, of 10 sheep each, the first group in each lot to include the 10 sheep making the ten best gains in the lot, the second group to include the 10 sheep making the ten next best gains, and so on for the third, fourth, and, in the case of the Cotswold sheep, the fifth groups. We now wish to know what gains these groups make during the remainder of the experiment.

It is evident from the results shown in Table 22 that any selection of animals made according to the preliminary gains is practically without effect on the gains obtained in a subsequent feeding period of 16 weeks. In every lot, the average preliminary gains of the different groups are quite distinctly separated from each other, the average gain of the last group constituting only 30 to 50 percent of the average gain of the first group. However, in every case, at the end of the subsequent feeding periods there is little to choose as regards average gain in weight between the different groups. In only two out of the six lots is the greatest average gain during the subsequent feeding period made by the first group, while in one lot, the crossbred ewes, the last group exhibits the highest average gain. In two lots, Group II makes the best average gain, and in one lot, Group III has this distinction.

Does Physiological Selection Reduce the Experimental Error?—Let us next consider the effectiveness of physiological selection in reducing individuality in a subsequent feeding period, as regards gains in weight. In a study of this phase of the question, we have adopted the following procedure. We still regard the first four weeks of Lawes' experiments as a preliminary period, the gains in weight during this period affording the basis for physiological selection. We find the average gain of each lot during

Table 22.—Effect of Physiological Selection on Average Gains
(All weights expressed in pounds)

Average weights and gains per group	Group I	Group II	Group III	Group IV	Group V
40 Hampshire Wethers (27)					
Initial weight	116.8	113.1	115.4	108.5	
Preliminary gain	16.0	11.6	9.3	5.7	
Gain in 4 weeks........	9.4	7.6	11.1	9.0	
Gain in 8 weeks........	20.0	16.4	21.1	17.0	
Gain in 12 weeks........	31.5	26.8	33.3	27.0	
Gain in 16 weeks........	43.2	36.8	46.0	38.0	
Gain in 20 weeks........	54.1	50.9	55.2	48.5	
Gain in 22 weeks........	60.2	59.5	63.5	54.8	
40 Sussex Wethers (27)					
Initial weight	92.3	86.9	86.3	86.5	
Preliminary gain	14.1	11.1	9.3	5.8	
Gain in 4 weeks........	7.5	6.5	7.0	6.0	
Gain in 8 weeks........	13.2	12.4	11.6	11.0	
Gain in 12 weeks........	21.5	20.8	19.0	19.7	
Gain in 16 weeks........	27.0	25.4	22.7	25.1	
Gain in 20 weeks........	37.6	37.7	34.2	36.7	
Gain in 22 weeks........	44.9	44.4	39.9	42.6	
40 Leicester Wethers (29)					
Initial weight	100.2	104.3	102.4	98.4	
Preliminary gain	10.9	8.5	7.1	3.5	
Gain in 4 weeks........	5.1	4.0	1.6	3.3	
Gain in 8 weeks........	16.5	17.7	14.5	15.0	
Gain in 12 weeks........	27.3	29.9	26.4	25.1	
Gain in 16 weeks........	36.6	41.0	36.4	34.2	
46 Cotswold Wethers (28)					
Initial weight	116.4	116.6	121.0	123.9	121.2
Preliminary gain	17.9	15.9	14.6	12.9	8.7
Gain in 4 weeks........	14.3	13.2	13.4	10.1	12.3
Gain in 8 weeks........	29.0	26.2	26.5	24.1	23.8
Gain in 12 weeks........	39.3	36.1	38.4	35.4	32.2
Gain in 16 weeks........	52.3	47.4	51.8	49.4	44.1
40 Crossbred Wethers (29)					
Initial weight	95.5	95.8	94.9	94.2	
Preliminary gain	12.1	9.5	8.2	5.2	
Gain in 4 weeks........	6.3	6.9	7.5	6.9	
Gain in 8 weeks........	15.9	16.9	16.8	16.3	
Gain in 12 weeks........	29.3	28.9	28.1	27.5	
Gain in 16 weeks........	35.9	36.1	35.6	35.4	
40 Crossbred Ewes (29)					
Initial weight	91.6	88.7	91.2	93.5	
Preliminary gain	10.9	8.7	6.9	3.4	
Gain in 4 weeks........	5.2	5.9	4.5	7.4	
Gain in 8 weeks........	16.2	16.6	14.5	19.2	
Gain in 12 weeks........	26.2	27.0	24.1	29.2	
Gain in 16 weeks........	35.3	34.8	33.0	36.9	

this preliminary period, and select from each lot only those animals whose preliminary gains lie approximately within 1 lb. of the average gain for the lot. Thus, the 40 Hampshire wethers gained on an average 10.72 lbs. during the preliminary period, and we have therefore selected those wethers in the lot gaining 10, 11, or 12 lbs. during this period. The 40 Sussex wethers gained 10.07 lbs. during the first period, and therefore in this group only wethers gaining 9, 10, or 11 lbs. in the first four weeks have been selected. A similar selection has been made in the other four lots. The variability of the total gains made in these selected lots was then determined for this preliminary period, the subsequent four weeks, eight weeks, etc. A comparison of these coefficients with the corresponding coefficients for the complete lots indicates the effect of our selection. The data for this study are contained in Table 23.

In the case of the Hampshire wethers, during the preliminary four weeks the entire lot made gains possessing a coefficient of variation of 37.14. Fourteen of the 40 wethers have been selected, the selected wethers including all that gained either 10, 11, or 12 lbs. during this preliminary period. The coefficient of variation for this selected lot for the preliminary period is 7.68, a very low value, resulting from the artificial selection. During the subsequent four weeks the gains of the selected wethers exhibit a coefficient of variation of 21.33, the corresponding coefficient for the entire lot being only 30.54. This difference between the coefficients of variation of the complete lot and the selected lot decreases as the experiment progresses until at the end of 22 weeks, the two are, to all intents and purposes, equal. In the case of this lot, a very rigorous physiological selection of animals has resulted in a sub-lot which, at the end of a subsequent 22-week feeding period, is practically nothing better than a random sample of the complete lot.

In the case of the 40 Sussex wethers, the 46 Cotswold wethers, and the 40 Leicester wethers, a similar physiological selection results at the end of the subsequent feeding period in a selected lot whose coefficient of variation is 4 to 5 percent lower than that of the corresponding complete lot. In the case of the 40 crossbred wethers, a precisely similar selection results in a lot which at the end of the subsequent feeding period, is not to be differentiated from the complete lot as regards variability of gains. In the case of the 40 crossbred ewes, the same method of physiological selection results in a more variable lot thruout the subsequent feeding period.

These results indicate that a rigorous physiological selection of animals—much more rigorous than would be practicable in the ordinary feeding experiment—sometimes fails utterly to secure greater uniformity of gains after a subsequent feeding period,

TABLE 23.—EFFECT OF PHYSIOLOGICAL SELECTION ON THE VARIABILITY OF GAINS
(All gains expressed in pounds)

	Data concerning gains of complete lot			Data concerning gains of selected lot		
	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
40 Hampshire Wethers (14 Selected)						
Preliminary gains...	10.72	3.981	37.14	11.21	.861	7.68
Gains in 4 weeks...	9.62	2.938	30.54	9.64	2.056	21.33
Gains in 8 weeks...	19.17	4.868	25.39	18.79	4.280	22.79
Gains in 12 weeks...	30.30	7.366	24.31	29.93	5.824	19.46
Gains in 16 weeks...	41.87	9.827	23.47	41.11	8.918	21.69
Gains in 20 weeks...	52.07	9.533	18.31	51.82	8.930	17.23
Gains in 22 weeks...	59.39	9.612	16.18	59.68	9.258	15.51
40 Sussex Wethers (14 Selected)						
Preliminary gains...	10.07	3.364	33.39	10.29	.587	5.70
Gains in 4 weeks...	6.75	2.557	37.86	7.29	2.118	29.05
Gains in 8 weeks...	12.05	3.074	25.51	12.36	2.408	19.48
Gains in 12 weeks...	20.25	3.910	19.31	20.71	3.452	16.67
Gains in 16 weeks...	25.07	4.534	18.09	24.80	3.668	14.80
Gains in 20 weeks...	36.22	5.125	14.15	37.63	3.882	10.32
Gains in 22 weeks...	42.65	5.700	13.36	44.02	3.634	8.26
46 Cotswold Wethers (18 Selected)						
Preliminary gains...	14.46	3.338	23.09	14.22	.712	5.01
Gains in 4 weeks...	12.70	4.101	32.30	11.89	4.713	39.64
Gains in 8 weeks...	26.11	5.346	20.48	25.28	5.031	19.90
Gains in 12 weeks...	36.64	6.967	19.01	36.99	6.591	17.82
Gains in 16 weeks...	49.42	8.731	17.67	50.82	6.933	13.64
40 Leicester Wethers (15 Selected)						
Preliminary gains...	7.50	3.017	40.23	7.40	.611	8.26
Gains in 4 weeks...	3.50	4.117		1.60	3.592	
Gains in 8 weeks...	15.92	5.392	33.87	15.60	4.348	27.87
Gains in 12 weeks...	27.17	7.035	25.89	27.80	6.134	22.06
Gains in 16 weeks...	37.07	8.229	22.20	37.98	6.847	18.03
40 Crossbred Wethers (18 Selected)						
Preliminary gains...	8.75	2.653	30.32	9.11	.657	7.21
Gains in 4 weeks...	6.90	2.567	37.20	7.50	1.572	20.96
Gains in 8 weeks...	16.47	3.529	21.43	17.11	3.089	18.05
Gains in 12 weeks...	28.45	4.477	15.73	28.67	4.819	16.81
Gains in 16 weeks...	35.75	5.422	15.16	35.93	5.370	14.95
40 Crossbred Ewes (15 Selected)						
Preliminary gains...	7.47	2.976	39.84	7.13	.806	11.30
Gains in 4 weeks...	5.75	2.817	49.00	4.80	2.663	55.48
Gains in 8 weeks...	16.62	3.953	23.78	15.27	3.785	24.80
Gains in 12 weeks...	26.62	4.316	16.21	25.27	4.139	16.38
Gains in 16 weeks...	35.03	5.170	14.76	33.67	5.965	17.72

sometimes has no marked effect on the subsequent variability, and sometimes does succeed in its purpose to a greater or less extent. From the data just analyzed one would infer that the chances are no better than even that physiological selection as rigorous as that employed will accomplish its purpose to any sensible degree.

Suppose, next, we test the effect of a slightly less rigorous physiological selection; for instance, a selection that would be much more suitable for experiment station purposes. We will take the lot of 40 Sussex wethers, because in this lot the method of selection already tested has yielded a lot more uniform as compared with the corresponding complete lot than any of the other lots. At the end of a subsequent 22-week feeding period, the coefficient of variation of total gains for the complete lot is found to be 13.36, and for the selected lot, 8.24, or over 5 percent less. In our second selection, instead of taking only those wethers that gained 9, 10, and 11 lbs. during the preliminary four weeks, *i.e.*, 14 wethers, we will take all wethers that gained 8, 9, 10, 11, or 12 lbs. during the same period. This gives a selected lot of 24 wethers out of the forty. The statistical data as regards this lot, the remaining 16 wethers, and the complete lot of 40 wethers are given in Table 24.

The results of this selection are remarkable. The coefficient of variation of the 24 selected wethers for the preliminary period is 13.02, and that for the 16 remaining wethers that were not selected, 51.95. For the next 4 weeks, the coefficient for the selected wethers is 38.14, and for the unselected, 36.20. For the 22 weeks the two coefficients are, in order, 14.80 and 11.27. The failure of this method of physiological selection in this case is obvious.

Conclusions.—The results given in Tables 22, 23, and 24 can bear but one interpretation. The gain exhibited by an animal during a given period of time affords little information as regards what gains it will make in subsequent periods, even tho the experimental conditions are as far as possible unchanged; hence the failure of moderate physiological selection and the uncertain effect and occasional failure of even the most rigorous physiological selection. Our conclusion is, therefore, that physiological selection is neither necessary nor desirable, and that even when conducted in the most rigorous manner its effect in reducing experimental error is problematical. It must be noted also that the preliminary period upon which selection has been based is a 4-week period, which is a longer period than would ordinarily be practicable, perhaps, in experiment station work. It is obvious, however, that with a shorter period, the result of physiological selection would be even more uncertain. We are inclined to believe that by far the more natural and satisfactory procedure is to make no physiological selection of animals whatever, to collect individual data wherever possible or practicable, and to cope with the natural variability that will be found to exist among the experimental results for individuals within the lots by the use of statistical methods. Any procedure for reducing such variability that will not deprive the ex-

TABLE 24.—EFFECT OF LESS RIGOROUS PHYSIOLOGICAL SELECTION ON THE VARIABILITY OF THE GAINS OF THE FORTY SUSSEX WETHERS

(All gains in weight expressed in pounds)

	Selected lot: 24 wethers			Unselected lot: 16 wethers			Complete lot: 40 wethers		
	Mean	Standard deviation	Coeffi-cient of variation	Mean	Standard deviation	Coeffi-cient of variation	Mean	Standard deviation	Coeffi-cient of variation
Preliminary gains	10.33	1.345	13.02	9.69	5.034	51.95	10.07	3.364	33.39
Gains in 4 weeks	7.04	2.685	38.14	6.31	2.284	36.20	6.75	2.557	37.86
Gains in 8 weeks	12.29	2.821	22.95	11.69	3.386	28.96	12.05	3.074	25.51
Gains in 12 weeks	20.37	3.795	18.63	20.06	4.069	20.28	20.25	3.910	19.31
Gains in 16 weeks	24.85	4.557	18.34	25.41	4.480	17.63	25.07	4.534	18.09
Gains in 20 weeks	36.77	5.402	14.69	35.41	4.404	12.44	36.22	5.125	14.15
Gains in 22 weeks	42.98	6.359	14.80	42.16	4.752	11.27	42.65	5.700	13.36

periment of its generality or its practical availability will be of value, of course, in rendering the feeding experiment more efficient as an instrument of research.

(*f*) *Summary of Methods of Reducing Experimental Error*

We have shown in this section of the bulletin that according to the evidence available for study, the necessary precision in the determination of the relative fattening powers of two rations or other systems of treatment of farm animals, or of the relative fattening qualities of two different lots of animals, not greatly dissimilar in character, is to be obtained in several ways. It is desirable, first, to select the experimental animals carefully. If we are to determine the relative fattening value of two rations, or two methods of shelter, or of confinement, or of such environmental factors as these, the animals in both lots should be of the same breed and type, sex, age, and, as far as possible, should have been under the same treatment for some time previous. Disregard of such requirements as these does not, as might at first be supposed, give to the conclusions of the experiment a more general applicability, but simply attaches to them an additional and entirely avoidable element of uncertainty, for the probability always exists that the different breeds, sexes, etc., react differently to the experimental conditions imposed. If we are testing the fattening qualities of two breeds of animals, or two lots at different ages, the animals within the lots should be homogeneous and the only difference between the lots should be that of breeding, or age, *i. e.*, the factor under investigation.

In the second place, the lots of animals employed should be fairly large. It seems unwise to use less than 10 or 15 animals to the lot, and wherever possible the lots should be of more generous proportions, for increasing the size of the lots is the most certain method of rendering the conclusions of the experiment more significant and less ambiguous. Large lots of animals, however, offer no excuse for a poor selection, because the objections attendant upon poor selection are not removed by increasing the number of animals experimented upon, except in so far as one may subdivide the lots into larger and larger groups of the requisite homogeneity.

In the third place, the experiment may be conducted in such a way that the experimental error, *i. e.*, the effect of individuality and unequal conditions within the lot, will continuously decrease and the experiment will become more and more efficient as an instrument for the solution of the problem at hand. We venture to say that this is perhaps one of the most important of the conclusions of this bulletin. It is universally conceded that the larger the size of the lots in a feeding experiment, the better. Some investigators, at least, fully appreciate the fact that the more homogeneous the lots as regards age, breed and type, sex, and previous treatment, the less ambiguous will be the experimental results obtained. It is also the general opinion that within certain limits peculiar to the animals under investigation, the longer the feeding period, the better for the solution of the problem at hand, but this opinion is founded upon the conviction that the animals must become thoroly adapted to the experimental conditions, and not upon any theorem concerning the experimental error. Our results afford a basis for the general proposition that conditions favorable for fattening are favorable for uniform gains. In conducting feeding experiments it appears that if experimental conditions, such as the prescribed rations, are constantly or increasingly favorable to good gains, the percentage variability of the gains and the experimental error will become less and less.

REPETITION OF FEEDING EXPERIMENTS

Aside from the above method of decreasing the experimental error in feeding trials, the necessary precision in the solution of problems of live-stock raising may be secured by the repetition of experiments that by themselves do not settle the point at issue. In an attempt to determine, by consulting experiment station literature, the efficacy of repetition of experiments in furnishing confirmatory evidence, a striking condition of affairs and one of vital importance, it would seem, to experiment station work, was discovered. After reviewing the large amount of material available for such a study, it was found that frequently when the same station, and in fact the same investigator, attempted to confirm the results of previous experiments that apparently pointed to very definite conclusions, entirely different results were obtained. This constitutes no reproach or criticism against the particular station or investigator who thus failed to duplicate results. It does indicate, however, some defect in the ordinary method of controlling the conditions in feeding experiments, which is worthy of investigation and remedy.

Henry's Experiments at Wisconsin with Pigs.—It was with no difficulty whatever that illustrations of the frequent failure of investigators to duplicate their own results were found. We shall first consider Henry's experiments at Wisconsin, extending over ten years and involving 280 pigs. The object of this extensive investigation was to test the value of feeding whole corn as compared with corn meal as the main portion of the ration for fattening pigs. Eighteen feeding trials were performed, and in fourteen of these trials the corn-meal lots made greater average gains in weight than the shelled-corn lots. The percentage differences in average gain in weight between lots varied from 31.22 to 0.19, six of the trials exhibiting percentages above 20 and six below 10. The number of pigs per lot in the eighteen trials is shown in the following table:

Trials	Lots per trial	Pigs per lot
4	2	3
1	2	4
2	2	5
1	2	6
1	2	7
2	2	8
2	2	9
1	2	10
2	2	12
1	2	14
1	2	19

For the experiment of 1899 on two lots of 19 pigs each the percentage difference between average lot gains was 0.19 in favor of the shelled-corn lot, while in the experiment of 1900 on two lots of 14 pigs each the percentage difference between average lot gains was 20.92 in favor of the corn-meal lot. The average initial weight of the pigs in the latter trial was about 175 lbs., and in the former trial, about 186 lbs. In the first trial, there were 10 pure-bred Poland-Chinas and 28 crossbred Poland-China-Berkshires, and in the second trial, 21 pure-bred Poland-Chinas and 7 crossbred Poland-China-Berkshires, divided between lots as equally as possible. The first trial contained 18 sows and 20 barrows; the second trial, 11 sows and 18 barrows. The same ration of ⅔ shelled corn or corn meal to ⅓ wheat middlings was fed in both trials. The methods of feeding the pigs were practically identical, the main difference, apparently, being that in the 1899 trial the shelled corn and middlings were fed separately to Lot I, while in the 1900 trial they were fed together. The 1899 trial extended over 12 weeks and the 1900 trial over 14 weeks. This brief comparative description of the two trials plainly shows their substantial identity as regards the planning and execution of the experiment and the known experimental conditions and does not in the least prepare one for the widely divergent results.

In the first trial, the shelled-corn lot gained, on an average, 1.338 lbs. per day, and the corn-meal lot, 1.336 lbs. In the second trial, the shelled-corn lot gained, on an average, 1.145 lbs. per day, while the corn-meal lot gained 1.413 lbs. An analysis of this latter experiment by the methods explained in Part I of this bulletin shows that under the conditions of the trial the odds are only 1 in about 7700 that on repetition the shelled-corn lot would give a greater average gain than the corn-meal lot. The fact that such a contradictory result was obtained in the preceding year indicates beyond all reasonable doubt that for some cause the two trials were not duplicates; that is, that there was some experimental condition or combination of conditions not under control and not defined, and yet operating in one trial but not in the other, or operating very unequally in the two trials, which created the discrepancy in the results obtained.

Further analysis of the data of the 1900 trial indicates that for some reason which the report does not specify, the shelled-corn lot ate considerably less corn and middlings than the corn-meal lot. Thus, Lot I consumed, on an average, 4.27 lbs. of shelled corn and 2.13 lbs. of wheat middlings per head per day, while Lot II consumed 4.51 lbs. of shelled corn and 2.26 lbs. of wheat middlings. In the 1899 trial, this marked difference between lots did not exist, Lot I consuming 4.44 lbs. of shelled corn and 2.22 lbs. of wheat middlings per day, on an average, and Lot II consuming 4.51 lbs. of corn meal and 2.25 lbs. of wheat middlings. Thus, the condition or conditions causing the discrepancy between these two supposedly duplicate trials were probably involved in the composition or the preparation of the rations fed, or possibly in the selection of animals that had been subjected to radically different treatment just previous to the experiment.

Wyoming Experiments with Sheep.—In Bulletins 81 and 85 of the Wyoming Experiment Station, A. D. Faville reports presumably duplicate feeding trials undertaken with the idea of testing the value of Wyoming-grown grain for fattening sheep. In the first test, performed in 1908-09, the 34 sheep constituting Lot III consumed, on an average, 2.83 lbs. of hay and 0.83 lb. of barley per day, and made an average daily gain in 91 days of 0.33 lb. The 35 sheep constituting Lot I consumed 2.72 lbs. of hay and 0.81 lb. of corn, and made an average daily gain of 0.30 lb. In the second trial, performed the following year, Lot II, consisting of 41 sheep, consumed 2.22 lbs. of hay and 0.89 lb. of barley per day, and made an average daily gain of 0.28 lb.; while Lot I, also consisting of 41 sheep, consumed less hay per day than Lot II, and 0.89 lb. of corn, and made an average daily gain of 0.35 lb. The average initial weights of the barley and corn lots in the first trial were 60.5 and 59.2 lbs., respectively, and in the second trial, 64.5 and 63.9 lbs. The sheep used in each trial represented various breeds, types, and sizes, divided between lots as evenly as possible. The individual data of these experiments are not given and a complete analysis is therefore impossible. Assuming, however, a variability of about 21 percent in all lots, we find that for the first trial the odds are 12 to 1 in favor of the barley ration, and, for the second trial, over 100,000 to 1 in favor of the corn ration. In the latter experiment it may be shown that even if the variability of the lots were as high as 79.0 percent, a value extremely improbable, the odds would still be 30 to 1 in favor of the corn ration. We must conclude that this is a second illustration of the fact that the most careful efforts to duplicate experimental conditions in feeding experiments as they are ordinarily run often result in failure.[a] The same bulletins offer a third illustration of this fact in the relation of the barley to the speltz lots in the two investigations.

Montana Experiments with Sheep.—F. B. Linfield reports supposedly duplicate feeding trials in Bulletins 47 and 59 of the Montana Station, the object being to test the value of local feeds in fattening sheep. In the first experiment, 22 lambs fed mixed grain and clover hay made an average daily gain of 0.286 lb. in 95 days, and a second lot of 22 lambs fed oats and clover hay made an average daily gain of only 0.220 lb. Again assuming a variability of about 21 percent, in the absence of more definite information, the odds are only 1 to 33,000 that repetition would result in a greater gain for the oats lot than for the mixed-grain lot. With a variability as high as 46.2 percent, these odds would still be 1 to 30. Nevertheless, in the second trial, performed the following year, 24 lambs fed mixed grain and clover hay made an average daily gain of 0.231 lb., while an equal number of lambs fed oats and clover hay made an average daily gain of 0.246 lb. Other similar examples occur in the same two bulletins, indicating the frequent inability of experiment station workers to duplicate their own experiments.

Minnesota and Pennsylvania Experiments with Steers.—In Bulletin 76 of the Minnesota Station, Thomas Shaw reports an investigation regarding the relative gains made by steers while being fattened during the winter in the stall and in an open shed. The seven steers fed in the barn made an average daily gain of 1.742 lbs. per steer in 140 days, while the seven steers fed in the open shed made an average daily gain of 2.256 lbs. on the same ration. In this bulletin the gains of the individual steers are given, and, applying biometric methods, we find that the odds are 1561 to 1 in favor of out-door feeding. Numerous experiments performed at the Pennsylvania Station, however, have uniformly

[a]Concerning the second experiment, Faville says: "The test with barley was hardly a fair one, as four of the lambs in this bunch did very poorly. This was through no fault of the grain." This explanation is hardly satisfactory, since (1) poor gains by four of the lambs would not lower the average of 41 gains to any marked degree, and (2) no reason is given for supposing that these poor gains were not due to the grain.

failed to show anything approximating a significant difference in rate of gain between lots fattened in a barn and lots fattened in an open shed during the winter.

Difficulties of Repetition.—The illustrations cited are sufficient to show the difficulty of truly duplicating feeding experiments as ordinarily planned and executed, that is, the difficulty of keeping constant, in two consecutive experiments, all conditions affecting to an appreciable extent the rate of growth of the experimental animals. The conclusion seems to be that the ordinary manner of conducting such experiments contains some serious defect. How serious the defect is and how important it is to remedy such defect is evident when one asks the question: If the experimentalist himself cannot duplicate his own experiments and obtain similar results even when the most careful attention is given to the details of management and of experimental conditions, what are the chances that the practical live-stock farmer, who necessarily cannot duplicate experimental conditions except in a very approximate manner, will duplicate the results obtained by experiment stations and profit by their recommendations? In many cases the chances are probably remarkably small.

When such instances of disagreement between two similarly conducted experiments occur, the attempt is often made to explain away and minimize the disagreement, but the fact that such disagreements occur in spite of all efforts to duplicate experimental conditions, is significant and worthy of serious investigation, since it is intimately concerned with the value to the agricultural community of all experiment station work of the type under discussion.

A Probable Explanation of These Difficulties.—The conclusion to be drawn from the occurrence of discrepancies between supposedly duplicate feeding trials is that the conditions deliberately imposed upon the experimental animals have not been sufficiently defined, so that if a more complete definition were made the explanation of the discrepancies would be revealed. It is conceivable, for example, that the conclusion that barley has a higher fattening value than speltz when fed to lambs applies only when certain grades of the two grains, definable, perhaps, by chemical analysis, are compared.

It appears, therefore, that in formulating the conclusions of a feeding experiment, it must always be borne in mind that rations of a definite chemical composition, as well as of a definite qualitative description, have been compared, and that the probability always exists that if the rations had been the same as regards qualitative description but much different as regards chemical composition, very different results would have been obtained. A chemical analysis of experimental rations may be supposed, therefore, to yield valuable if not indispensable data to the proper appreciation of feeding experiments.

Other conditions of the experiment should also be clearly specified in experiment station bulletins, and the tendency to continually generalize from data of a very specific description should be guarded against. Is the experimentalist in a position to assert, for instance, that his conclusions are not peculiar to the methods of feeding, the times of feeding, the preparation of the feeds, the mode of shelter, the extent of confinement, the breed of animals experimented upon, the particular herds or localities from which the animals were drawn, etc., etc., which he has employed? We venture to suggest that such possibilities are worthy of consideration, and that the determination as to which of two rations is the best for the fattening of animals is not the simple problem that it is frequently supposed to be.

VARIABILITY IN THE COMPOSITION OF FEEDSTUFFS

In connection with the question of the advisability of running chemical analyses on the experimental rations of feeding trials, it was thought essential to investigate, if only in a preliminary way, the natural variability to which the composition of some of the more common American feedstuffs is subjected. For it is of course obvious that if this variability is slight, so as to be negligible for all practical purposes, there is no necessity for the analysis of rations in each experiment, the average analyses compiled by the Bureau of Chemistry, for instance, being sufficient; on the other hand, if this variability is of such size that it cannot properly be disregarded, then, for the full appreciation of feeding experiments, experimental rations must in each case be analyzed.

The study of the variability in the composition of feedstuffs, therefore, is undoubtedly of considerable importance, and, in view of the large mass of data available, it could be pursued as extensively as the most ardent statistician might desire. The statistical measures of variation above developed are indispensable to such a study. In the preliminary study of this question that has been undertaken and that has yielded the results briefly summarized below, these statistical constants have been employed. The importance of a complete study of the natural variability in the composition of American feedstuffs is such that it is hoped to continue the study later.

Corn.—Corn has long been recognized as one of the most stable cereals as regards composition. Thus, Richardson says, speaking of American corn: "There is apparently the same amount of ash, oil, and albuminoids in a corn wherever it grows, with the exception of the Pacific slope, where......there seems to be no facility for obtaining or assimilating nitrogen."[a] Hopkins has even doubted the advisability of excepting corn from the Pacific slope, with apparent justification.[b]

However, the statement above quoted may very easily be misunderstood. It means simply that the average analyses for corn from the different states of the union, when compiled from a sufficient number of analyses, generally agree within narrow limits. For example, Richardson reports analyses of corn sampled in different states from the crop of 1883.[c] The average percentages of protein run as follows: 9 samples from New York, 10.54; 20 samples from Illinois, 10.06; 16 samples from Minnesota, 10.07; 15 samples from Dakota, 10.75; 13 samples from Nebraska, 10.47; and 11 samples from California, 10.26. The agreement is certainly very close, considering the numbers of samples from each state.

The statement that corn has a very stable composition thus means that there are no constant differences in its composition in different localities of the country. It does not mean that its composition is practically constant in any one locality. Thus, referring again to Richardson's analyses, the 20 samples of dent corn from Illinois exhibit a coefficient of variation of 11.79 as regards protein content, certainly no inconsiderable variability. Hopkins[d] analyzed three rows of kernels taken lengthwise of the ear, from 163 ears of Burr's white corn grown on the Illinois Experiment Station Farm in 1896. The 163 analyses gave the following results:

	Ash	Protein	Fat	Carbohydrates
Average	1.426	10.93	4.690	82.96
Standard deviation	.1090	1.048	.4232	1.182
Coefficient of variation	7.64	9.58	9.02	1.42

We have determined the variability of several groups of samples of corn, each group comprising samples from a single state and a single year's crop, tho not always of a single variety or even of a single class. As a matter of fact, the differences in composition between different classes and varieties of corn (excluding sweet corn from consideration) are apparently slight, judging from the data we have studied. From the coefficients of variation obtained in each group of samples, we have computed average co-

[a]U. S. Dept. Agr., Bur. Chem., Bul. 1, p. 67. 1883.
[b]Ill. Agr. Exp. Sta., Bul. 53, p. 136. 1898.
[c]U. S. Dept. of Agr., Report for 1884, pp. 84-85.
[d]Ill. Agr. Exp. Sta., Bul. 55, pp. 208-9. 1899.

efficients, proper consideration being given to the size of the groups in combining their coefficients.[a]

For protein, we have obtained an average coefficient of variation of 9.30, and for ash, an average coefficient of 12.59, these two coefficients involving 233 analyses. The following coefficients involve analyses of 154 samples of corn: moisture, 8.94; fat, 9.22; fiber, 16.77; and carbohydrate, 1.93.

The question arises, How are these coefficients to be interpreted? We know roughly that the great bulk of fluctuations of sampling lie within a range of ± 3 times the standard deviation from the mean,[b] except when the frequency distribution is of a very abnormal type. It has been our experience that while the distribution of percentages of the constituents of feeds is very often far from being *normal,* especially in the case of small percentages, such as of fiber or ash in corn (see page 471), they are nevertheless not ordinarily extremely asymmetrical, so that we can set the limits of such distribution at roughly ± 3 times the standard deviation from the mean. Thus, if the average percentage of protein in a year's crop in Illinois, for instance, is 10.50, the standard deviation of samples taken thruout the state, as regards their protein content, could be estimated at 9.30 percent of 10.50, or 0.976, and the rough estimate may be made that all such samples would possess protein contents ranging between $10.50 \pm (3 \times 0.976$ percent), *i.e.,* between 7.57 and 13.43 percent. The extreme deviations allowed for by these limits, however, would be of rare occurrence, and if we are concerned, for instance, with the range within which any one sample of corn would be practically certain to fall, perhaps fairer limits would be ± 2.25 times the standard deviation, that is, between 8.30 and 12.70 percent. Thus, if we applied the average of 10.50 percent of protein to any one sample of Illinois corn for the purpose of determining the protein intake of a lot of animals in a feeding experiment, we might be in error to the extent of 20 to 30 percent of the total intake of protein, and it may be said without exaggeration that errors of 9 to 12 percent must be expected from such an approximate method of determining protein consumption.

In the case of the ash intake, a still cruder approximation would result from the use of an average percentage, since an error of 35 to 40 percent might result, while errors of 12 to 15 percent would be of relatively frequent occurrence. On the other hand, an average percentage of carbohydrate could be used with confidence, since, with the most atypical sample of corn, an error of more than 6 percent could hardly result, while the most frequent errors would be those of 2 to 3.5 percent.

[a]Since the standard deviation of the coefficient of variation decreases inversely as the square root of twice the number of observations (see formula on p. 486), in averaging coefficients it was thought best to weight each with $\sqrt{2n}$.

[b]Yule, "Theory of Statistics," p. 262.

The question under consideration may be approached from another standpoint. We have calculated the nutritive ratios and *production values* of 61 samples of flint corn grown in Connecticut in the same year, the analyses of which are given in the Report of the Connecticut (New Haven) Station for 1893.

The average nutritive ratio was 1:10.89, and the standard deviation of the second member of the ratio, 1.398, or 12.84 percent. According to the standard adopted, the limits of distribution may be set at the ratios 1:6.70 and 1:15.08.[a] Ratios of 1:8 or 9, and 1:12 or 13 cannot be regarded as extremely improbable of occurrence.

The nutritive ratio has long been considered a valuable factor in indicating the general character of a food and the function it is likely to perform in a ration. The above calculations would appear to indicate that for corn this ratio is extremely variable for different samples of the grain.

The average *production value* of the 61 samples of Connecticut flint corn was 89.38 therms per 100 lbs. of grain, the standard deviation being 1.348 therms, or 1.50 percent of the average. This is a small percentage deviation and it may therefore be concluded that, as regards energy value, different samples of corn do not vary to any appreciable extent,[b] or at least to an extent that cannot properly be neglected in practical work.

The more important constituents of corn whose variability cannot properly be neglected are the protein, ash, and moisture. Concerning the latter constituent, while its variation in grains is not of any particular moment to the nutritive value of the grain as ordinarily considered, it may, and probably does, bear a close relation to the palatability of the grain for farm animals.

Wheat.—Sharply contrasted with the stability in the composition of corn in different sections of the country is the extreme variability in the composition of wheat. Richardson[c] gives the average composition of wheat from different sections of the country as follows:

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[a]Of the 61 ratios actually calculated, the lowest was 1:8.52, and the highest 1:15.17, indicating, as would be expected from the discussion on page 471, that deviations of any given extreme magnitude are more frequent above the mean than below, due to the smallness of the numbers in the second members of the ratios and to their extreme variability. The same condition exists in the case of the distribution of percentages of crude fiber, and in a modified form, in the case of ash percentages, while percentages of protein, moisture, and fat exhibit a distribution more nearly approaching the normal.

[b]Chamberlain's figures indicate that substantially the same is true of other grains. See Bul. 120, Bur. of Chem., U. S. Dept. of Agr. 1909.

[c]U. S. Dept. Agr., Report for 1884, p. 77.

TABLE 25.—AVERAGE COMPOSITION OF AMERICAN WHEAT

Section	Number of analyses	Water	Ash	Protein	Carbo-hydrates
Atlantic and Gulf states	117	10.34	1.77	11.35	76.54
Middle states	91	10.61	1.85	12.50	75.04
Western states	177	9.83	2.06	12.74	75.37
Pacific states	20	10.25	1.87	9.73	78.15

The variation in the percentage of protein is very marked, and is in fact somewhat obscured by considering such large areas as those in the table. Thus, Richardson gives the average protein content of 8 samples of Oregon wheat as 8.60 percent, of 22 samples of North Carolina wheat as 10.43 percent, of 33 samples of Pennsylvania wheat as 11.44 percent, of 106 samples of Colorado wheat as 12.73 percent, of 19 samples of Texas wheat as 13.14 percent, of 13 samples of Minnesota wheat as 13.19 percent, and of 12 samples of Dakota wheat as 14.95 percent.[a]

Not only does wheat vary markedly in composition from one section of the country to another, but also from one crop to the succeeding crop in the same locality. The wheat investigations conducted by the Washington Station on the Washington crops of 1905-09 inclusive and reported in Bulletins 84, 91, and 100 are of interest in connection with this point. Considering the Bluestem variety only, since this variety was better represented than any other, 22 samples of the 1905 crop gave an average percentage of moisture of 10.54, of protein, 11.79, and of ash, 1.93; for the crop of 1906, represented by 24 samples, these percentages were 11.25, 13.75, and 2.18 respectively; for 30 samples of the crop of 1907, 10.83, 11.56, and 1.69; for 22 samples of the crop of 1908, 9.20, 13.25, and 1.88; and for 28 samples of the crop of 1909, 8.11, 12.15, and 1.74.

From such evidence as the above, it seems that wheat is one of the most susceptible of grains to environmental influences.

As regards the variability of wheat in any one locality and from any one crop, we have obtained the following average coefficients of variation from data compiled by Richardson: for moisture, 7.10, involving 242 samples; for protein, 9.66, involving 242 samples; for ash, 11.73, involving 242 samples; for fat, 11.34, involving 104 samples; and for fiber, 19.49, involving also 104 samples. The coefficients obtained for the carbohydrate constituents were comparable to those obtained for corn.

Comparing these average coefficients with those given above for corn, it seems that in the case of the protein content the two grains are about equally variable; as regards moisture, wheat seems the least variable; in the case of fat, corn is the least variable; in

[a]In this connection see also Bul. 128, Bur. of Chem., U. S. Dept. Agr., by LeClerc. 1910.

the case of ash, the difference is slight and probably of no significance; and in the case of fiber, both grains exhibit a high variability, testifying to the general untrustworthiness of average percentages of fiber in grains.

The Washington wheat investigations mentioned above yield coefficients very different from those obtained from Richardson's data. Of the Washington analyses, we have considered only the data for the three varieties best represented, *i.e.,* the Bluestem, Club, and Turkey Red. Coefficients of variation were computed for each variety for each of the five crops investigated. The fifteen coefficients thus obtained, representing 247 analyses, were averaged together, each being weighted with the square root of twice the number of analyses from which it was derived (see footnote, page 542). The fifteen coefficients for the percentage of moisture averaged 9.88, and the fifteen coefficients for protein, 13.64. The average coefficient of variation for moisture is thus almost 3 percent higher than the corresponding average from Richardson's data, while the average coefficient for protein is almost exactly 4 percent higher than the protein coefficient of Richardson's analyses. This would appear to indicate that in Washington the composition of wheat varies to a much greater extent than elsewhere. In fact, the average coefficient of variation for the protein content of Washington wheat, 13.64, is higher than the protein coefficient obtained for any other single state, the highest single coefficient for the other states being 12.67, obtained from 61 analyses of Colorado wheat for 1883.

From the above study of the variation to which the composition of wheat is subjected as its environment changes with the locality and the year of growth, it is obvious that average percentages covering the entire country, either for one year's crop or for several combined, can have very little if any practical utility, since they are not strictly applicable to the crop of any one state for any one year, and since they are not even approximately applicable to the crops of many of the states. In this respect, wheat is markedly different from corn, for which average analyses seem to be about equally applicable to all sections, tho, even in the case of corn, variations from year to year seem to occur and oftentimes to be of such magnitude that they cannot properly be neglected.

Considering only the variation in the composition of wheat for any one state and for any one year's crop, for most sections of the country the evidence would seem to indicate that corn and wheat are not widely dissimilar, being closely comparable especially as regards variation in protein content.

Grains in General.—We have made no statistical study of grains other than corn and wheat. However, of these two corn seems to be regarded as the most stable and wheat as the most labile of the grains. From a close inspection of the analyses collected by Chamberlain in Bulletin 120 of the Bureau of Chemistry, and from the data of Richardson, LeClerc, and Jenkins and Winton,[a] we are inclined to believe that all grains may be roughly characterized as follows: (1) the energy value, either total or that available for metabolism or that available for fattening, of one unit weight of dry substance of any grain is approximately constant, no matter where or when grown; (2) with the exception of corn, the chemical composition of grains raised in different sections of the country varies decidedly and depends, not so much upon the variety of the grain, but upon the climatic conditions peculiar to the locality of the crop; (3) all grains vary in composition from year to year, the extent of the variation in composition seemingly depending upon the extent of the variation in meteorological conditions, corn being apparently the least and wheat the most susceptible to such changes; (4) the content of moisture, protein, and ash in grains varies considerably, even in the same locality and in crops of the same year, the variation being such that if the average composition for a given locality and a given year be applied to any one sample of grain for that locality and year, an error of 10 and 15 percent would not be improbable, while an error of 30 to 40 percent would not be impossible.

Roughages.—We have made no detailed study of the variability in the composition of roughages. Inspection of such data as those compiled by Jenkins and Winton[a] would seem to indicate that roughages are much more variable in composition than grains. This is to be expected when it is recalled that with these feeds, besides the climatic conditions, the fertilizers used, the time of cutting, the manner and time of curing, etc., are probably of considerable importance in modifying the composition of the feed.

From 52 analyses of commercial alfalfa meal obtained from several bulletins on the analysis of commercial feedstuffs,[b] we found an average percentage of protein of 14.83, a standard deviation of 2.172, and a coefficient of variation of 14.65. The latter figure indicates a very considerable variability, a deviation from the mean of 44 percent being possible, while deviations of 15 to 25 percent would be of rather frequent occurrence.

Commercial Concentrates.—In obtaining information concerning the variability in composition of some of the commoner com-

[a]U. S. Dept. of Agr., Off. Exp. Sta., Bul. 11. 1892.

[b]Bulletins 141 and 152 of the Purdue Station, Bulletin 141 of the Texas Station, Bulletins 316 and 340 of the New York Station at Geneva, Bulletin 147 of the New Hampshire Station, and Bulletins 71, 78, and 120 of the Massachusetts Station.

mercial concentrated feedstuffs, we have utilized the data from a large number of bulletins on feedstuff inspection. The average coefficients obtained are given in Table 26.

TABLE 26.—VARIABILITY IN THE COMPOSITION OF COMMERCIAL FEEDSTUFFS[a]

Feedstuff	Protein content		Fat content	
	Number of analyses	Average variability	Number of analyses	Average variability
Wheat bran	678	6.87	352	12.01
Wheat middlings and shorts	963	8.97		
Corn chops	916	8.64		
Cottonseed meal or cake	722	5.29	711	18.73
Linseed meal, old process	73	5.74	73	15.91
Gluten feed	59	10.09	59	31.84
Beef scraps[b]	24	8.47		
Beef scraps[c]	29	7.05		
Tankage[b]	9	6.14		
Tankage[d]	19	4.08		
Blood meal[e]	8	4.25		

Assuming that the distribution of the percentages of protein is approximately normal, in appreciating the significance of the above coefficients of variation the following statement may be made: If samples of wheat bran be taken thruout Illinois, for instance, for any one year, and the percentage of protein in each be determined, 1 sample on an average out of every 7 taken would exhibit a content of protein at least 10 percent greater or less than the average content for all samples, and 1 sample on an average out of every 32 would exhibit a protein content at least 15 percent removed from the average protein content for all samples. In the case of standard wheat middlings and shorts, 1 sample out of every 4 would give a protein content 10 percent or more on either side of the mean, and 1 out of every 11, a content 15 percent or more on either side of the mean. For the other feedstuffs, the following figures would hold approximately:

Feedstuff	Number of samples 10 percent or more greater or less than the mean	Number of samples 15 percent or more greater or less than the mean
Corn chops	1 out of every 4	1 out of every 12
Cottonseed meal	1 out of every 17	1 out of every 214
Linseed meal	1 out of every 12	1 out of every 110
Gluten feed	1 out of every 3	1 out of every 8
Beef scraps[b]	1 out of every 4	1 out of every 13
Beef scraps[c]	1 out of every 7	1 out of every 30
Tankage[b]	1 out of every 10	1 out of every 68
Tankage[d]	1 out of every 70	1 out of every 4500
Blood meal	1 out of every 53	1 out of every 2200

[a]All adulterated samples were left out of the computations contained in this table when adulteration was noted.
[b]Guarantee of about 40 percent protein.
[c]Guarantee of about 55 percent protein.
[d]Guarantee of about 60 percent protein.
[e]Guarantee of about 80 percent protein.

From such considerations it appears that if an average analysis be used in computing the protein intake of experimental animals in a feeding trial, instead of a direct analysis, as far as the above commercial feeding stuffs are concerned an error of 10 percent or more would not be infrequent in most cases, and in some cases an error of even 15 percent or more should not occasion surprise.

Conclusions.—It is evident from such a preliminary study of the question of the variability in the composition of American feedstuffs, that as regards feeding experiments, *the practical utility of average analyses is limited, and in the case of many of the grains and roughages is small indeed.* This conclusion is especially to be emphasized in the case of averages supposed to apply to the entire country and to all crops, since it cannot be doubted that marked differences occur in the composition of grains and roughages from locality to locality and are even likely to occur in the same locality in different years. These remarks apply, in the case of grains, to the content of moisture, protein, and ash especially; while, in the case of roughages, even the energy value of a unit weight of fresh substance may be subject to marked variation, a problem that we hope to investigate further. The protein content of commercial concentrates is also often subject to marked variation. Even when averages are taken of the composition of any one feed in any one locality for any one year, it has been demonstrated that samples possessing protein, ash, and moisture contents 10 percent, 15 percent, or more, greater or less than the mean contents, must be reckoned with.

In view of the great variability in the composition of feedstuffs and of the fact that a proximate analysis of rations can be secured relatively easily, we are inclined to believe that one cannot afford to omit such a precaution in feeding experiments, especially when they are otherwise comprehensively planned and capable of quite definitely settling the problem at hand.

PART III. SUMMARY AND CONCLUSIONS

(1) *Difficulties in Interpreting Feeding Experiments.*—The simple feeding experiment is of value in the solution of many problems of practical live-stock raising. Under the best conditions, however, the results of the feeding trial do not point unequivocally to one conclusion, but are of more or less ambiguous significance. The cause of this ambiguity is the dissimilarity existing among the gains of individual animals due to what may be termed *individuality* as well as to unequal conditions within the lot of animals.

One of the essential problems in the interpretation of a feeding experiment is the comparison of the gains in weight obtained for one lot of animals with the gains in weight obtained for another lot, the purpose of the comparison being to determine whether the difference in treatment accorded the two lots, or the difference in their make-up, as the case may be, has been instrumental in securing a difference in their gaining abilities. If one can assure himself by the proper methods of analysis that the relative position of the average gain of one lot with respect to the average gain of the second lot will remain essentially unaltered if the experiment be repeated on other similar animals under similar conditions, it follows that one is justified in attributing to the essential difference or differences in treatment or make-up between the two lots, an influence on their gaining qualities. If one cannot so assure himself, there remains only the alternative conclusion that whatever differences in gains are observed between the two lots are due entirely to the individualities of the animals and to other uncontrolled factors.

(2) *The Frequency Distribution.*—One of the most fruitful conceptions of the biometric method of analysis is that of the frequency distribution. A set of data obtained under comparable experimental conditions is to be thought of as tending to assume a definite distribution about some typical value, to which value the arithmetic mean, or the common average, is often a good approximation, in spite of the fact that the sources of variation under such conditions act in a random fashion. It is on this tendency of comparable experimental data to assume a definite frequency distribution, expressible by a frequency curve capable of mathematical definition, that all attempts to predict the result of repeating an experiment must be based.

(3) *Use of Average Results.*—Average results should be used with extreme caution. An average is at best only an imperfect description of a series of experimental data, and when used for comparative purposes is often extremely misleading. The calculation of an average should not be considered a reason for not

collecting or reporting the original data, since only by reference to the original data can its value be determined, and consequently only by publishing original data can experiment station workers criticise and properly appreciate each other's investigations.

(4) *Variation and Its Measurement.*—In adequately comparing the gains exhibited by one lot of animals with those exhibited by a second lot, it is necessary to calculate, not only the average gain of the lot, but also the variation or dispersion of the gains within the lot, a measurement of the latter being a measurement of the influence of the uncontrolled factors in the experiment. A good measure of variation for this purpose is the *standard deviation,* which may be defined as the square root of the average squared deviation of all individual gains from the average gain for the lot.

The average of a series of gains in weight, as well as the individual gains, must be considered as possessing a variability due to the experimental factors that were not under control, and since these uncontrolled factors find direct expression in the variability of gains within the lot, it follows that the variability of an average gain bears a definite relation to the variability of the individual gains within the lot. Obviously, the variability of an average gain decreases as the size of the lot increases, and it may be shown that the relation is such that the presumptive standard deviation of the average gain is equal to the standard deviation of the original gains divided by the square root of their number.

(5) *The Probable Error.*—In predicting the result of repeating a feeding experiment, on two lots of animals we will say, using other animals, but subjecting them to the same conditions that obtained in the given experiment, we first make the assertion that the most probable average lot gains that would be obtained in a second experiment are the average lot gains actually obtained in the first experiment. Our prediction is very inadequate, however, until we estimate from the data of the first experiment what deviations in a second experiment we must expect from these most probable values, since it would be remarkable indeed if exact duplication occurred. It is the purpose of the probable error of these average lot gains to afford this information.

The probable error of an average gain is that value which, when added to and subtracted from the average, defines two limiting values such that the odds are even that a second experiment will give an average gain falling between them. If we add to and subtract from an average gain 3.17 times its probable error, there are obtained two limiting values such that the odds are 30 to 1 that a second experiment will give an average falling between them. Now odds of 30 to 1 represent a degree of confidence amounting to practical certainty, so that we may feel reasonably certain that a second experiment will give an average gain for a lot of animals of a specified description and under specified conditions, lying somewhere within an interval defined by adding to or subtracting from the average gain experimentally obtained 3.17 times its probable error. The probable error of an average gain is obtained by simply multiplying the standard deviation of the average by 0.6745.

It is generally desired, however, to determine the significance not only of average lot gains, but also of differences between average lot gains. The probable error of such a difference may then be calculated by squaring the probable errors of the two averages involved, adding, and extracting the square root of the sum. The probable error of a difference between two average gains defines its significance in exactly the same manner as the probable error of an average gain defines the significance of that average.

By the use of such a probability method as that briefly outlined above, we are able to interpret the results of feeding experiments in a fairly satisfactory manner. The element of uncertainty resulting from the meaningless variation existing among individual gains, due to uncontrolled experimental factors, has been definitely and reasonably defined.

(6) *Coefficients of Variation.*—For some purposes, the standard deviation is inadequate as a measure of variation, due to the fact that it depends upon the units of measurement employed, and for gains obtained during different periods of time or gains exhibited by different kinds of animals, is correlated with the average gain. For extensive comparisons of variation, therefore, the *coefficient of variation* is used, this coefficient being simply the standard deviation calculated as a percentage of the average. The coefficient of variation of gains within lots is a good measure of the *experimental error.*

From an extensive review of experiment station literature in this country, we have obtained an average coefficient of variation of gains of about 21 for similarly treated lots of sheep. For steers and swine, an average coefficient of about 17 has been obtained. From these figures, supplemented by a detailed study of the data, it appears probable that sheep in general exhibit greater variability in gaining qualities than do either steers or swine. The small amount of data we have collected concerning the fattening of poultry indicate an average variability of about 16 percent. Apparently poultry may be classed with steers and swine as regards variability of gains.

Extreme discrepancies were found to exist among individual coefficients of variation. This is doubtless due in part to the heterogeneity of the data, but it is in large part to be expected from the mere size of the coefficients. A determination of a relation between particular rations or systems of treatment and the variability of gains is practically impossible except in extensive or in repeated experiments.

(7) *Number of Animals Required per Lot.*—Based upon the average coefficients of variation found for sheep and for steers and swine, calculation indicates that experimental lots should contain at least 10 to 14 animals, or even 25 to 30 animals when the rations or other conditions under investigation are very similar. The necessity of using at least 10 to 15 animals per lot in feeding trials seems to be well established. Wherever this number can be increased, the better, for this is the surest and most generally recognized means of increasing the significance of experimental results. Again, however, it is well to note that increasing the size of lots is no remedy for a poor selection of experimental animals. Furthermore, increasing the size of lots cannot *eliminate* individuality, but merely reduces its effect on the average. It has been shown that when there are as many as 40 animals to the lot, an appreciable degree of uncertainty still attaches to average lot gains. Also it should be borne in mind that the beneficial effect of increasing the size of lots varies not with the number in the lot, but with the square root of this number. Thus, for the same standard deviation of individual gains, a lot of 10 animals will give a probable error of the average gain only twice as large as a lot of 40 animals.

(8) *Uniformity of Gains is Desirable.*—Whenever and whereever possible it is advantageous to reduce the experimental error of feeding trials, *i.e.*, to increase the uniformity of gains within the lots, provided the value of the experiment and its practical availability are not also thereby reduced. The smaller the coefficient of variation of the gains in weight within a lot, other things being equal, the smaller the minimum percentage difference between its average gain and that for a second lot that can be definitely traced to the difference in treatment or to the difference in make-up between the two lots. Hence a reduction of the experimental error means a reduction in the coefficient of variation of gains within the lots.

(9) *Selection of Animals to Insure Uniformity of Gains.*—It is well known that animals at different ages exhibit different rates of growth and different fattening qualities. It is also obvious that different breeds of the same species of animals often exhibit similar differences, especially if they are of different general types, and even where it is not obvious that breed differences exist it is not justifiable to assume that they do not exist. The available data indicate with a high degree of certainty that wethers gain faster than ewes, barrows faster than sows, and cockerels faster than pullets, at least at the fattening age. Furthermore, it is beyond dispute that differences in treatment of animals previous to ex-

periment may frequently be the cause of differences in fattening qualities. The careful and intelligent selection of the experimental animals is one of the best methods of reducing the experimental error and thus obtaining more valuable and more significant results without interfering with conditions that the experiment must conform to by reason of the use to which its conclusions are to be put. We cannot over-emphasize the necessity of securing perfectly homogeneous lots as regards age, breed, type, sex, and previous treatment. The great preponderance of evidence indicates that by thus selecting the animals for experimental purposes, the experimental error will be greatly reduced. The necessity of selecting homogeneous lots of animals is not appreciably diminished by the balancing of heterogeneous lots.

(10) *Good Gains are Uniform Gains.*—In any experiment involving two or more lots of animals, it has in general been found that the lots exhibiting the best average gains also exhibit the more uniform gains, and vice versa.

(11) *Changes in the Variability of Gains During an Experiment.*—It has been found from experiments in which the experimental animals have been weighed periodically during the investigation that frequently the coefficient of variation of gains progressively decreases from the beginning of the experiment to the end, the rate of decrease being greater during the early periods than during the later periods of the feeding trial. Apparently this decrease would not, under the best conditions, continue indefinitely, but would gradually attain to a minimum coefficient characteristic of the particular sample of animals under observation and of the particular experimental conditions.

In other experiments, a continuous decrease in the coefficient of variation of gains is not evident. In most cases of this description that we have analyzed, a more or less close correlation between changes in ration and changes in variability of gains may be observed, such that an increasing ration is generally accompanied by a decreasing coefficient of variation, a constant ration by a constant or slightly increasing coefficient, and a decreasing ration by an increasing coefficient. Unfavorable weather conditions seem also to be instrumental in producing more variable gains, while in a few instances the correlation between ration and coefficient of variation above defined seems to be complicated or obscured by other factors, such as the relation of food intake to body weight or bodily requirements. While the evidence adduced does not unanimously point to one explanation of the changes in variability of gains during the course of a feeding trial, considerable support may be found for the general statement that when conditions are constantly or increasingly favorable to growth and fattening, an increasing uniformity of gains is generally secured, or in other words, the experimental error is progressively reduced.

It seems, therefore, that whenever practicable and whenever the nature of the experiment will permit, the animals should be induced to consume an increasing amount of food, that is, a constant ration per 100 lbs. live weight. A considerable increase in the ration near the close of the experiment for the purpose of "finishing off" the animals for the market is frequently very efficacious in securing more uniform gains.

(12) *Physiological Selection.*—Another method of reducing the experimental error of feeding trials that is in vogue in one form or another at different stations, has been investigated. The essence of this method is the selection for experiment of only those animals that during the course of a preliminary feeding period have proved themselves to be functionally similar as regards the rate of growth or fattening. Hence we have called the method *physiological selection.* From theoretical considerations alone, it appears that even if physiological selection is efficacious in accomplishing its purpose of eliminating poor gainers and reducing experimental error, it will so multilate the feeding experiment itself as to render it much less valuable to practical live-stock farming and to limit its applicability and thus reduce its significance.

Experimental evidence, however, indicates clearly that physiological selection does not eliminate the poor gainers. In fact, it appears that those animals exhibiting the poorest gains in a preliminary period are in general no worse than a random sample of the entire group of animals in a subsequent feeding experiment. Furthermore, physiological selection is very inefficient in reducing experimental error, even when conducted along the most rigorous lines. Hence this method is both theoretically faulty and practically incompetent to accomplish its purposes.

(13) *Repetition of Experiments.*—The necessary precision in feeding trials may be attained by a reduction of the experimental error as above shown or by repetition of the experiment. From a study of the efficacy of repetition, it appears that frequently under the most favorable conditions, feeding experiments cannot be duplicated. Frequently experiment stations have obtained results from feeding trials pointing unequivocally to a certain conclusion, and yet subsequent attempts to duplicate such experiments have yielded results quite incompatible with the first conclusion. The gravity of such a situation cannot be over-emphasized. Its remedy seems to be, first, the more careful reporting of experimental conditions, including a chemical analysis of rations, and second, the conviction that the conclusions of feeding experiments are more intimately connected with the particular experimental conditions

that obtained than has heretofore been believed. The conclusion, for instance, that one feed is better for fattening purposes than another may be totally at fault if other samples of the two feeds, possessing quite different compositions, be used, or if other breeds of animals, or animals more (or less) mature, be used, or other methods of preparing the feeds or sheltering the animals be followed. Such possibilities should always be kept in mind, and the frequent tendency to generalize from data of a very specific description should be carefully guarded against.

(14) *Variability in the Composition of Feedstuffs.*—The advisability of submitting experimental rations to a chemical analysis is clearly indicated by a study of the variability in the composition of feedstuffs. In the case of grains, this variability is negligible, apparently, as far as the energy value of the feed is concerned, but it is considerable and in many cases extreme in the case of the moisture, protein, and ash content. With roughages, inspection of analytical data would indicate an even greater variability than with grains, apparently involving even the energy value. In the case of commercial concentrates, variation of the protein content is often quite comparable to that in grains, tho in the more highly nitrogenous concentrates, such as blood meal with a protein guarantee of 80 percent, the percentage variability is less evident.

(15) *Individual Feeding Not Essential.*—The simple feeding experiment concerning itself entirely with the gains in weight and the feed consumption of farm animals under certain definite experimental conditions, has served many useful purposes and yielded much valuable information to practical live-stock farming. Its purpose is to yield specific information which must generally be considered in connection with the specific conditions under which it was conducted, as opposed, for instance, to the purpose of the nutrition experiment, which is the securing of more or less general information, not so strictly limited by the conditions under which the experimental data were collected. Therefore, it is neither necessary nor, in fact, expedient that the technic of the simple feeding experiment be carried to the same degree of refinement as that of the nutrition experiment proper. Any great refinement of the former is objectionable from the standpoint of the practical availability of the results of feeding trials.

Thus, the individual feeding of animals in ordinary feeding trials seems unnecessary, if not inadvisable, because we are here imposing an experimental condition entirely out of harmony with ordinary practical live-stock raising, and while the experimental error may very probably be reduced by seeing to it that each animal obtains the same amount of feed per 100 lbs. live weight for instance, the practical availability of the experimental data obtained would undoubtedly be greatly reduced. The individual feeding of animals may yield valuable data for some purposes. However, the variability in the consumption of feed and consequently in the gains produced cannot be presumed to be the same in individual feeding as in lot feeding.

(16) *Publication of Results.*—The results of feeding experiments should be published, not only with the idea of describing a particular investigation, but also with the idea of determining, in so far as such a determination is possible, whether a reasonable probability exists that the practical live-stock farmer will actually benefit himself by applying the results of the investigation to his own live stock. If no such probability exists, the farmer should be specifically warned. The elaborate analysis necessary for answering such a question will very probably not be appreciated by the majority of the readers of experiment station bulletins, but this is no excuse for not using such analytical methods at the expense of accuracy in the formulation of conclusions and recommendations. As a matter of fact, the analysis undertaken need constitute no part of the bulletin published, the purpose of such analysis being primarily simply to check or rectify conclusions.

(17) *Formulating Conclusions.*—In formulating the conclusions of feeding experiments, the necessity of keeping in mind the possibility that several of the specific experimental conditions may seriously limit the applicability of the results of the investigation should not be lost sight of. Thus, Ration A may be superior to Ration B under some, but not all, conditions. The possibility, if not the probability, exists that if the constituents of Ration A are not up to a certain standard, the reverse relation may hold; hence the necessity of a chemical analysis of the rations used in order that one may know the actual conditions under which the experimental conclusions may reasonably be applied. It is not sufficient simply to enumerate the individual feeds of which the rations are constituted and the proportions in which they enter into the rations. An exhaustive and repeated chemical anlysis of rations is neither necessary nor especially advantageous. In fact, if a fairly complete analysis of feeds be made at the beginning of the experiment and substantially the same feeds be used thruout the subsequent feeding period, it may be necessary to run only moisture determinations on the feeds from time to time during the experiment. If variation in the moisture content of feeds is not appreciable during storage, even the repetition of moisture determinations will be unnecessary. However, an ordinary analysis should be made of each new supply of feed from a sample fairly representative of the entire supply.

Other conditions than the composition of rations may limit the applicability of conclusions. The manner in which the feeds are given to the animals, *e.g.*, whether they be given *ad libitum* or in restricted quantities, may determine to some extent the relative merits of rations. The breed or type of animals experimented upon may be still another limiting factor. The age or condition of the animals may be still other limiting factors. Such considerations as these, which are associated with greater or less degrees of probability, should receive due attention in interpreting feeding experiments, and the assertion that a given experiment indicates a superiority of one ration over another should be made only in close connection with a brief statement of the more important experimental conditions.

In conclusion, we take pleasure in acknowledging the valuable assistance of Professor H. L. Rietz in aiding us to a proper comprehension of the technic of the statistical methods and of their general applicability to agricultural problems.

APPENDIX

TABLE I.—STATISTICAL DATA ON SHEEP

Experiment No.[a]	Length of experiment, days	Lots		Initial weight of sheep			Gain in weight of sheep		
		No.	No. of sheep	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
American Feeding Experiments									
1	92	I	10	63.5	5.53	8.71	32.9	8.25	25.08
	92	II	10	64.6	6.71	10.39	36.5	9.02	24.71
	92	III	10	64.1	4.39	6.85	41.3	7.15	17.31
	92	IV	10	63.5	5.71	8.99	34.5	3.95	11.45
	92	V	10	63.1	5.68	9.00	34.4	4.05	11.77
	92	VI	10	63.6	6.31	9.92	33.4	6.07	18.17
2	70	I	14	21.0	7.54	35.90	30.9	5.53	17.90
	70	II	14	24.2	6.60	27.27	32.2	5.11	15.87
	70	III	14	22.7	7.39	32.56	27.5	4.70	17.09
	70	IV	14	22.8	3.94	17.28	28.3	6.59	23.29
3	98	I	10	98.6	7.93	8.04	28.3	6.84	24.17
	98	II	10	77.8	3.98	5.12	30.4	8.46	27.83
	98	III	10	61.9	5.68	9.18	31.6	5.74	18.16
4	60	I	10	87.7	8.95	10.21	31.3	4.80	15.34
	60	II	10	87.4	12.13	13.88	23.4	7.79	33.29
5	44	Ia	12	67.6	6.48	9.59	16.4	3.48	21.22
	31	Ib	11	67.1	7.00	10.43	10.6	6.17	58.21
	44	IIa	11	72.2	6.48	8.98	16.2	3.30	20.37
	31	IIb	12	65.7	8.27	12.59	9.9	3.93	39.70
	44	IIIa	12	73.6	4.84	6.58	18.9	3.55	18.78
	31	IIIb	12	65.6	7.85	11.97	11.9	3.68	30.92
6	105	I	16	67.2	5.78	8.60	34.4	9.27	26.95
	105	II	16	67.5	4.61	6.83	36.8	4.74	12.88
	105	III	16	66.6	4.71	7.07	35.6	7.74	21.74
	105	IV	16	67.0	4.39	6.55	37.5	4.94	13.17
	105	V	16	67.0	4.99	7.45	38.2	4.70	12.30
	105	VI	16	66.8	5.71	8.55	39.3	7.14	18.17

[a]These numbers are also the reference numbers to the bibliography given on pages 578-9.

TABLE I.—STATISTICAL DATA ON SHEEP (*Continued*)

Experiment No.[a]	Length of experiment, days	Lots		Initial weight of sheep			Gain in weight of sheep		
		No.	No. of sheep	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
American Feeding Experiments (*Continued*)									
7	105	I	12	83.9	13.05	15.55	25.0	9.44	37.76
	105	II	12	83.9	11.93	14.22	37.9	8.23	21.72
8	70	Ia	17	31.6	9.10	28.80	35.8	4.08	11.40
	70	Ib	17	67.5	9.04	13.39	24.8	5.03	20.28
	70	IIa	17	31.8	9.78	30.75	36.7	5.67	15.45
	70	IIb	17	68.5	10.40	15.18	21.2	6.68	31.51
9	70	Ia	6	51.0	6.88	13.49	31.2	5.14	16.47
	70	Ib	6	82.2	8.78	10.68	20.2	3.71	18.37
	70	IIa	6	49.8	8.63	17.33	30.0	4.87	16.23
	70	IIb	6	79.8	13.01	16.30	14.2	3.23	22.75
	70	IIIa	6	52.5	8.54	16.27	35.2	3.76	10.68
	70	IIIb	6	87.7	11.63	13.26	16.0	2.89	18.06
	70	IVa	6	52.3	6.80	13.00	36.2	2.79	7.71
	70	IVb	6	88.5	6.08	6.87	21.0	3.11	14.81
10	70		5	59.7	11.13	18.64	28.4	5.51	19.40
11	111	I	10	70.5	8.80	12.48	31.5	7.32	23.24
	111	II	10	70.5	8.41	11.93	31.5	3.16	10.03
	111	III	10	70.5	11.72	16.62	27.6	6.08	22.03
	111	IV	10	70.5	8.21	11.64	28.5	5.21	18.28
	111	V	10	70.3	9.62	13.68	24.8	6.77	27.30
	111	VI	9	70.7	10.40	14.71	31.2	6.71	21.51
	111	VII	9	71.1	9.34	13.13	30.5	4.86	15.93
	111	VIII	10	70.5	8.64	12.26	27.2	5.24	19.26
	111	IX	9	71.4	7.82	10.95	30.0	8.71	29.03
	111	X	9	70.3	4.74	6.74	23.6	6.37	27.00
12	110	I	9	80.8	12.44	15.39	39.0	8.92	22.87
	110	II	9	78.0	11.14	14.28	40.2	4.08	10.15
	110	III	9	80.7	9.11	11.29	38.4	11.21	29.19

[a]These numbers are also the reference numbers to the bibliography given on pages 578-9.

TABLE I.—STATISTICAL DATA ON SHEEP (*Continued*)

Experiment No.[a]	Length of experiment, days	Lots		Initial weight of sheep			Gain in weight of sheep		
		No.	No. of sheep	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
American Feeding Experiments (*Continued*)									
12 (*continued*)	110	IV	8	79.2	6.69	8.45	38.6	10.08	26.11
	110	V	9	81.2	12.21	15.04	33.8	6.38	18.87
	110	VI	9	81.0	9.96	12.30	40.3	13.32	33.05
	110	VII	9	80.9	14.00	17.31	37.2	6.92	18.60
	110	VIII	8	82.0	8.83	10.77	34.2	10.17	29.74
	110	IX	9	81.9	6.87	8.39	37.0	7.29	19.70
13	98	I	10	75.2	9.07	12.06	32.4	6.84	21.11
	98	II	10	74.0	6.32	8.54	34.4	5.81	16.89
	98	III	10	74.8	9.92	13.26	33.2	6.23	18.76
	98	IV	10	72.9	6.11	8.38	25.8	8.74	33.88
	98	V	10	73.4	8.85	12.06	31.7	6.66	21.01
	98	VI	10	73.9	6.52	8.82	28.5	6.70	23.51
	98	VII	10	72.7	9.49	13.05	33.4	8.00	23.95
	98	VIII	10	75.3	11.16	14.82	30.2	16.71	55.33
	98	IX	10	74.3	10.87	14.63	32.3	6.00	18.58
	98	X	10	74.5	7.94	10.66	29.6	6.70	22.63
14	98	I	5	105	6.86	6.53	28.5	3.74	13.12
	98	II	5	106	7.13	6.73	37.1	2.54	6.85
15	98	I	5	102	12.40	12.16	34.5	1.60	4.64
	98	II	5	100	6.42	6.42	22.5	5.27	23.42
	98	III	5	114	9.44	8.28	18.1	4.61	25.47
	98	IV	5	118	11.30	9.58	6.4	4.92	76.84
16	168	I	7				54.0	3.09	5.73
	168	II	7				60.5	9.46	15.64
	168	III	7				61.4	3.76	6.12
Average									**21.63**

[a]These numbers are also the reference numbers to the bibliography given on pages 578-9.

TABLE 1.—STATISTICAL DATA ON SHEEP (*Continued*)

Experiment No.[a]	Length of experiment, days	Lots		Initial weight of sheep			Gain in weight of sheep		
		No.	No. of sheep	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
English Feeding Experiments									
17	87	I	10	117.1	10.98	9.38	43.2	7.40	17.13
	101	II	10	117.2	8.98	7.66	40.8	5.88	14.41
	94	III	10	117.3	9.02	7.69	37.6	7.43	19.76
	108	IV	10	117.1	8.42	7.19	26.5	5.57	21.02
18	101	I	12	111.2	4.18	3.76	35.8	8.64	24.13
	101	II	11	110.6	5.05	4.57	32.4	5.88	18.15
	101	III	12	111.0	4.32	3.89	33.2	8.81	26.54
	101	IV	11	111.6	3.91	3.50	39.5	6.90	17.47
19	111		12	116.9	3.57	3.05	54.2	7.86	14.50
20	104	I	14	121.7	8.93	7.34	29.3	13.25	45.22
	104	II	14	121.6	7.83	6.44	36.9	5.90	15.99
21	98	I	15	123.4	7.46	6.05	40.7	5.65	13.88
	98	II	15	123.1	7.13	5.79	41.7	7.58	18.18
	98	III	15	123.3	7.43	6.03	42.5	5.69	13.38
	98	IV	15	123.4	9.09	7.37	44.8	7.61	16.99
22	87	I	15	137.0	9.94	7.26	31.5	10.03	31.84
	87	II	15	137.1	6.98	5.09	29.1	6.42	22.06
	87	III	14	134.9	7.63	5.66	27.4	9.21	33.61
	87	IV	13	136.4	11.08	8.12	30.1	8.92	29.63
23	93	I	24	109.4	7.53	6.88	49.2	6.05	12.30
	93	II	24	109.5	7.41	6.77	42.0	7.79	18.55
	93	III	24	109.5	7.78	7.11	43.9	5.65	12.88
24	80	I	20	106.7	5.53	5.18	32.8	7.39	22.54
	80	II	20	106.7	6.72	6.30	31.1	7.83	25.19
	80	III	20	106.7	5.64	5.29	35.2	5.15	14.64

[a]These numbers are also the reference numbers to the bibliography given on pages 578-9.

TABLE I.—STATISTICAL DATA ON SHEEP (*Continued*)

Experiment No.[a]	Length of experiment, days	Lots		Initial weight of sheep			Gain in weight of sheep		
		No.	No. of sheep	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
English Feeding Experiments (*Continued*)									
25	97	I	5	111.6	4.04	3.62	26.0	10.31	39.65
	97	II	5	109.6	7.23	6.60	28.3	9.23	32.61
	97	III	5	111.7	3.46	3.10	31.1	5.83	18.75
	97	IV	5	112.9	1.92	1.70	18.8	4.28	22.77
26	134	I	5	121.4	2.84	2.34	30.5	2.05	6.72
	134	II	5	121.4	2.94	2.42	28.6	9.37	32.76
	134	III	5	120.4	2.87	2.38	27.8	6.11	21.98
	134	IV	5	120.4	2.42	2.01	24.2	3.54	14.63
	77	V	30	110.6	7.87	7.12	35.7	4.24	11.87
27	182	I	40	113.4	8.17	7.20	69.62	11.041	15.86
	182	II	40	88.0	5.74	6.52	52.72	7.183	13.62
28	140		46	119.6	9.81	8.20	63.67	10.492	16.48
29	140	I	40	101.3	9.94	9.81	44.57	9.526	21.37
	140	II	40	95.1	4.85	5.10	44.50	6.052	13.60
	140	III	40	91.2	5.26	5.77	42.50	5.572	13.11
Average									**20.40**

[a]These numbers are also the reference numbers to the bibliography given on pages 578-9.

TABLE 2.—STATISTICAL DATA ON STEERS

Experiment No.[a]	Length of experiment, days	Lots		Initial weight of steers			Gain in weight of steers		
		No.	No. of steers	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
American Feeding Experiments									
30	84	I	5	1153	28.0	2.43	107	22.3	20.88
	140	II	5	1212	51.0	4.21	203	31.2	15.35
31	140	I	7	1078	88.0	8.16	244	37.4	15.34
	140	II	7	1091	98.6	9.04	316	45.9	14.53
32	105	I	10	948	71.2	7.51	214	47.7	22.33
	105	II	6	948	56.6	5.97	227	35.3	15.55
	105	III	6	950	81.8	8.61	197	23.2	11.78
33	147	I	6	916	62.9	6.87	358	56.7	15.83
	147	II	6	936	70.7	7.55	331	43.7	13.19
	147	III	6	932	63.8	6.85	336	88.1	26.22
	147	IV	6	928	39.7	4.28	363	46.2	12.73
	147	V	5	955	75.9	7.95	377	48.8	12.94
	147	VI	6	925	87.0	9.41	333	51.5	15.46
34	132		6	1311	81.8	6.24	301	29.2	9.70
35	126	I	12	829	42.9	5.17	267	45.5	17.04
	126	II	12	838	35.7	4.26	248	38.2	15.40
36	116	I	12	994	102.3	10.29	230	42.3	18.40
	116	II	12	993	83.7	8.43	227	45.9	20.22
37	114	I	12	995	98.2	9.87	175	20.2	11.54
	114	II	12	956	77.7	8.13	175	63.5	36.29
38	70	I	12	1115	55.7	5.00	144	23.7	16.46
	70	II	12	1124	58.8	5.23	159	28.4	17.86
39	70	I	12	1181	56.7	4.80	118	20.6	17.46
	70	II	12	1201	56.5	4.70	126	29.8	23.65

[a]These numbers are also the reference numbers to the bibliography given on pages 578-9.

TABLE 2.—STATISTICAL DATA ON STEERS (*Continued*)

Experiment No.[a]	Length of experiment, days	Lots		Initial weight of steers			Gain in weight of steers		
		No.	No. of steers	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
American Feeding Experiments (*Continued*)									
40	146	I	6	787	72.4	9.20	214	29.4	13.74
	146	II	6	765	59.3	7.75	240	18.7	7.80
41	100	I	12	1065	88.7	8.33	202	46.3	22.92
	100	II	12	1063	77.3	7.27	183	34.6	17.91
42	126	I	12	887	64.7	7.30	260	45.7	17.58
	126	II	12	889	125.4	14.11	256	64.6	25.23
43	154	I	10				2.486[b]	.354	14.24
	154	II	15				2.499	.503	20.13
	154	III	15				2.181	.415	19.03
	154	IV	15				2.473	.489	19.77
	154	V	15				2.470	.388	15.71
	154	VI	15				2.412	.385	15.96
	154	VII	15				2.534	.242	9.55
	154	VIII	10				2.106	.290	13.77
	154	IX	10				2.025	.431	21.28
	154	X	10				1.995	.539	27.02
44	182	I	5	1221	35.6	2.92	436	53.9	12.36
	182	II	5	1211	96.1	7.94	268	57.2	21.35
	182	III	5	1215	116.5	9.59	284	40.5	14.26
	182	IV	5	1225	70.8	5.78	313	43.6	13.93
45	129	IV	5	1074	88.6	8.25	274	59.1	21.57
	129	V	5	1072	65.2	6.08	276	26.6	9.62
46	150	I	5	1061	90.3	8.51	326	32.8	10.05
	150	II	5	1062	34.5	3.25	294	18.8	6.40
Average									**16.73**

[a]These numbers are also the reference numbers to the bibliography given on pages 578-9.
[b]Average daily gain instead of total gain given in this experiment.

TABLE 2.—STATISTICAL DATA ON STEERS (*Continued*)

Experiment No.[a]	Length of experiment, days	Lots		Initial weight of steers			Gain in weight of steers		
		No.	No. of steers	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
Canadian Feeding Experiments									
47	162	I	6	1192	58.5	4.91	325	29.6	9.10
	162	II	6	994	48.0	4.83	279	52.3	18.75
48	135	I	8				331	29.3	8.85
	135	II	8				286	32.2	11.26
	135	III	8				278	24.6	8.85
Average....									**9.66**
English Feeding Experiments									
49	106	Ia	4	1144	45.1	3.94	159	25.7	16.16
	91	Ib	4	1283	28.1	2.19	176	21.2	12.04
	98	IIa	4	1139	41.0	3.60	194	17.9	9.23
	84	IIb	4	1281	69.3	5.41	200	43.7	21.85
50	123	III	4	1095	46.4	4.24	226	16.0	7.08
	137	IV	4	1095	61.3	5.60	253	85.2	33.68
		I	4	1094	88.4	8.08	1.95[b]	.299	15.33
		II	4	1096	67.3	6.14	1.63[b]	.846	51.90
51	112	I	4	1214	19.1	1.57	156	35.3	22.63
	112	II	4	1214	40.7	3.35	206	29.8	14.47
52	108	II	4	1222	35.7	2.92	181	23.7	13.09
53	40	Ia	4	1216	34.7	2.85	87	34.0	39.06
	40	IIa	4	1216	31.3	2.57	122	11.0	9.02
	71	Ib	4	1303	59.1	4.54	195	14.3	7.33
	71	IIb	4	1338	23.5	1.76	141	25.8	18.30
54	61	I	4	1082	85.9	7.94	18	26.2	
	61	II	4	1083	59.3	5.48	126	24.3	19.31

[a]These numbers are also the reference numbers to the bibliography given on pages 578-9.
[b]Average daily gain instead of total gain.

TABLE 2.—STATISTICAL DATA ON STEERS (*Continued*)

Experiment No.[a]	Length of experiment, days	Lots		Initial weight of steers			Gain in weight of steers		
		No.	steers No. of	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
				English Feeding Experiments (*Continued*)					
55	112	Ia	4	1019	30.5	2.99	213	33.4	15.68
	112	IIa	4	1020	58.4	5.73	207	18.7	9.03
	112	Ib	4	1152	18.7	1.62	159	11.3	7.11
	112	IIb	4	1149	56.2	4.89	185	39.1	21.14
56	107	I	6	1177	36.4	3.09	215	53.2	24.75
	107	II	6	1176	57.9	4.92	217	29.4	13.55
57	107	I	4	1176	64.9	5.52	235	36.9	15.70
Average									**18.15**

Table 3.—Statistical Data on Swine

Experiment No.[a]	Length of experiment, days	Lots: No.	Lots: No. of pigs	Initial weight of pigs: Mean	Initial weight of pigs: Standard deviation	Initial weight of pigs: Coefficient of variation	Gain in weight of pigs: Mean	Gain in weight of pigs: Standard deviation	Gain in weight of pigs: Coefficient of variation
American Feeding Experiments									
58	63	I	19	111.1	13.30	11.97	54.9	8.51	15.50
	63	II	19	110.1	10.95	9.95	49.5	13.88	28.04
59	84	I	19	186.5	14.7	7.89	112.4	16.02	14.25
	84	II	19	186.2	18.9	10.15	112.2	14.82	13.21
60	56	I	21	101.9	12.9	12.66	71.0	9.40	13.24
	56	II	21	101.8	11.2	11.05	68.3	8.80	12.88
61	55		23	164.0	21.57	13.15	49.7	4.40	8.85
62	73	I	7	61.0	4.21	6.90	72.6	16.35	22.52
	98	II	7	30.3	5.34	17.62	81.3	18.06	22.21
	98	III	6	36.0	6.35	17.64	88.3	18.24	20.66
	98	IV	9	24.7	3.30	13.36	86.8	16.62	19.15
	98	V	8	36.7	4.86	13.24	90.6	10.11	11.16
	98	VI	6	40.2	7.09	17.63	98.7	8.78	8.90
63	84	Ia	8	187.0	19.04	10.18	124.0	14.97	12.07
	84	IIa	9	184.2	14.04	7.62	102.5	14.33	13.98
	84	Ib	8	184.2	17.89	9.71	128.7	21.48	16.69
	84	IIb	8	183.9	16.86	9.17	99.9	6.15	6.16
64	100	I	9	136.3	33.0	24.21	174.8	21.3	12.19
	100	II	9	140.2	13.5	9.63	178.6	41.4	23.18
	100	III	9	137.1	29.6	21.59	185.8	27.6	14.85
	100	IV	9	134.9	16.6	12.31	116.3	26.6	22.87

[a]These numbers are also the reference numbers to the bibliography given on pages 578-9.

TABLE 3.—STATISTICAL DATA ON SWINE (*Continued*)

Experiment No.[a]	Length of experiment, days	Lots		Initial weight of pigs			Gain in weight of pigs		
		No.	No. of pigs	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
American Feeding Experiments (*Continued*)									
65	112	I	10	59.9	13.7	22.89	103.4	19.4	18.76
	112	II	10	59.8	15.5	25.92	125.5	21.3	16.97
	112	III	10	59.8	15.6	26.09	133.2	17.6	13.21
	112	IV	9	57.7	10.6	18.37	140.9	39.1	27.75
	112	V	10	60.1	14.9	24.79	153.9	20.8	13.51
	112	VI	10	59.9	11.9	19.87	133.7	8.4	6.28
	112	VII	10	59.3	15.3	25.80	90.9	33.7	37.07
	112	VIII	10	59.1	11.1	18.78	100.2	28.3	28.24
	112	IX	10	58.9	12.0	20.37	121.8	17.8	13.82
	112	X	10	58.8	20.0	34.01	102.5	49.7	48.49
66	98	I	14	174.1	27.6	15.85	112.2	15.83	14.11
	98	II	14	175.4	27.9	15.91	138.4	21.65	15.64
67	70	I	9	354.4	35.5	10.02	137.2	17.70	12.90
	70	II	9	345.9	35.2	10.19	149.8	11.97	7.99
68	70	I	10	225.4	38.4	17.03	78.9	11.90	15.08
	70	II	10	223.2	36.8	16.48	107.6	14.21	13.21
69	126	I	7	66.4	9.84	14.82	171.0	31.96	18.69
	126	II	8	65.2	8.86	13.59	146.4	21.71	14.83
70	84	I	12	67.9	11.74	17.29	100.4	15.58	15.52
	84	II	12	68.5	16.14	23.56	108.2	17.84	16.49
71	84	I	5	183.6	66.2	36.06	109.8	20.5	18.67
	84	II	5	175.0	71.7	40.97	140.2	31.7	22.61

[a]These numbers are also the numbers to the bibliography given on pages 578-9.

TABLE 3.—STATISTICAL DATA ON SWINE (*Continued*)

Experiment No.[a]	Length of experiment, days	Lots		Initial weight of pigs			Gain in weight of pigs		
		No.	No. of pigs	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
American Feeding Experiments (*Continued*)									
72	91	I	6	188.7	23.7	12.56	123.5	28.1	22.75
	91	II	6	190.5	12.3	6.46	151.5	14.4	9.50
73	83	I	6	136.3	9.03	6.63	102.3	6.65	6.50
	83	II	6	138.2	10.76	7.79	124.5	21.90	17.62
74	150	I	8	88.0	8.73	9.92	79.4	16.6	20.91
	150	II	8	88.1	8.15	9.25	93.4	17.5	18.77
Average									**17.12**
Canadian Feeding Experiments									
75		I	6	63.7	6.75	10.60	119.5	4.50	3.77
		II	5	37.2	8.82	23.71	140.4	10.80	7.69
76		I	6	95.3	9.56	10.03	1.128[b]	.0433	3.84
		II	6	94.2	13.46	14.29	1.225	.1289	10.52
		III	6	89.3	11.80	13.21	1.197	.1340	11.19
		IV	6	89.3	13.82	15.48	1.083	.1205	11.13
77		I	10	57.5	19.68	34.23	1.265[b]	.2527	19.98
		II	10	57.6	16.50	28.64	1.228	.1825	14.86
		III	10	57.9	20.00	34.54	1.213	.1386	11.43
		IV	10	59.1	21.43	36.26	1.280	.1965	15.35
Average									**10.98**

[a]These numbers are also the reference numbers to the bibliography given on pages 578-9.

[b]Average daily gains instead of total gains given in these experiments.

TABLE 4.—STATISTICAL DATA ON POULTRY

Experiment No.[a]	Length of experiment, days	Lots			Age at beginning of experiment, days	Gain in weight of poultry		
		No.	No. of birds	Sex		Mean	Standard deviation	Coefficient of variation
Canadian Feeding Experiments								
78	42	I	5	Cockerel	60	36.2	3.36	9.28
	42	II	6	Pullet	60	30.4	3.41	11.22
	42	IV	6	Cockerel	60	39.2	7.67	19.57
	42	VIII	6	Cockerel	77	39.6	3.02	7.63
	42	IX	6	Cockerel	63	48.9	6.80	13.91
79	42	A	6	Cockerel	84	26.7	8.28	31.01
	42	B	6	Cockerel	84	44.0	7.05	16.02
80	28	I	6	Pullet	77	23.2	1.60	6.88
	28	II	6	Pullet	77	21.7	1.95	9.00
81	42	I	6	Cockerel	70-77	49.2	4.56	9.27
	42	II	6	Cockerel	70-77	38.9	10.53	27.07
82	42	I	6	Cockerel	84	41.6	9.40	22.60
	42	II	6	Cockerel	84	35.1	11.54	32.88
83	35	I	8	Cockerel	90	34.1	5.16	15.12
	35	II	8	Cockerel	90	36.0	2.65	7.36
84	28		9	Cockerel		16.5	3.34	20.24
Average								**16.20**

[a]These numbers are also the reference numbers to the bibliography given on pages 578-9.

Number of Animals to Include in an Experimental Lot

Two equal lots of animals of a given species are fed according to two different methods or treated otherwise in a distinctive fashion.[a] After a feeding period of a given length, Lot I exhibits an average gain of a lbs., and Lot II an average gain of b lbs. The coefficient of variation of the gains in Lot I we shall call C_1, and that of Lot II, C_2. Therefore, the best estimates of the standard deviations of the two average gains in weight are respectively, $\frac{C_1 a}{100\sqrt{n}}$, and $\frac{C_2 b}{100\sqrt{n}}$, n being the number of animals in the lots. Now, let the percentage difference between the two average lot gains a and b be designated by the letter c (or rather, by $c \times 100$), that is, let

$$(a-b) \div \tfrac{1}{2}(a+b) = c.$$

This being so, it follows that

$$b = \frac{2-c}{2+c} \times a, \text{ and } (a-b) = \frac{2ac}{2+c}.$$

The standard deviation of the difference $(a-b)$ is equal to the square root of the sum of the squares of the standard deviations of a and b, or, denoting this standard deviation by $\sigma_{a\text{-}b}$

$$\sigma_{a\text{-}b} = \sqrt{\left[\frac{C_1 a}{100\sqrt{n}}\right]^2 + \left[\frac{C_2 b}{100\sqrt{n}}\right]^2} = \frac{1}{100\sqrt{n}}\sqrt{C_1^2 a^2 + C_2^2 b^2}.$$

Substituting the value of b in terms of a and c above found,

$$\sigma_{a\text{-}b} = \frac{1}{100\sqrt{n}}\sqrt{C_1^2 a^2 + C_2^2 a^2\left[\frac{2-c}{2+c}\right]^2} = \frac{a}{100\sqrt{n}}\sqrt{C_1^2 + C_2^2\left[\frac{2-c}{2+c}\right]^2}.$$

The ratio of the difference $(a-b)$ to its standard deviation is therefore

$$\frac{a-b}{\sigma_{a\text{-}b}} = \frac{2ac}{2+c} \div \frac{a}{100\sqrt{n}}\sqrt{C_1^2 + C_2^2\left[\frac{2-c}{2+c}\right]^2} = \frac{2c \times 100\sqrt{n}}{\sqrt{C_1^2(2+c)^2 + C_2^2(2-c)^2}}.$$

Now, in order that the odds be at least 30 to 1 that the difference $(a-b)$ is significant in the sense that it is in part due to the difference in the treatment accorded Lots I and II,[b] this ratio of $(a-b)$ to the presumptive standard deviation of $(a-b)$ must be at least equal to 1.849, a number obtainable from a table of the values of the normal probability integral, such as that in C. B. Daven-

[a]The following discussion will also, of course, apply to two equal lots of animals of different type, breed, age, sex, etc., treated similarly.

[b]Or, in the case of dissimilar lots treated alike, to the difference in breed, type, age, sex, previous treatment, etc., between Lots I and II.

port's "Statistical Methods," 2d ed., p. 119. Therefore, by solving the equation

$$\frac{2\ C \times 100\ \sqrt{n}}{\sqrt{C_1^2(2+c)^2 + C_2^2(2-c)^2}} = 1.849$$

for n, assigning different values to c and the most probable values available for C_1 and C_2, we obtain an estimate of the least number of animals per lot that can be used in satisfactorily demonstrating the significance of the corresponding percentage difference c. For the use to which the above formula is to be put, we shall simplify the problem by assuming that $C_1 = C_2 = C$. The formula to be solved for n then reduces to

$$\frac{c \times 100\sqrt{n}}{C\sqrt{2 + \frac{1}{2}c^2}} = 1.849, \text{ or } n = \left[\frac{1.849\ C\sqrt{2 + \frac{1}{2}c^2}}{100\ c}\right]^2.$$

In constructing Table 1, page 487, the values assigned to C are 21 for sheep and 17 for swine and steers, these values being taken from the data in the Appendix, Tables 1, 2, and 3.

CHANGE IN VARIABILITY OF GAINS IN WEIGHT AS RELATED TO FEED CONSUMPTION

TABLE 5.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF TWO LITTERS OF PIGS, AND TOTAL CONSUMPTION OF DRY SUBSTANCE PER LOT PER WEEK[a]

(All weights expressed in pounds)

Total gain	Statistical data of total gains in weight			Dry substance consumed per week	Statistical data of total gains in weight			Dry substance consumed per week
	Mean	Standard deviation	Coefficient of variation		Mean	Standard deviation	Coefficient of variation	
	Lot I. Litter of 8 Duroc-Jersey Pigs				Lot II. Litter of 9 Poland-China Pigs			
In 1 week........	4.43	0.86	19.32	117	2.78	1.04	37.41	123
In 2 weeks.......	8.09	1.76	21.76	79	4.22	1.09	25.83	68
In 3 weeks.......	14.03	2.55	18.18	111	7.39	1.31	17.73	80
In 4 weeks.......	21.00	2.76	13.15	115	11.78	1.40	11.91	86
In 5 weeks.......	25.84	3.36	13.00	65	16.42	1.66	10.13	94
In 6 weeks.......	34.31	4.08	11.89	125	21.67	2.44	11.25	69
In 7 weeks.......	41.19	4.81	11.68	132	26.72	2.59	9.70	93
In 8 weeks.......	46.31	3.81	8.23	124	31.22	2.71	8.68	86
In 9 weeks.......	49.06	5.70	11.62	131	36.61	2.64	7.20	122
In 10 weeks.......	60.44	6.32	10.45	149	44.00	3.92	8.91	120
In 11 weeks.......	66.25	7.37	11.13	166	48.83	3.78	7.74	140
In 12 weeks.......	71.81	8.29	11.54	151	54.72	4.33	7.91	123
In 13 weeks.......	76.00	7.20	9.47	152	57.72	4.02	6.97	122
In 14 weeks.......	86.31	7.72	8.95	168	64.89	3.95	6.08	145
In 15 weeks.......	91.62	9.30	10.15	196	70.67	4.43	6.27	170
In 16 weeks.......	97.62	10.25	10.50	202	77.72	5.51	7.09	183
In 17 weeks.......	104.60	9.77	9.34	217	83.55	4.11	4.92	192

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TABLE 6.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF TWO LOTS OF PIGS, AND TOTAL FEED CONSUMPTION PER LOT PER WEEK (28)

(All weights expressed in pounds)

Total gain	Statistical data of total gains in weight			Total feed consumption per week	
	Mean	Standard deviation	Coefficient of variation	Corn	Shorts
Lot I. 14 Pigs (Whole Corn)					
In 1 week	7.21	2.81	38.95	350	175
In 2 weeks	18.64	4.74	25.46	392	196
In 3 weeks	26.71	4.60	17.24	392	196
In 4 weeks	37.93	5.49	14.46	420	210
In 5 weeks	45.36	6.15	13.55	420	210
In 6 weeks	54.64	8.08	14.78	420	210
In 7 weeks	64.36	8.81	13.69	448	224
In 8 weeks	72.93	10.33	14.16	448	224
In 9 weeks	80.50	10.55	13.11	448	224
In 10 weeks	89.64	12.14	13.54	448	224
In 11 weeks	96.78	13.69	14.15	448	224
In 12 weeks	104.9	14.75	14.06	448	224
In 13 weeks	114.0	13.86	12.16	420	210
In 14 weeks	112.2	15.83	14.11	350	175
Lot II. 14 Pigs (Corn Meal)					
In 1 week	6.71	3.32	49.53	350	175
In 2 weeks	20.86	6.32	30.31	406	203
In 3 weeks	28.79	5.70	19.79	406	203
In 4 weeks	39.93	5.77	14.46	448	224
In 5 weeks	48.36	7.19	14.86	448	224
In 6 weeks	57.78	6.63	11.48	448	224
In 7 weeks	70.14	7.77	11.08	476	238
In 8 weeks	80.86	11.35	14.04	476	238
In 9 weeks	92.50	13.04	14.10	476	238
In 10 weeks	103.5	14.54	14.05	476	238
In 11 weeks	114.9	16.76	14.59	476	238
In 12 weeks	125.5	18.55	14.78	476	238
In 13 weeks	135.9	20.98	15.44	448	224
In 14 weeks	138.4	21.65	15.64	373	187

TABLE 7.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF TWO LOTS OF PIGS, AND TOTAL FEED CONSUMPTION PER LOT PER WEEK (30)

(All weights expressed in pounds)

Total gain	Statistical data of total gains in weight			Total weekly feed consumption		Statistical data of total gains in weight			Total weekly feed consumption	
	Mean	Standard deviation	Coeffi- cient of variation	Corn	Shorts	Mean	Standard deviation	Coeffi- cient of variation	Corn	Shorts
	Lot I. 10 Pigs (Shelled Corn)					Lot II. 10 Pigs (Corn Meal)				
In 1 week...	6.8	3.34	49.12	353	75	4.9	4.50	91.92	348	69
In 2 weeks..	11.1	4.95	44.59	375	70	16.8	7.95	47.30	415	70
In 3 weeks..	21.3	7.68	36.07	386	70	30.8	8.98	29.14	468	70
In 4 weeks..	30.4	7.32	24.09	408	70	43.2	9.85	22.79	488	70
In 5 weeks..	38.8	8.49	21.89	420	70	55.1	10.33	18.75	490	70
In 6 weeks..	46.5	9.62	20.70	420	70	65.8	10.62	16.14	490	70
In 7 weeks..	55.0	10.28	18.70	420	70	76.0	11.61	15.28	490	70
In 8 weeks..	63.6	9.97	15.68	404	70	86.9	13.63	15.68	452	70
In 9 weeks..	69.7	11.51	16.51	398	70	96.2	14.38	14.95	450	70
In 10 weeks..	78.9	11.90	15.08	376	70	107.6	14.21	13.21	446	70

TABLE 8.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF TWO LOTS OF PIGS, AND TOTAL FEED CONSUMPTION PER LOT PER WEEK (29)

(All weights expressed in pounds)

Total gain	Statistical data of total gains in weight			Total weekly feed consumption		Statistical data of total gains in weight			Total weekly feed consumption	
	Mean	Standard deviation	Coefficient of variation	Corn	Shorts	Mean	Standard deviation	Coefficient of variation	Corn	Shorts
	Lot I. 9 Pigs (Whole Corn)					Lot II. 9 Pigs (Corn Meal)				
In 1 week...	18.4	3.37	18.27	382	68	18.0	3.94	21.91	383	68
In 2 weeks..	33.8	5.92	17.53	495	63	34.9	6.92	19.83	495	63
In 3 weeks..	45.8	12.92	28.22	504	63	49.0	7.92	16.15	504	63
In 4 weeks..	60.0	11.50	19.17	540	63	67.6	10.07	14.90	549	63
In 5 weeks..	68.9	15.35	22.28	567	63	80.8	10.19	12.62	567	63
In 6 weeks..	84.9	18.83	22.21	565	62	99.3	8.08	8.14	567	63
In 7 weeks..	100.5	18.29	18.20	560	62	114.3	9.59	8.39	567	63
In 8 weeks..	108.0	15.87	14.69	567	63	125.9	12.45	9.89	567	63
In 9 weeks..	123.1	19.40	15.76	567	63	139.3	11.68	8.38	567	63
In 10 weeks..	137.2	17.70	12.90	567	63	149.8	11.97	7.99	567	63

TABLE 9.—CHANGE IN VARIABILITY OF TOTAL GAINS IN WEIGHT OF TWO LOTS OF PIGS, AND TOTAL FEED CONSUMPTION PER LOT PER WEEK (32)

(All weights expressed in pounds)

Total gain	Statistical data of total gains in weight			Total feed consumption per week		
	Mean	Standard deviation	Coefficient of variation	Corn	Wheat middlings	Skim milk
Lot I. 12 Pigs (Whole Corn)						
In 1 week	6.33	1.89	29.80	125	125	168
In 2 weeks	13.50	2.63	19.48	129	129	168
In 3 weeks	21.42	2.87	13.40	157	155	168
In 4 weeks	29.75	3.00	10.10	158	158	168
In 5 weeks	41.08	5.01	12.19	180	181	168
In 6 weeks	46.17	6.82	14.76	163	163	161
In 7 weeks	56.58	7.51	13.27	170	170	168
In 8 weeks	61.42	10.13	16.50	186	186	168
In 9 weeks	71.42	10.49	14.69	201	201	168
In 10 weeks	81.92	12.19	14.88	223	223	168
In 11 weeks	90.67	13.18	14.53	233	233	168
In 12 weeks	100.40	15.60	15.54	243	243	168
Lot II. 12 Pigs (Corn Meal)						
In 1 week	5.08	2.36	46.50	128	128	168
In 2 weeks	11.83	3.14	26.57	134	134	168
In 3 weeks	20.58	3.71	18.01	165	165	168
In 4 weeks	29.58	5.04	17.04	161	161	168
In 5 weeks	41.33	5.54	13.41	188	188	168
In 6 weeks	47.83	7.36	15.39	187	187	161
In 7 weeks	58.83	8.38	14.25	200	200	168
In 8 weeks	66.75	11.50	17.23	212	212	168
In 9 weeks	76.75	12.51	16.30	229	229	168
In 10 weeks	86.67	14.21	16.40	241	241	168
In 11 weeks	99.08	16.64	16.78	257	257	168
In 12 weeks	108.20	17.86	16.51	271	271	168

BIBLIOGRAPHY

1. Craig, S. J. and Melvin, L. R. Ill. Agr. Exp. Sta. Bachelor Thesis. 1906.
2. Craig, J. A. Wis. Agr. Exp. Sta. Bul. 32. 1892.
3. Coffey, W. C. Ill. Agr. Exp. Sta. Bachelor Thesis. 1906.
4. Wilson, J. W. So. Dak. Agr. Exp. Bul. 119. 1910.
5. Wilson, J. W. Ibid.
6. Coffey, W. C. Ill. Agr. Exp. Sta. Master Thesis. 1909.
7. Chilcott, E. C. and Thornber, W T. So. Dak. Agr. Exp. Sta. Bul. 71. 1901.
8. Carlyle, W. L. Wis. Agr. Exp. Sta. 16th Annual Report. 1899.
9. Carlyle, W. L. Wis. Agr. Exp. Sta. 15th Annual Report. 1898.
10. Craig, J. A. Wis. Agr. Exp. Sta. Bul. 32. 1892.
11. Wilson, J. W. and Skinner, H. G. So. Dak. Agr. Exp. Sta. Bul. 86. 1904.
12. Wilson, J. W. and Skinner, H. G. So. Dak. Agr. Exp. Sta. Bul. 80. 1903.
13. Mumford, H. W. Mich. Agr. Exp. Sta. Bul. 136. 1896.
14. Arkell, T. R. N. H. Agr. Exp. Sta. Bul. 152. 1911.
15. Arkell, T. R. Ibid.
16. Grindley, H. S., Coffey, W. C., and Emmett, A. D. Ill. Agr. Exp. Sta. Unpublished manuscript. 1912.
17. Voelcker, J. A. Journ. Roy. Agr. Soc. of Engl. Vol. 63. 1902. From Woburn Station.
18. Voelcker, J. A. Journ. Roy. Agr. Soc. of Engl. Vol. 62. 1901. From Woburn Station.
19. Voelcker, J. A. Journ. Roy. Agr. Soc. of Engl. Vol. 60. 1899. From Woburn Station.
20. Voelcker, J. A. Ibid.
21. Voelcker, J. A. Journ. Roy. Agr. Soc. of Engl. Vol. 59. 1898. From Woburn Station.
22. Voelcker, J. A. Journ. Roy. Agr. Soc. of Engl. Vol. 57. 1896. From Woburn Station.
23. Voelcker, J. A. Journ. Roy. Agr. Soc. of Engl. Vol. 53. 1892. From Woburn Station.
24. Voelcker, J. A. Journ. Roy. Agr. Soc. of Engl. Vol. 56. 1895. From Woburn Station.
25. Lawes, J. B. Journ. Roy. Agr. Soc. of Engl. Vol. 10. 1849. From Rothamsted Station.
26. Lawes, J. B. Ibid.
27. Lawes, J. B. Journ. Roy. Agr. Soc. of Engl. Vol. 12. 1851. From Rothamsted Station.
28. Lawes, J. B. Journ. Roy. Agr. Soc. of Engl. Vol. 13. 1852. From Rothamsted Station.
29. Lawes, J. B. Journ. Roy. Agr. Soc. of Engl. Vol. 16. 1855. From Rothamsted Station.
30. Shaw, T. Minn. Agr. Exp. Sta. Bul. 76. 1902.
31. Shaw, T. Ibid.
32. Watson, G. C. and Risser, A. K. Penn. Agr. Exp. Sta. Bul. 57. 1901.
33. Carmichael, B. E. Ohio Agr. Exp. Sta. Bul. 193. 1908.
34. Sheppard, J. H. and Richards, W. B. No. Dak. Agr. Exp. Sta. Bul. 73. 1906.
35. Mairs, T. I. and Risser, A. K. Penn. Agr. Exp. Sta. Bul. 64. 1903.
36. Mairs, T. I. and Risser, A. K. Penn. Agr. Exp. Sta. Bul. 68. 1904.
37. Mairs, T. I. and Miller, N. G. Penn. Agr. Exp. Sta. Bul. 74. 1905.
38. Mairs, T. I. Penn. Agr. Exp. Sta. Bul 83. 1907.
39. Mairs, T. I. Ibid.
40. Mairs, T. I. Ibid.
41. Mairs, T. I. and Tomhave, W. H. Penn. Agr. Exp. Sta. Bul. 88. 1908.
42. Mairs, T. I. and Tomhave, W. H. Ibid.
43. Mumford, H. W. Ill. Agr. Exp. Sta. Bul. 103. 1905.
44. Georgeson, C. C., Burtis, F. C., and Shelton, Wm. Kan. Agr. Exp. Sta. Bul. 34. 1895.

45. Georgeson, C. C., Burtis, F. C., and Otis, D. H. Kan. Agr. Exp. Sta. Bul. 39. 1893.
46. Georgeson, C. C., Burtis, F. C., and Otis, D. H. Kan. Agr. Exp. Sta. Bul. 47. 1894.
47. Georgeson, C. C., Burtis, F. C., and Otis, D. H. Kan. Agr. Exp. Sta. Bul. 51. 1895.
48. Robertson, R. Canadian Experimental Farms. Report for 1901. 360-363.
49. Voelcker, J. A. Journ. Roy. Agr. Soc. of Engl. Vol. 63. 1902. From Woburn Station.
50. Voelcker, J. A. Journ. Roy. Agr. Soc. of Engl. Vol. 62. 1901. From Woburn Station.
51. Voelcker, J. A. Journ. Roy. Agr. Soc. of Engl. Vol. 60. 1899. From Woburn Station.
52. Voelcker, J. A. Journ. Roy. Agr. Soc. of Engl. Vol. 59. 1898. From Woburn Station.
53. Voelcker, J. A. Ibid.
54. Voelcker, J. A. Journ. Roy. Agr. Soc. of Engl. Vol. 56. 1895. From Woburn Station.
55. Voelcker, J. A. Journ. Roy. Agr. Soc. of Engl. Vol. 57. 1896. From Woburn Station.
56. Voelcker, J. A. Journ. Roy. Agr. Soc. of Engl. Vol. 53. 1892. From Woburn Station.
57. Voelcker, J. A. Ibid.
58. Carlyle, W. L. Wis. Agr. Exp. Sta. 15th Annual Report. 1898.
59. Henry, W. A. Wis. Agr. Exp. Sta. 16th Annual Report. 1899.
60. Carlyle, W. L. Ibid.
61. Michael, L. G. and Kennedy, W. J. Iowa Agr. Exp. Sta. Bul. 113. 1910.
62. Wing, H. H. N. Y. (Cornell) Agr. Exp. Sta. Bul. 220. 1904.
63. Henry, W. A. Wis. Agr. Exp. Sta. 15th Annual Report. 1898.
64. Kennedy, W. J. and Robbins, E. T. Iowa Agr. Exp. Sta. Bul. 91. 1907.
65. Kennedy, W. J. and Robbins, E. T. Ibid.
66. Henry, W. A. Wis. Agr. Exp. Sta. 17th Annual Report. 1900.
67. Henry, W. A. Wis. Agr. Exp. Sta. 15th Annual Report. 1898.
68. Henry, W. A. Ibid.
69. Carlyle, W. L. and Hopkins, A. G. Wis. Agr. Exp. Sta. 17th Annual Report. 1900.
70. Henry, W. A. and Otis D. H. Wis. Agr. Exp. Sta. Bul. 145. 1907.
71. Henry, W. A. and Otis, D. H. Ibid.
72. Henry, W. A. and Otis, D. H. Ibid.
73. Sheppard, J. H. and Richards, W. B. N. Dak. Agr. Exp. Sta. Bul. 84. 1909.
74. Georgeson, C. C., Burtis, F. C., and Otis, D. H. Kan. Agr. Exp. Sta. Bul. 47. 1894.
75. Grisdale, J. H. Canadian Experimental Farms. Report for 1899: 61.
76. Robertson, R. Canadian Experimental Farms. Report for 1900: 309-310.
77. Robertson, R. Canadian Experimental Farms. Report for 1899: 255-256.
78. Shutt, F. T. Canadian Experimental Farms. Report for 1902: 219-222.
79. Shutt, F. T. Canadian Experimental Farms. Report for 1902: 222-223.
80. Shutt, F. T. Canadian Experimental Farms. Report for 1902: 226-227.
81. Shutt, F. T. Canadian Experimental Farms. Report for 1902: 226-227.
82. Shutt, F. T. Canadian Experimental Farms. Report for 1902: 228-230.
83. Gilbert, A. G. Canadian Experimental Farms. Report for 1905: 256.
84. Shutt, F. T. Canadian Experimental Farms. Report for 1898: 214.