A Technical Study of the Growth of White Leghorn Chickens

By H. H. Mitchell, L. E. Card,
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By H. H. Mitchell, L. E. Card, and T. S. Hamilton[a]

THE FORMULATION of feeding standards applying to different classes of animals and to a variety of conditions is one of the most practical contributions of the science of nutrition to the feeding of farm animals. How greatly these standards have modified feeding practice cannot be told, but undoubtedly a knowledge of feeding standards and their limitations will aid the livestock man materially in the intelligent appreciation of his business, particularly in the ability to cope successfully with changing conditions of feed supply and to avoid exploitation by manufacturers of commercial feeds, mineral mixtures, and other products for livestock.

Feeding standards should promote maximal production with a minimum of overfeeding. They should include a factor of safety so that ordinary variation in the composition and nutritive value of feeds and in the functional capacities of animals will rarely result in underfeeding. But obviously a definite factor of safety cannot be included in a feeding standard in any intelligent fashion until the actual minimum requirements of animals for the different nutrients have been determined. Hence feeding standards for farm animals must ultimately be based upon satisfactory determinations of minimum animal requirements.

Feeding a farm animal in exact accord with its requirements for protein, or mineral matter, or even energy, may never be necessary or advisable, but when an animal is nonproducing at certain seasons of the year, or when protein concentrates become relatively high in price, it may become expedient to approximate these requirements, so that an exact knowledge of them becomes of practical value and importance.

For these reasons, a study of the minimum nutritive requirements of chickens is justified from practical as well as scientific considerations. The fact that little information of this character has been obtained for chickens is but another reason for undertaking the present series of investigations.

In Bulletin 278 of this Station[10]* a study of the growth of White Plymouth Rock chickens was reported. The study reported in this

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bulletin is a similar investigation of Single Comb White Leghorn chickens. The purpose of both bulletins may be briefly described as follows:

1. To secure additional data on the normal rate of growth of chickens. The practical value of this information lies in the aid it will afford the animal husbandman in judging the success of his own feeding operations.

2. To determine how the visceral organs and the different anatomical parts of the carcass increase during growth, and how their weights, expressed as percentages of the body weight, vary with age. This information determines the value of the carcass of the chicken at any age as a source of food and, conversely, the amount of wastage incurred in the preparation of birds of different ages for the table. It also possesses considerable biological interest in relation to the comparative study of growth among different species of animals.

3. To determine the chemical composition of chickens of different ages and, by the application of mathematical methods for the description of growth changes, the rates of deposition of the different food nutrients in the body at any age. The daily amounts of energy, of protein, and of mineral matter required for growth are determined primarily by the amounts added to the body each day, tho in satisfying these requirements by food the composition of the food in *net* nutrients, rather than in *total* nutrients, must be considered.

DESCRIPTION OF EXPERIMENT

A flock of 1,000 Single Comb White Leghorn chicks, hatched about April 15, 1926, was available for this study. The chicks were range-reared at the University poultry farm on a ration consisting of yellow corn 80 parts, wheat middlings 10 parts, wheat bran 10 parts, ground limestone 5 parts, bone meal 5 parts, salt 1 part, and skim milk *ad libitum*. At the age of 10 weeks the cockerels and pullets were separated. The birds were weighed individually every two weeks, except for certain unavoidable irregularities in time in the latter part of the experiment.

Samples of birds were removed for measurement and analysis according to weight. A sample of 10 newly hatched chicks (2 days old) was taken at the start of the experiment, and when the average weight of each flock reached approximately .5 pound, 1 pound, 1.5 pounds, 2 pounds, 3 pounds, and 4 pounds, samples of 10 cockerels and 10 pullets weighing very close to the average of their respective flocks were removed. A final sample of 10 cockerels was taken when the remaining cockerels averaged about 5 pounds in weight. All withdrawals of samples were made at the time of the biweekly weighings.

The following measurements were made upon all birds removed for slaughter:

1. Depth from front end of keel bone to back
2. Depth from rear end of keel bone to back
3. Length from rump to shoulder
4. Circumference of trunk just back of wings
5. Length of shank
6. Length of middle toe
7. Length of drumstick
8. Length of keel bone
9. Breadth from hip to hip

Upon completion of these measurements the birds were bled and dry-picked. The skins were removed, stretched, and outlined on paper, and their areas determined with a planimeter. The carcasses were then cut up and the weights of the following viscera and parts were taken:

1. Blood
2. Feathers
3. Head
4. Neck
5. Shanks and feet
6. Skin
7. Legs above hock
8. Wings
9. Torso
10. Heart
11. Liver
12. Kidneys
13. Spleen
14. Lungs
15. Testicles (or ovaries and oviduct)
16. Pancreas
17. Gall-bladder
18. Gizzard
19. Gullet, crop, and proventriculus
20. Intestines
21. Contents of alimentary canal
22. Total bones in dressed carcass
23. Total flesh (including fat) in dressed carcass

For each group of 10 birds the following samples were composited for chemical analysis:

1. Feathers
2. Total bones in dressed carcass
3. Flesh and fat in dressed carcass, skin, and edible viscera, including liver, heart, and gizzard (minus lining)
4. Offal, including blood, head, shanks, and feet and all viscera except those included in Sample 3

All composite samples were analyzed for moisture, nitrogen, ether extract, ash, and calcium, and their content of gross energy was determined in the bomb calorimeter. The samples were preserved by refrigeration only. The percentage of dry substance in each sample was corrected, so far as possible, for moisture losses during dissecting, weighing, and grinding.

EXPERIMENTAL RESULTS

GROWTH AS MEASURED BY BODY WEIGHT

The average body weights of the cockerels and pullets by two-week intervals up to 24 weeks of age and at irregular intervals up to

40 weeks of age are given in Table 1. The table also contains the standard deviations and coefficients of variation of the body weights of the two groups of birds at each weighing.

In this investigation the variation in body weight was less than 10 percent at hatching; at 6 weeks of age it increased to 16.6 percent

TABLE 1.—GROWTH AND VARIABILITY IN BODY WEIGHT OF WHITE LEGHORN CHICKENS

Age	Cockerels				Pullets			
	Number	Body weight			Number	Body weight		
		Average	Stand. dev.	Coef. of variation		Average	Stand. dev.	Coef. of variation
wks.		*gms.*				*gms.*		
0	417	35.3	2.90	8.2	362	35.0	3.48	9.9
2	417	93	10.74	11.6	362	90	11.01	12.3
4	417	188	29.2	15.5	362	177	28.3	16.0
6	417	334	55.5	16.6	362	302	59.9	19.9
8	404	505	75.1	14.9	346	443	68.9	15.6
10	392	715	118	16.5	335	605	87.3	14.4
12	380	882	126	14.3	324	740	89.6	12.1
14	362	1 052	329	31.3	317	844	107	12.6
16	344	1 239	157	12.7	307	988	136	13.7
18	335	1 378	202	14.7	304	1 113	131	11.8
20	330	1 486	111	7.4	299	1 218	143	11.7
22	329	1 621	203	12.5	293	1 327	141	10.6
24	319	1 716	182	10.6	269	1 380	137	9.9
28	311	1 883	201	10.6	231	1 694	...	....
36	47	2 334	...	....	205	1 694	...	....
40	47	2 309	...	....	203	1 726	...	....

NOTE—The sex of all chicks was recorded at 6 weeks of age. Weight data secured on chicks dying before reaching 6 weeks of age are therefore excluded from this table.

for the cockerels and to 19.9 percent for the pullets, and then decreased irregularly to about 10 percent at the later ages. The decrease in variation of weight with increasing age was more regular and rapid for the pullets than for the cockerels. These changes of weight variability with age parallel in a general way those reported by Titus and Jull[17*] for Rhode Island Red chickens receiving skim milk in their mash and by Hanson and Heys[8*] for rats.

These growth data may be profitably compared with those published by Buckner, Wilkins, and Kastle[3*] from the Kentucky Agricultural Experiment Station and by Card and Kirkpatrick from the Connecticut (Storrs) Station.[4*] This comparison is made graphically in Fig. 1, from which it appears that the growth obtained with White Leghorn chickens in this investigation was not greatly different from that reported from the other two studies. At the younger ages growth was somewhat slower in the Illinois investigation, but at the later ages it was at least as rapid.

Mathematical Description of Growth. The value of a mathematical description of the growth of White Leghorn chickens in body

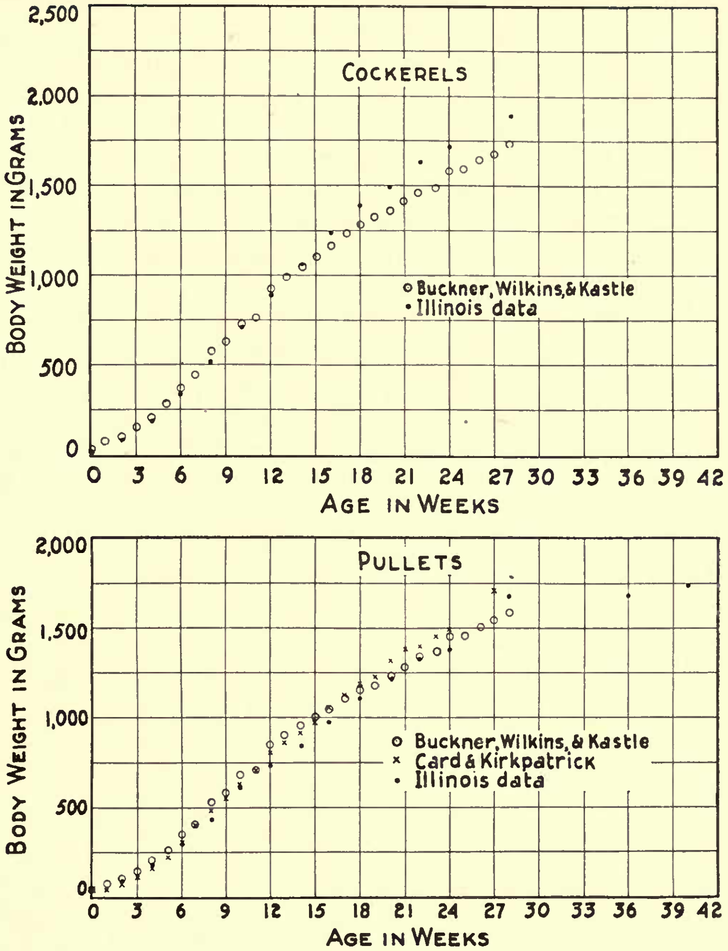


FIG. 1.—GROWTH OF WHITE LEGHORN CHICKENS

weight, as well as in the weights of chemical constituents, certainly justifies the labor involved. This description has been made purely as a step in the interpretation of the data secured in this study, with no pretense or implication that definite laws of growth for White Leghorn chickens are being defined in this way. The rationale of this application of mathematics is as follows:

Animal growth, in any of its numerous aspects, is a dynamic phenomenon which may be supposed to proceed in a smooth and definite manner when the influence of disturbing factors is removed.

Growth is ordinarily studied in piecemeal fashion by attempting to determine the change with time of some animal measurement, such as body weight, or the weight of some definite organ, or the weight of protein in the body. If this is depicted graphically on coordinate paper, it will, under ideal conditions, move along a smooth curve, often a relatively simple one, the shape of which is defined by a simple mathematical function (equation) relating age (time) to the variable in question. More often, however, a simple mathematical equation will not describe the entire growth change, but only a fraction of it. Yet for the time range over which it describes the growth change, the mathematical equation is a complete, concise, and serviceable description of it.

Quantitative observations of growth changes can be made only rarely under the ideal conditions just considered, this being particularly true of the growth changes occurring in farm animals. The confinement of large numbers of these animals under uniform and favorable environmental conditions is quite impracticable. Hence disturbances in growth due to weather changes, feed changes, and digestive and other minor pathological affections of the animal occur, and they occasion irregularities in the measurements secured that bear no definite significance in relation to growth. When such measurements are plotted on coordinate paper, it is impossible to connect them by a curved line of any simple description, even over narrow ranges of time. The description by a mathematical equation of a series of actual observations upon the time changes occurring in growing animals is thus not a simple process. A choice must be made of the mathematical function that will be used, based upon the gross shape of the age-weight relationship, or upon the functions that have been used with most success in describing similar data. The constants in the mathematical function chosen must then be determined from the observational data by some method designed to secure a satisfactory fit.

The mathematical equation thus obtained from the observed data expresses in the most satisfactory manner the time changes that would have been observed under the ideal conditions previously considered. This equation may therefore be used as a substitute for the mass of data from which it was derived, in the same way, and for precisely the same reason, as an arithmetic mean (average) may be used to represent a mass of data clustering about a point rather than a curve.

The advantages of thus reducing a series of variable and disconnected observations relating to growth to a continuous mathematical function are important. From such a function the most probable value of the growth measurement may be computed for *any instant of time*, regardless of the time intervals at which measurements were actually taken. Also the estimation of the value of the measurement at any given time is not unduly affected by any disturbing conditions that may have produced irregularities in growth at or near that time, since the estimation is based upon *all* the data obtained rather than on a few selected values. From the equations describing the growth data, the *rate of change* in the measurement *at any instant of time*, as well as the change in the measurement during any definite interval of time, may also be readily computed—a most important advantage of this mathematical method of analysis. The original mass of data cannot, by any other method, be made to yield satisfactory information of this nature. Hence for the most productive study of growth the application of mathematical methods is essential.

Growth Curves and Equations. Many attempts have been made to describe the growth of animals and of plants by means of mathematical equations relating the measurement under consideration with the age of the animal, taken either from birth or from conception. Such equations may be purely empirical in character, the investigator being content to use any type of equation that will fit the data satisfactorily and yet not contain an inordinate number of constants, the values of which are to be determined from the data. On the other hand, other investigators have selected certain types of equations on the basis of definite assumptions concerning the laws of growth. In these equations the constants possess a certain biological significance and may be evaluated approximately by mere inspection of the data, or by simple graphical methods.

The latter type of equation unquestionably would possess a marked preference over the former if the laws of change that they express were established for growth, or were so plausible as to be generally acceptable. But such is not the case; their value in expressing growth changes must after all rest upon an empirical basis, i.e., upon the success with which they describe the change, with time, of actual growth measurements. The two equations of this character that have been used the most in this country are the Robertson equation,[15*] in which growth changes are likened to the progress of an autocatalytic monomolecular chemical reaction, and the equation of Brody,[2*] which assumes that after a certain stage of growth is reached, successive increments in growth bear a definite and constant relationship to each other. Neither equation (the latter admittedly) has been found satisfactory in describing growth from its beginning to its completion, and in using them in a rational way to describe certain segments of the growth curve one must postulate the existence of cycles of growth. In defining these cycles there is always the danger of ascribing to fortuitous depressions or accelerations of growth, occasioned by changes in environmental conditions, a biological significance that they do not possess. After all, the advantages of these so-called rational growth equations seem to be that they have been used with some degree of success in describing animal growth, that they possess only three constants to be evaluated, and that these constants possess a more or less definite biological significance.

In a recent discussion of the kinetics of growth, Gray[7*] says:

" . . . the comparison of metazoon growth with the behavior of comparatively simple chemical reactions meets with three main difficulties. Firstly, a series of observations which approximate to a sigmoid curve can only be expressed in the form of a specific differential equation when the accuracy of the observations reaches a very high level. Until such data are available it is impossible to determine how far they can only be expressed by the highly specific curves applicable to chemical systems. Secondly, there is no direct method of determining the active mass of the growing substance or of the other factors involved in the reaction: these may be proportional to the weight of the organism although no definite proof exists. Thirdly, the growing system is known to be statistically heterogeneous, and in the absence of reliable evidence to the contrary, it is intrinsically improbable that the system will behave like a system whose heterogeneity is constant . . .

"An equation representing the size of a population of cells or of an organism in terms of age, yields, on differentiation, a quantitative but empirical representation of the factors controlling the rate of growth, but since more than one equation can always represent a typical growth curve within the limits of probable error, a selection of one particular equation rests solely on the intrinsic probability of its differential form. The degree of probability can only be established by direct experiment."

Concerning Robertson's method of using his exponential equation successively in describing successive "cycles of growth," Gray says that by selecting suitable constants and "by using an appropriate number of superimposed curves there can be no doubt that an equation of this type can be shown to express the facts. Unless, however, there are definite experimental reasons for adopting this procedure, the equation has no real meaning unless its advocates can prove that no other equation will fit the facts."

Regarding Brody's exponential equations Gray says:

". . . it is sufficient to point out that any curve can be expressed as a series of straight lines or exponential curves if suitable limits are selected. Unless, therefore, there is good independent evidence that the whole growth cycle is divisible into a finite number of successive and different processes, the process of subdivision of the growth curve is purely arbitrary."

Mathematical Analysis of Growth Data. In the present investigation the choice lay between the application of two so-called rational growth equations, in the manner of Titus and Jull,[17*] or the use of one frankly empirical equation. The growth data relating to body weight are fairly numerous, but the chemical data, which are to be interpreted by this means also, consist of several series of only seven or eight observations each. To fit two equations containing three constants each to such small series of data was not considered advisable. Therefore, with some feeling of regret, a purely empirical polynomial equation of the fourth degree of the type

$$W = a + bt + ct^2 + dt^3 + et^4 \tag{1}$$

was used thruout. In all cases the constants of this polynomial were determined by the method of least squares.[1]

For the age-body-weight relation, the following equations were obtained for cockerels and pullets, respectively:

$$W = -4 + 43.70t + 4.072t^2 - .1611t^3 + .001731t^4 \tag{2}$$

$$W = 21 + 33.98t + 3.149t^2 - .1083t^3 + .0008637t^4 \tag{3}$$

Here W is the body weight in grams and t the age in weeks from

TABLE 2.—GROWTH OF WHITE LEGHORN CHICKENS, OBSERVED AND ESTIMATED
(All weights in grams)

Age	Cockerels—body weight			Pullets—body weight		
	Observed	Calculated[1]	Difference	Observed	Calculated[2]	Difference
wks.						
0	35	..	....	35	21	−14
2	93	99	+ 6	90	101	+11
4	188	226	+38	177	201	+24
6	334	372	+38	302	316	+14
8	505	558	+53	443	443	0
10	715	706	− 9	605	576	−29
12	882	865	−17	740	713	−27
14	1 052	1 031	−21	844	850	+ 6
16	1 239	1 192	−47	988	984	− 4
18	1 378	1 344	−34	1 113	1 112	− 1
20	1 486	1 487	+ 1	1 218	1 232	+14
22	1 621	1 618	− 3	1 327	1 342	+15
24	1 716	1 738	+22	1 380	1 440	+60
26	.....	1 844	....	.....	1 525	....
28	1 883	1 963	+80	1 694	1 595	−99
30	.....	2 024	....	.....	1 651	....
32	.....	2 100	....	.....	1 691	....
34	.....	2 170	....	.....	1 715	....
36	2 334	2 237	−97	1 694	1 725	+31
38	.....	2 305	....	.....	1 719	....
40	2 309	2 379	+70	1 726	1 700	−26

[1]Using the equation: $W = -4 + 43.70t + 4.072t^2 - .1611t^3 + .001731t^4$.
[2]Using the equation: $W = 21 + 33.98t + 3.149t^2 - .1083t^3 + .0008637t^4$.

[1]Acknowledgment is made to Miss Florence L. White, Research Assistant in the Bureau of Business Research of the University of Illinois, for the mathematical work of fitting this equation to the growth data reported in this bulletin.

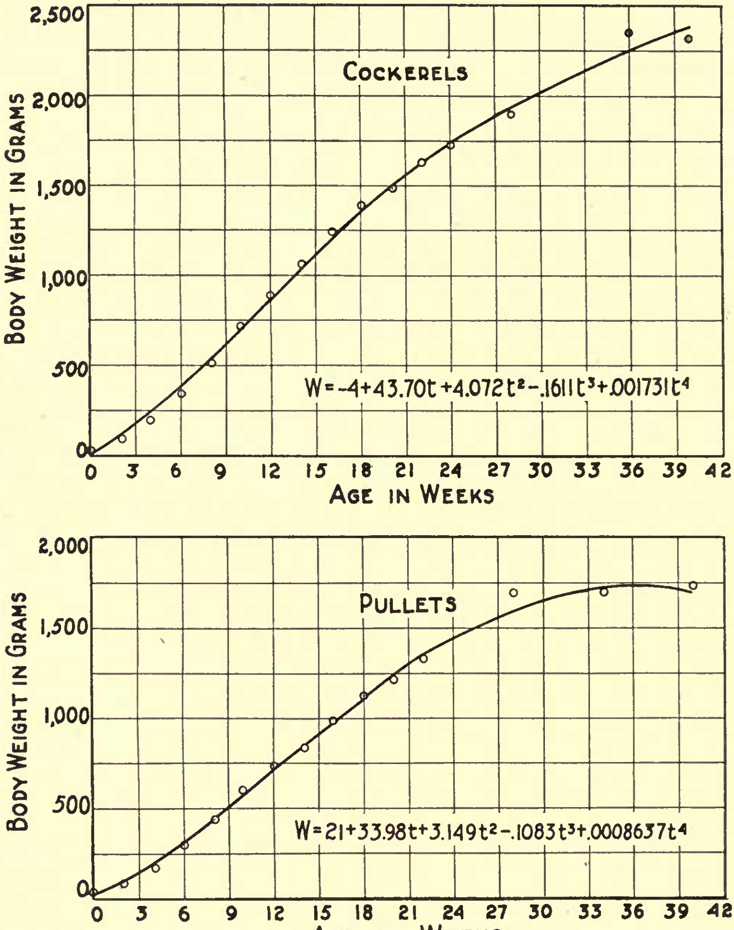


FIG. 2.—GROWTH OF WHITE LEGHORN CHICKENS, OBSERVED AND ESTIMATED

hatching. The fit of these equations to the two sets of growth data is shown numerically in Table 2 and graphically in Fig. 2. From hatching to about 20 weeks of age the average body weights of both cockerels and pullets appear to follow an S-shaped curve, with a point of inflection at an age of 8 or 10 weeks that is not adequately reflected in the polynomial equation. A somewhat better fit for the data of this range has been obtained by the use of Robertson's growth equation.[15]*

The differentiation of Equations 2 and 3 will permit the calculation of the rates of gain $\left(\frac{dW}{dt}\right)$ at any age. Expressed as the rate of gain in grams per day, these differential equations are—

For the cockerels: $$\frac{dW}{dt} = 6.2 + 1.163t - .0690t^2 + .000989t^3 \qquad (4)$$

For the pullets: $$\frac{dW}{dt} = 4.8 + .900t - .0464t^2 + .000493t^3 \qquad (5)$$

From these equations it may be calculated that at the ages (obtained from Equations 2 and 3) at which the chickens attained average weights of .5, 1, 1.5, 2, 3, 4, and 5 pounds, the rates of gain in grams per day were as given in Table 3.

TABLE 3.—ESTIMATED RATES OF GAIN IN BODY WEIGHT BY WHITE LEGHORN CHICKENS AT DIFFERENT BODY WEIGHTS

Body weight	Cockerels		Pullets	
	Age	Daily gain	Age	Daily gain
lbs.	*wks.*	*gms.*	*wks.*	*gms.*
.5	4.0	9.9	4.4	7.9
1	6.9	11.2	8.2	9.4
1.5	9.6	11.9	11.5	9.8
2	12.5	11.8	14.8	9.6
3	18.2	10.5	22.4	7.2
4	25.4	7.4	....	...
5	36.9	4.8	....	...

GROWTH IN SIZE AND FORM OF BODY

The average linear and circumference measurements of the birds, taken before slaughter, are summarized in Tables 4 and 5, each average representing 10 individual measurements.[1] The individual measurements for each weight group were generally very uniform. The coefficients of variation have been calculated for the cockerel measurements and will be found in Table 6. Of the 61 coefficients there recorded, 96.7 percent were equal to or less than 6, 91.8 percent were equal to or less than 5, 80.3 percent were equal to or less than 4, 50.8 percent were equal to or less than 3, and 14.8 percent were equal to or less than 2. These birds were more uniform in size than in weight (Table 1).

Percentage Increases. Change in size of birds with increasing age, as revealed by these linear and circumference measurements, may be studied to better advantage by expressing each average value as a percentage of the corresponding value at the .5-pound weight. The percentages for cockerels are given in Table 7, and those for pullets in Table 8. These tables include also similar percentages for

[1]No measurements of this nature were taken on the day-old chicks.

body surface as determined from skin area. Expressed in this manner, it appears that the birds increased in size in such a way that their shape or conformation, exclusive of feathering, did not change greatly. This seems to be a proper interpretation of the fact that at any weight the measurements taken, except the length of the middle toe, were approximately the same percentages of the corresponding measurements of the lightest birds measured. The body weight and the surface area of the birds, however, increased much more rapidly than

TABLE 4.—AVERAGE BODY MEASUREMENTS OF WHITE LEGHORN COCKERELS AT DIFFERENT WEIGHTS

(Each figure is an average of 10 birds; all measurements in centimeters)

Approximate slaughter weight	.5 lb.	1 lb.	1.5 lb.	2 lbs.	3 lbs.	4 lbs.	5 lbs.
Age in days	44	58	72	86	107	156	219
Live weight in grams	218	477	678	875	1 317	1 719	2 136
Depth at front end of keel	5.7	7.4	8.4	....	10.9	12.2	12.6
Depth at rear end of keel	5.5	6.8	7.8	....	9.5	10.0	10.9
Breadth at hips	4.0	5.2	5.9	6.3	7.8	8.5	9.4
Length of keel	5.6	7.5	8.6	10.7	11.1	12.3	13.3
Length of drumstick	7.5	10.0	11.6	13.3	15.5	16.6	17.1
Length of shank	5.7	7.7	9.0	10.1	12.0	12.5	12.9
Length of middle toe	4.5	5.7	6.3	7.0	7.8	7.8	7.9
Distance from rump to shoulder	9.6	12.7	14.5	16.0	19.0	20.4	21.3
Midcircumference	14.7	20.1	22.9	24.9	28.5	31.7	34.0

TABLE 5.—AVERAGE BODY MEASUREMENTS OF WHITE LEGHORN PULLETS AT DIFFERENT WEIGHTS

(Each figure is an average of 10 birds; all measurements in centimeters)

Approximate slaughter weight	.5 lb.	1 lb.	1.5 lbs.	2 lbs.	3 lbs.	4 lbs.
Age in days	44	58	72	100	159	233
Live weight in grams	223	468	669	890	1 367	1 716
Depth at front end of keel	5.7	7.4	8.5	9.7	10.8	11.3
Depth at rear end of keel	5.3	6.7	7.8	8.6	9.6	11.2
Breadth at hips	4.0	5.3	6.1	6.7	7.9	8.7
Length of keel	5.4	7.7	8.5	9.5	11.6	11.8
Length of drumstick	7.4	10.2	11.7	13.3	14.1	14.4
Length of shank	5.6	7.7	8.9	10.0	10.3	10.5
Length of middle toe	4.4	5.6	6.4	6.5	6.8	6.7
Distance from rump to shoulder	9.7	13.0	14.9	16.5	18.6	19.3
Midcircumference	15.2	20.2	23.1	25.8	29.6	30.6

TABLE 6.—COEFFICIENTS OF VARIATION OF BODY MEASUREMENTS OF WHITE LEGHORN COCKERELS AT DIFFERENT WEIGHTS

Approximate slaughter weight	.5 lb.	1 lb.	1.5 lbs.	2 lbs.	3 lbs.	4 lbs.	5 lbs.
Depth at front end of keel	2.3	3.8	2.4	...	2.4	3.3	2.0
Depth at rear end of keel	3.6	5.1	3.4	...	3.2	7.1	3.2
Breadth at hips	2.4	3.0	2.1	2.2	2.0	1.9	3.4
Length of keel	11.2	4.0	4.6	3.4	5.8	4.4	4.7
Length of drumstick	4.3	1.8	3.1	5.8	2.9	2.7	3.6
Length of shank	3.0	2.3	3.0	2.6	3.7	3.0	4.6
Length of middle toe	5.0	3.4	3.9	4.6	2.6	2.5	3.6
Length from rump to shoulder	3.1	2.5	1.7	2.7	2.4	3.1	1.5
Midcircumference	2.5	2.4	2.1	3.1	2.0	2.0	1.7

the linear measurements, the body weight increasing more rapidly than the body surface.

For surfaces of similar shape the areas will vary with the squares of any linear measurement of the geometrical figure inclosing the surface. The skin areas of the birds, particularly of the pullets, it is

TABLE 7.—RELATIVE INCREASE IN BODY WEIGHT, BODY SURFACE, AND BODY MEASUREMENTS OF WHITE LEGHORN COCKERELS DURING GROWTH
(Expressed in percentage)

Approximate slaughter weight	.5 lb.	1 lb.	1.5 lbs.	2 lbs.	3 lbs.	4 lbs.	5 lbs.
Body weight	100	219	311	401	604	789	980
Body surface	100	193	286	335	465	522	574
Body measurements							
Depth at front end of keel	100	130	147	...	191	214	221
Depth at rear end of keel	100	124	142	...	173	182	198
Breadth at hips	100	130	147	157	195	212	235
Length of keel	100	134	154	191	198	220	237
Length of drumstick	100	133	155	177	207	221	228
Length of shank	100	135	158	177	210	219	226
Length of middle toe	100	127	140	156	173	173	176
Distance from rump to shoulder	100	132	151	167	198	212	222
Midcircumference	100	137	156	169	194	216	231

TABLE 8.—RELATIVE INCREASE IN BODY WEIGHT, BODY SURFACE, AND BODY MEASUREMENTS OF WHITE LEGHORN PULLETS DURING GROWTH
(Expressed in percentage)

Approximate slaughter weight	.5 lb.	1 lb.	1.5 lbs.	2 lbs.	3 lbs.	4 lbs.
Body weight	100	210	300	399	613	770
Body surface	100	185	251	313	399	415
Body measurements						
Depth at front end of keel	100	130	149	170	189	198
Depth at rear end of keel	100	126	147	162	181	211
Breadth at hips	100	132	152	167	197	217
Length of keel	100	143	157	176	215	219
Length of drumstick	100	138	158	180	191	195
Length of shank	100	137	159	179	184	187
Length of middle toe	100	127	145	148	155	152
Distance from rump to shoulder	100	134	154	170	192	199
Midcircumference	100	133	152	170	195	201

interesting to note, varied approximately in accordance with the square of the average linear measurement, exclusive of the length of the middle toe. For example, the linear measurements of the 1-pound pullets, with the exception noted, averaged 1.34 times the corresponding measurements of the .5-pound pullets. The square of 1.34 is 1.80, which approximates closely to 1.85, the ratio of the surface area of the 1-pound pullets to the surface area of the .5-pound pullets. The square of the average ratio of the eight linear measurements of the 1.5-pound pullets to those of the .5-pound pullets is 2.37, which is not far removed from the corresponding surface ratio of 2.51. For the 2-pound pullets, the squared ratio relating to the linear measurements is 2.96 as compared with 3.13, and for the 3- and 4-pound pullets, the comparable ratios are, respectively, 3.72 and 3.99, and 4.12 and 4.15.

The agreement is not so close for the cockerels. For the successive groups of cockerels starting with the 1-pound birds, the ratios are as follows: 1.74 and 1.93, 2.28 and 2.86, 2.99 and 3.35, 3.84 and 4.65, 4.49 and 5.22, and 5.06 and 5.74.

Effect of Sex. The effect of sex upon body size is most effectively shown by the calculations given in Table 9. In this table the nine

TABLE 9.—AVERAGE BODY MEASUREMENTS OF WHITE LEGHORN PULLETS AT DIFFERENT WEIGHTS, EXPRESSED AS PERCENTAGES OF CORRESPONDING MEASUREMENTS OF COCKERELS OF LIKE WEIGHT

Approximate slaughter weight	.5 lb.	1 lb.	1.5 lbs.	2 lbs.	3 lbs.	4 lbs.
Body surface	111	106	97	103	95	88
Body measurements						
Depth at front end of keel	100	100	101	...	99	93
Depth at rear end of keel	96	99	100	...	101	112
Breadth at hips	100	102	103	106	101	102
Length of keel	96	103	99	89	105	96
Length of drumstick	99	102	101	100	91	87
Length of shank	98	100	99	99	86	84
Length of middle toe	98	98	101	93	87	86
Distance from rump to shoulder	101	102	103	103	98	95
Midcircumference	103	100	101	104	104	97

average linear measurements of the six weight groups of pullets have been expressed as percentages of the corresponding average measurements of the cockerel groups of the same weight. The linear differences between pullets and cockerels were not marked except for the three leg measurements for the 3- and 4-pound weights; in these cases, the cockerels surpassed the pullets. In breadth at hips, the pullets were consistently larger, on the average, than the cockerels, and in mid-circumference they were larger except at the 4-pound weight.

SURFACE AREA AT DIFFERENT AGES

The significance of the determination of the surface area of animals relates to the basal heat production. That the basal heat production of animals of a given species and age is more closely related to body surface than to any other measurement of size, including body weight, has been repeatedly demonstrated.

Skin Areas of the Birds. The surface area of the White Leghorn chickens examined in this investigation was determined by measuring the area of the skin after removal from the body. The skin was removed and cut in such a way that it could be flattened out evenly on paper. It was then stretched at as uniform a tension as possible, pinned down to the paper, and outlined with a pencil. The area within the outline was measured with a planimeter.

The areas of the skins were determined in this way in order to obtain fairly reproducible values. The great elasticity of chicken skin is a formidable obstacle to its use for this purpose and the degree of accuracy of any individual area measurement is not great, altho the accuracy of an average of 10 measurements on birds of approximately the same weight is presumably over three times as great. In all probability the average skin area for each group of 10 birds is only approximately equal to the corresponding body surface. However, the ratio of skin area (as determined) to body surface may be fairly constant, in which case the skin area can be used for most purposes as a satisfactory unit of reference for basal heat production.

For the larger birds the surface area of the combs and wattles was also determined as being equal to twice the outlined area. The average results of these measurements have been assembled in Table 10.

TABLE 10.—AVERAGE SKIN AREAS OF WHITE LEGHORN CHICKENS OF DIFFERENT WEIGHTS AND SEX
(Each figure is an average of 10 birds)

Cockerels				Pullets			
Body weight	Skin area	Area of combs and wattles[1]	Total	Body weight	Skin area	Area of combs and wattles[1]	Total
gms.	*sq. cms.*	*sq. cms.*	*sq. cms.*	*gms.*	*sq. cms.*	*sq. cms.*	*sq. cms.*
31.1[2]	86	...	86	...	...	..	...
218	294	...	294	222	325	..	325
477	568	...	568	468	602	..	602
678	840	36	876	669	815	..	815
874	986	66	1 052	890	1 016	..	1 016
1 317	1 367	116	1 483	1 367	1 298	34	1 332
1 719	1 536	124	1 660	1 716	1 350	72	1 422
2 136	1 689	160	1 849	.....	.....	..	.....

[1]The areas given are twice the areas outlined. [2]The sex of these birds was not determined.

Estimation of Skin Area by Mathematical Formula. In using these data for the development of a formula for the estimation of surface, the areas of combs and wattles have not been considered. The growth of these appendages is largely a sex characteristic, and the ratio of the area thus added to the added weight is of an entirely different order from the ratio of surface to weight for the remainder of the body.

Furthermore, the growth of comb and wattles is readily influenced by environmental conditions. Birds raised indoors, for example, will show a much greater development of these appendages than birds raised outdoors. It seemed hopeless, therefore, to expect to find a formula involving body weight, or body weight and some linear body measurement, that would satisfactorily estimate a surface area inclusive of the area of combs and wattles.

From the average body weight and the average skin area of each group of birds, the constant k in the Meeh equation, $S = kW^{2/3}$, was calculated, with the results given in Table 11, S being the surface area in square centimeters and W the body weight in grams.

TABLE 11.—MEEH CONSTANTS FOR EACH GROUP OF WHITE LEGHORN CHICKENS

Weight group	Cockerels	Pullets
lbs.		
At hatching	8.70	....
.5	8.12	8.86
1	9.30	9.99
1.5	10.88	10.65
2	10.79	10.98
3	11.40	10.81
4	10.70	9.92
5	10.18	....

Evidently the unmodified Meeh formula will not apply thruout the weight range of these birds, tho for birds above a weight of 1 pound a satisfactory application of the formula seemed possible. For birds of both sexes a constant of 10.39 seemed to give the best fit. The estimates of area by the Meeh equation with this value of k, and the deviations from the observed areas will be found in Table 12.

Applying to the data a formula involving a linear body measurement as well as weight, of the type used in the previous study of the growth of White Plymouth Rock chickens, gave the estimates of

TABLE 12.—ESTIMATED SURFACE AREAS OF WHITE LEGHORN CHICKENS BY MEEH FORMULA:

$S = 10.39\ W^{.667}$

Average body weight (W)	Observed surface area	Estimated surface area (S)	Deviations	
			Absolute	Percentage
Cockerels				
gms.	*sq. cms.*	*sq. cms.*	*sq. cms.*	
31[1]	86	103	+ 17	+19.8
218	294	376	+ 82	+27.9
477	568	634	+ 66	+11.6
678	840	802	− 38	− 4.5
874	986	950	− 36	− 3.7
1 317	1 367	1 245	−122	− 8.9
1 719	1 536	1 491	− 45	− 2.9
2 136	1 689	1 723	+ 34	+ 2.0
Pullets				
222	325	381	+ 56	+17.2
468	602	626	+ 24	+ 4.0
669	815	795	− 20	− 2.5
890	1 016	961	− 55	− 5.4
1 367	1 298	1 281	− 17	− 1.3
1 716	1 350	1 489	+139	+10.3

[1]The sex of this group was not determined.

surface contained in Table 13. The formula used was $S = 6.01 W^{.5} L^{.6}$, in which L is the distance from rump to shoulder in centimeters. This measurement, related to body length, can be determined with considerable accuracy. The total body length of a live chicken, from tip of beak to rump, is not, in our experience, susceptible to accurate

TABLE 13.—ESTIMATED SURFACE AREAS OF WHITE LEGHORN CHICKENS BY FORMULA:
$S = 6.01\ W^{.5}\ L^{.6}$

Average body weight (W)	Distance from rump to shoulder (L)	Observed surface area	Estimated surface area (S)	Deviations	
				Absolute	Percentage
Cockerels					
gms.	*cms.*	*sq. cms.*	*sq. cms.*	*sq. cms.*	
311[1]	4.7	86	85	− 1	− 1.2
218	9.6	294	345	+ 51	+17.3
477	13.0	568	612	+ 44	+ 7.7
678	14.9	840	791	− 49	− 5.8
874	16.0	986	938	− 48	− 4.9
1 317	19.0	1 367	1 276	− 91	− 6.7
1 719	20.4	1 536	1 522	− 14	− .9
2 136	21.3	1 689	1 741	+ 52	+ 3.1
Pullets					
223	9.7	325	351	+ 26	+ 8.0
468	13.0	602	606	+ 4	+ .7
669	14.9	815	786	− 29	− 3.6
890	16.5	1 016	964	− 52	− 5.1
1 367	18.6	1 298	1 284	− 14	− 1.1
1 716	19.3	1 350	1 471	+121	+ 9.0

[1]The sex of these birds was not determined.

measurement, since it varies so much with the tension used in stretching out the bird.

The estimations of surface area by the weight-length formula are not greatly superior to those made by the use of the Meeh equation. For the eleven groups of birds weighing 1 pound or over, the average percentage deviation of the estimated from the observed areas, neglecting signs, was 4.42 by the weight-length formula and 5.19 by the Meeh formula.

In all probability a satisfactory formula for the estimation of the surface area of chickens can be obtained only from direct measurements of the body surface by some such method as that used by Cowgill and Drabkin[5]* for the dog.

Direct Determination of Surface Area. Some time after the conclusion of this experiment it was decided to attempt the direct determination of the surface area of White Leghorn chickens by a mold method. Satisfactory results were secured upon 25 chickens, varying in body weight from 109 to 2,142 grams. The method used was as follows.

The birds were killed by bleeding and debraining, and were then dry picked. They were next measured and laid out in a standard supine position with neck and wings extended and legs as nearly contracted as the method of molding permitted. The wings were pinned down in the desired position, and the legs were supported on strings suspended from a laboratory ring stand. The comb and wattles were then cut off, as were the ear lobes in the larger birds. The surface of the bird was then covered closely with strips of ordinary medical sterilized gauze, either 2 inches or 1 inch in width, which were made to adhere to the body and to each other by collodion applied with a brush. By varying the size of gauze and the length of the strip, it was possible to cover all parts of the body regardless of their curvature. The shanks and feet, however, were not covered. After the ventral part of the body was covered, the bird was turned over and covered on the dorsal side without changing the position of legs and wings. The completed mold was dry in an hour or less, during which time a slight contraction of the gauze occurred insuring a tight fit. In removing the mold from the body, it was first cut in two parts along the median sagittal line, and then was cut along the neck, wings, and legs as necessary for convenient removal. After removal from the body, the mold was cut into pieces of such size and shape that they would lie flat. The pieces were outlined with a pencil on a large sheet of paper and their combined area was determined with the planimeter. The mold was cut into 17 to 50 pieces, the number depending upon the size of the bird. The comb and wattles were also outlined and the area doubled, allowance being made in the case of the comb for the area of the surface of attachment to the head. The ear lobes, when large enough to require separate treatment, were outlined and measured, and allowance was made for the area of attachment. The area of the shanks and feet was determined by skinning one shank and foot, determining the area of the skin by cutting up, outlining, and applying the planimeter, and doubling this area.

For a number of the birds the areas of the two halves of the carcass were determined separately in order to ascertain the accuracy of the method. In Table 14 the mold areas of the two halves of all chickens on which this test was made are compared. Evidently the method is capable of close duplication, within 2 percent, when the mold is fitted to the carcass in a standard position. In other tests it was clearly shown that the surface area of the extended leg or wing is considerably greater than that of the same member contracted, and that the difference is not due to the formation of folds or wrinkles of skin in the latter position.

Besides the live weight and surface area three linear measurements were taken on the picked carcass: (a) the over-all length, from tail to tip of beak, (b) the rump-to-shoulder length, and (c) the circumference of thorax taken over the keel and just behind the wings. On many of the birds the picked, bled weight was also recorded. These measurements and weights are all contained in Table 15.

TABLE 14.—SURFACE AREAS OF MOLDS FROM RIGHT AND LEFT HALVES OF WHITE LEGHORN CHICKENS[1]

Bird No.	Sex	Body weight	Surface area		Difference
			Left side	Right side	
		gms.	*sq. cms.*	*sq. cms.*	*perct.*
22	Pullet	1 074	483	491	1.64
24	Cockerel	1 799	646	659	1.99
25	Cockerel	1 978	693	707	2.00
26	Cockerel	1 458	580	580	0
27	Cockerel	1 653	628	625	.48
28	Cockerel	1 841	651	641	1.55
29	Cockerel	2 142	728	729	.14

[1]Exclusive of shanks and feet and of combs and wattles.

TABLE 15.—BODY WEIGHTS, SURFACE AREAS, AND BODY MEASUREMENTS OF WHITE LEGHORN CHICKENS

Bird No.	Sex	Body weight	Surface area	Length over all	Rump to shoulder	Circumference	Picked weight
		gms.	*sq. cms.*	*cms.*	*cms.*	*cms.*	*gms.*
8	..	110	227	18	7.4	11	...
9	..	109	220	18	7.4	10.5	...
11	m	235	376	25	9.1	14	...
12	m	341	526	27.5	11.1	15	...
13	m	449	618	29	11.8	17	...
14	m	555	731	33	13.2	18	490
15	m	578	781	33.5	13.2	19.5	504
16	f	668	795	35.5	13.7	19.5	570
21	f	840	908	39.5	16.1	22.5	712
18	f	984	1 014	39.5	17.0	23.5	861
23	f	1 059	1 038	42	16.5	24	920
17	m	1 072	1 155	40.5	16.7	23.5	948
22	f	1 074	1 127	44.5	16.8	24.5	937
20	f	1 109	1 174	41	16.9	23.5	947
19	f	1 213	1 152	41.5	17.6	25	1 095
5	f	1 273	1 172	40.5	16.0	24.5	1 121
7	f	1 329	1 247	45	17.2	25	.....
26	m	1 458	1 470	45.5	18.5	26.5	1 270
6	f	1 495	1 469	46	....	29.5	.....
10	f	1 513	1 435	47	18.2	27	.....
27	m	1 653	1 602	48	18.9	28.5	1 423
24	m	1 799	1 684	48	19.4	27.5	1 612
28	m	1 841	1 612	48	18.0	28	1 600
25	m	1 978	1 720	50.5	19.9	29	1 725
29	m	2 142	1 894	49.5	21.3	30	1 918

Prediction Formulas for Surface Area. In attempting to fit a prediction formula to these measurements of surface area, it was realized that a close fit was hardly to be expected, because of a variable feather coat which would affect body weight but not body surface as measured from the picked carcass, and because of a variable growth of comb and wattles, the size of these parts depending in particular on sex and to some extent on nutritive condition. An extensive growth of comb and wattles would increase the body weight somewhat, but would have an entirely disproportionate effect upon surface area.

Using the method of least squares, the Meeh formula, $S = kW^{.667}$, was fitted to the data in Table 15, with the result that k was evaluated at 10.64. The areas of the birds calculated by means of this constant are given in Column 4 of Table 16, and the percentage deviations

TABLE 16.—COMPARISON OF CALCULATED AND OBSERVED SURFACE AREAS OF WHITE LEGHORN CHICKENS

Bird No.	Sex	Observed surface area	$S = 10.64\,W^{.667}$	Difference	$S = 8.19\,W^{.705}$	Difference	$\frac{W^{.333}}{L}$
		sq. cms.	*sq. cms.*	*perct.*	*sq. cms.*	*perct.*	
8	..	227	244	+ 7.49	226	− .44	.266
9	..	220	243	+10.45	224	+1.82	.265
11	m	376	405	+ 7.71	385	+2.39	.247
12	m	526	519	− 1.33	501	−4.75	.254
13	m	618	624	+ .97	608	−1.62	.264
14	m	731	718	− 1.78	707	−3.28	.249
15	m	781	738	− 5.51	727	−6.91	.249
16	f	795	813	+ 2.26	805	+1.26	.246
21	f	908	947	+ 4.30	946	+4.18	.239
18	f	1 014	1 052	+ 3.75	1 058	+4.33	.252
23	f	1 038	1 105	+ 6.45	1 115	+7.42	.243
17	m	1 155	1 114	− 3.55	1 124	−2.68	.253
22	f	1 127	1 115	− 1.06	1 126	− .09	.230
20	f	1 174	1 140	− 2.90	1 151	−1.96	.252
19	f	1 152	1 210	+ 5.03	1 227	+6.51	.257
5	f	1 172	1 249	+ 6.57	1 269	+8.28	.268
7	f	1 247	1 286	+ 3.13	1 308	+4.89	.244
26	m	1 470	1 368	− 6.94	1 396	−5.03	.249
6	f	1 469	1 391	− 5.31	1 421	−3.27	.249
10	f	1 435	1 402	− 2.30	1 433	− .14	.244
27	m	1 602	1 487	− 7.18	1 526	−4.74	.246
24	m	1 684	1 573	− 6.59	1 620	−3.80	.253
28	m	1 612	1 598	− .87	1 646	+2.11	.255
25	m	1 720	1 676	− 2.56	1 732	+ .70	.249
29	m	1 894	1 767	− 6.71	1 832	−3.27	.260
Average	..	.....	.....	4.51	.....	3.73	.251

from the observed values in Column 5. The average percentage deviation, disregarding signs, is 4.51.

If the exponent of W (body weight in grams) in the Meeh formula, as well as its coefficient k, be evaluated from the data by the method of least squares, the prediction formula becomes $S = 8.19W^{.705}$. The calculated areas of the birds by this formula and the percentage deviations are given in Columns 6 and 7 of Table 16. The average percentage deviation is 3.73, somewhat less than that obtained with the first formula, and the fit to the data is appreciably better at the two ends of the range. The second formula is thus a distinct improvement over the first. Of the 25 cases only 5 show deviations greater than 5 percent, and all are within 10 percent. Closer fits of prediction formulas to surface-area measurements have been obtained with other animals but, as already explained, the prospects of obtaining a close fit of any formula to surface-area measurements in chickens are not encouraging.

An attempt was made to improve the formula by the introduction of a term defining the nutritive condition of the animal. According to

TABLE 17.—AVERAGE WEIGHTS OF PARTS OF CARCASSES OF WHITE LEGHORN COCKERELS KILLED AT DIFFERENT WEIGHTS
(Each figure is an average of 10 birds; all weights in grams)

Approximate slaughter weight	Hatching weight	.5 lb.[1]	1 lb.	1.5 lbs.	2 lbs.	3 lbs.	4 lbs.	5 lbs.
Age in days	2	44	58	72	86	107	156	219
Live weight	31.1	218	477	678	875	1 317	1 719	2 136
Viscera and offal								
Blood	1.07	8.00	19.4	27.6	32.8	53.8	79.0	109
Feathers	....[2]	11.6	35.6	55.9	65.7	88.5	134	179
Head	4.15	13.0	21.1	28.7	39.1	61.9	69.5	84.8
Shanks and feet	1.35	10.5	23.0	32.0	41.9	63.6	71.7	84.7
Heart	.231	1.75	2.65	3.38	4.09	6.12	7.96	11.5
Liver	1.06[3]	7.02	12.6	15.8	20.0	24.5	34.0	44.5
Kidneys	.226	2.98	5.32	6.10	7.70	8.71	11.30	13.7
Pancreas	.085	.97	1.92	2.10	2.26	3.16	3.90	4.58
Spleen	.016	.31	.71	1.10	1.60	2.25	2.69	3.59
Lungs	.268	1.42	2.62	3.59	4.20	6.87	9.29	10.3
Testicles	....	.074	.20	.39	3.44	7.18	5.55	4.80
Intestinal tract exclusive of gizzard	2.55	19.5	39.6	49.9	58.8	78.0	101	106
Gizzard	1.67	8.0	14.3	19.8	20.6	28.9	38.6	43.4
Contents of digestive tract	3.56[4]	9.4	16.6	20.5	21.1	32.3	42.1	61.8
Dressed carcass								
Neck	1.04	7.5	16.6	21.3	27.4	42.9	52.0	59.1
Skin	3.24[2]	14.8	30.0	42.6	54.9	87.7	120	138
Legs above hock	3.47	32.5	79.4	124	168	272	350	448
Wings	.77	13.9	31.9	45.9	60.0	93.7	113	133
Torso	3.55	42.8	107.0	158	214	327	446	553
Total bone in carcass (except head, shanks, and feet)	11.8[5]	34.4	75.2	95.8	131	200	246	297
Total flesh and fat in carcass (except head, shanks, and feet)	....	56.0	150	237	327	517	695	862

[1]Average for 11 birds. [2]The feathers were not removed from the skin. [3]This weight includes the weight of the gall bladder. [4]Yolk sac + contents. [5]Bones were not separated from the flesh.

Cowgill and Drabkin,[5*] a term that should serve this purpose is obtained by dividing the cube root of the body weight by the body length. In the last column of Table 16, this factor, involving the length in centimeters from tail to tip of beak, is given for each bird. If this factor is capable of serving a useful purpose in improving a prediction formula involving only the body weight, the nutritive factor would be expected to be out of line for birds whose calculated areas deviated most widely from the observed. But a comparison of the last two columns in Table 16 does not reveal such a situation. The greatest positive deviation, 8.28 percent, it is true, is associated with the highest nutritive correction factor, .268, but the next highest factor, .266, is obtained with a bird (No. 8) for which a very close prediction of surface area was obtained; this is also true of the two

TABLE 18.—AVERAGE WEIGHTS OF PARTS OF CARCASSES OF WHITE LEGHORN PULLETS KILLED AT DIFFERENT WEIGHTS

(Each figure is an average of 10 birds; all weights in grams)

Approximate slaughter weight	Hatching weight	.5 lb.[1]	1 lb.	1.5 lbs.	2 lbs.	3 lbs.	4 lbs.
Age in days	2	44	58	72	100	159	233
Live weight	31.1	223	468	669	890	1 367	1 716
Viscera and offal							
Blood	1.07	8.35	18.9	25.4	31.9	50.9	58.9
Feathers	....[2]	13.7	39.5	56.3	78.4	102	97.2
Head	4.15	11.7	18.6	23.1	27.7	38.0	44.7
Shanks and feet	1.35	9.82	21.5	29.9	35.3	42.8	45.4
Heart	.231	1.39	2.28	2.79	3.40	5.13	6.73
Liver	1.06[3]	6.32	11.2	14.9	17.7	24.4	31.7
Kidneys	.226	2.85	4.69	6.08	7.23	9.61	11.4
Pancreas	.085	1.02	1.80	1.97	2.52	3.21	3.23
Spleen	.016	.35	.85	1.14	1.57	2.62	2.15
Lungs	.268	1.46	2.38	3.33	4.66	5.87	6.53
Ovaries[4]	.....	.....	.....	.....	.....	3.72	42.3
Intestinal tract exclusive of gizzard	2.55	18.7	36.2	46.4	62.0	99.7	124
Gizzard	1.67	8.74	14.5	20.4	25.4	34.8	39.0
Contents of digestive tract	3.56[5]	11.0	14.9	20.0	23.8	33.9	38.8
Dressed carcass							
Neck	1.04	7.43	15.4	20.8	27.1	35.5	39.3
Skin	3.24[2]	14.4	28.4	39.9	56.1	98.5	129
Legs above hock	3.47	31.9	80.6	120	163	250	304
Wings	.77	14.2	33.1	46.9	62.9	85.0	95.9
Torso	3.55	47.8	109	165	236	410	549
Total bone in carcass (except head, shanks, and feet)	11.8[6]	32.8	68.7	102	124	166	197
Total flesh and fat in carcass (except head, shanks, and feet)	....	62.6	160	239	354	593	764

[1]Average for 9 birds. [2]The feathers were not removed from the skin. [3]This weight includes the weight of the gall bladder. [4]This includes the weight of oviduct. [5]Yolk sac + contents. [6]Bones were not separated from the flesh.

next highest factors, .265 and .264. The lowest nutritive factor, .230, is also associated with a bird for which a very good prediction was secured. These considerations do not indicate that the cause of the poor predictions obtained by using the second prediction formula was a variable nutritive condition of the birds. Hence no systematic attempt was made to introduce this factor into the prediction formula.

Sex Differences. From the fact that the six largest positive percentage deviations of predicted from observed areas relate to females, while the five largest negative deviations relate to males, it seems evident that sex is a determining factor in surface area, even before excessive comb growth is present (Nos. 12 and 15). Unfortunately the present data are not suitable for the derivation of separate prediction formulas for each sex, since the females measured are all of intermediate weight, while the males are, with two exceptions, either lighter than 578 grams or heavier than 1,653 grams.

RELATIVE AND ABSOLUTE GROWTH OF VISCERA AND OF DIFFERENT PARTS OF CARCASS

A number of the larger visceral organs from each of the slaughtered birds and of certain more or less well-defined parts of the carcass were weighed in this investigation. The average weights, each representing 10 individual weights, have been summarized in Tables 17 and 18.

TABLE 19.—AVERAGE WEIGHTS OF PARTS OF CARCASSES OF WHITE LEGHORN COCKERELS KILLED AT DIFFERENT WEIGHTS, EXPRESSED IN PERCENTAGE OF EMPTY BODY WEIGHT

(Each figure is an average of 10 birds)

Approximate slaughter weight	Hatching weight	.5 lb.	1 lb.	1.5 lbs.	2 lbs.	3 lbs.	4 lbs.	5 lbs.
Age in days	2	44	58	72	86	107	156	219
Percentage "fill"	11.4	4.3	3.5	3.0	2.4	2.5	2.4	2.9
Empty weight in grams	27.5	209	460	658	854	1 285	1 677	2 074
Offal								
Feathers	....[1]	5.55	7.74	8.50	7.69	6.89	7.99	8.63
Blood	3.89	3.83	4.22	4.19	3.84	4.19	4.71	5.26
Head	15.1	6.22	4.59	4.36	4.58	4.82	4.14	4.09
Shanks and feet	4.91	5.02	5.00	4.86	4.91	4.95	4.28	4.08
Total offal	23.9	20.6	21.6	21.9	21.0	20.8	21.1	22.1
Viscera								
Heart	.84	.84	.58	.51	.48	.48	.47	.55
Liver	3.85[2]	3.36	2.74	2.40	2.34	1.91	2.03	2.15
Kidneys	.82	1.43	1.16	.93	.90	.68	.67	.66
Pancreas	.31	.46	.42	.32	.26	.25	.23	.22
Spleen	.06	.15	.15	.17	.19	.18	.16	.17
Lungs	.97	.68	.57	.55	.49	.53	.55	.50
Testicles	.....	.04	.04	.06	.40	.56	.33	.23
Digestive tract	15.3	13.2	11.7	10.6	9.30	8.32	8.32	7.20
Total viscera	22.1	20.2	17.4	15.5	14.4	12.9	12.8	11.7
Dressed carcass								
Skin	11.8[1]	7.08	6.52	6.47	6.43	6.82	7.16	6.65
Neck	3.78	3.59	3.61	3.24	3.21	3.34	3.10	2.85
Legs above hock	12.6	15.6	17.3	18.8	19.7	21.2	20.9	21.6
Wings	2.80	6.65	6.93	6.98	7.03	7.29	6.74	6.41
Torso	12.9	20.5	23.3	24.0	25.1	25.4	26.6	26.7
Total dressed carcass	43.9	53.4	57.7	59.5	61.5	64.0	64.5	64.2
Total bone in dressed carcass	42.9[3]	16.5	16.3	14.6	15.3	15.6	14.7	14.3
Total flesh and fat in dressed carcass	....	26.8	32.6	36.0	38.3	40.2	41.4	41.6
Total flesh, fat, edible viscera[4] and skin	53.6	41.9	45.5	48.4	49.9	51.7	53.5	53.0

[1]The feathers were not removed from the skin for this group of birds. [2]This includes the gall bladder. [3]Bones and flesh were not separated for this group. [4]Including heart, liver and gizzard.

These weights are expressed as percentages of the corresponding empty body weights in Tables 19 and 20.

The average weights of all organs and parts increased progressively in absolute value as the body weight increased, with few exceptions, the significance of which is evidently negligible when the individual weights are consulted. The relative weight of the offal parts (feathers, blood, head, and shanks and feet) remained fairly constant for the cockerels after a body weight of .5 to 1 pound was reached. The

TABLE 20.—AVERAGE WEIGHTS OF PARTS OF CARCASSES OF WHITE LEGHORN PULLETS KILLED AT DIFFERENT WEIGHTS, EXPRESSED IN PERCENTAGE OF EMPTY BODY WEIGHT

(Each figure is an average of 10 birds)

Approximate slaughter weight	Hatching weight	.5 lb.	1 lb.	1.5 lbs.	2 lbs.	3 lbs.	4 lbs.
Age in days	2	44	58	72	100	159	233
Percentage "fill"	11.4	4.9	3.2	3.0	2.7	2.5	2.3
Empty weight in grams	27.5	212	453	649	866	1 333	1 677
Offal							
Feathers	.....[1]	6.46	8.72	8.67	9.05	7.65	5.80
Blood	3.89	3.94	4.17	3.91	3.68	3.82	3.51
Head	15.1	5.52	4.11	3.56	3.20	2.85	2.67
Shanks and feet	4.91	4.63	4.75	4.61	4.08	3.21	2.71
Total offal	23.9	20.5	21.7	20.7	20.0	17.5	14.7
Viscera							
Heart	.84	.66	.50	.43	.39	.38	.40
Liver	3.85[2]	2.98	2.47	2.30	2.04	1.83	1.89
Kidneys	.82	1.34	1.04	.94	.83	.72	.68
Pancreas	.31	.48	.40	.30	.29	.24	.19
Spleen	.05	.17	.19	.18	.18	.20	.13
Lungs	.97	.69	.53	.51	.54	.44	.39
Ovaries[3]	.....	.....	.....	.....	.....	.28	2.52
Digestive tract	15.3	12.9	11.2	10.3	10.1	10.1	9.72
Total viscera	22.1	19.2	16.3	15.0	14.4	14.2	15.9
Dressed carcass							
Skin	11.8[1]	6.79	6.27	6.15	6.48	7.39	7.69
Neck	3.78	3.50	3.40	3.20	3.13	2.66	2.34
Legs above hock	12.6	15.0	17.8	18.5	18.8	18.8	18.1
Wings	2.62	6.70	7.31	7.33	7.26	6.38	5.72
Torso	12.9	22.5	24.1	25.4	27.3	30.8	32.7
Total dressed carcass	43.7	54.5	58.9	60.5	63.0	66.0	66.6
Total bone in dressed carcass	42.9[4]	15.5	15.2	15.7	14.3	12.5	11.7
Total flesh and fat in dressed carcass	....	29.5	35.3	36.8	40.9	44.5	45.6
Total flesh, fat, edible viscera[5] and skin	....	44.1	47.8	48.8	52.6	56.7	57.9

[1]The feathers were not removed from the skin for this group of birds. [2]This includes the gall bladder. [3]Includes weight of oviduct. [4]Bones and flesh were not separated for this group. [5]Including heart, liver, and gizzard.

average percentage weights of the sum of these parts varied for all weights from 20.6 to 23.9. For the pullets the offal parts decreased in relation to the empty weight at the higher body weights of 3 and 4 pounds. The relative weight of blood, however, did not share in this tendency.

Percentage Increases in Organ Weights. The percentage weights of viscera showed a general tendency to decrease with age, tho frequently in an irregular manner. This decrease was most marked for the younger ages. The percentage weight of the spleen in both sexes showed little tendency to variation aside from a marked increase from hatching to the .5-pound weight. The cockerels seem to be clearly distinguished from the pullets by a more rapid decrease in the percentage weight of the digestive tract. Beyond the 1.5-pound weight the pullets possessed a larger average weight of digestive apparatus,

TABLE 21.—RELATIVE INCREASE IN WEIGHT OF PARTS OF CARCASSES OF WHITE LEGHORN COCKERELS WITH INCREASE IN BODY WEIGHT
(Expressed in percentage)

Approximate slaughter weight	.5 lb.	1 lb.	1.5 lbs.	2 lbs.	3 lbs.	4 lbs.	5 lbs.
Age in days	44	58	72	86	107	156	219
Offal							
Feathers	100	307	482	566	763	1 155	1 543
Blood	100	243	345	410	673	988	1 363
Head	100	162	221	301	476	535	652
Shanks and feet	100	219	305	399	606	683	807
Total offal	100	230	335	416	621	822	1 061
Viscera							
Heart	100	151	193	234	350	455	657
Liver	100	179	225	285	349	484	634
Kidneys	100	179	205	258	292	379	460
Pancreas	100	198	216	233	326	402	472
Spleen	100	229	355	516	726	868	1 158
Lungs	100	185	253	296	484	654	725
Digestive tract	100	196	253	289	389	508	543
Total viscera	100	190	243	284	378	498	567
Dressed carcass							
Skin	100	203	288	371	593	811	932
Neck	100	221	284	365	572	693	788
Legs above hock	100	244	382	517	837	1 077	1 378
Wings	100	229	330	432	674	813	957
Torso	100	250	369	500	764	1 042	1 292
Total dressed carcass	100	238	351	470	738	970	1 194
Total bone in dressed carcass	100	219	278	381	581	715	863
Total flesh and fat in dressed carcass	100	268	423	584	923	1 241	1 539
Total flesh, skin, fat, and edible viscera	100	239	364	488	759	1 024	1 256

both absolute and relative, than the cockerels. The weight of heart was, on the average, always greater for the cockerels than for the pullets.

The total weight of dressed carcass increased slowly with increasing body weight for the cockerels, and appreciably faster for the pullets. At all weights the dressed carcasses of the females averaged heavier than those of the males, owing entirely to additional muscular and fatty tissue. For weights above 1.5 pounds the bones in the dressed carcasses of the males outweighed the bones in the females.

These comparisons of the weights of organs and parts of carcass for birds of different weights and different sex are presented in Tables 21, 22, and 23 in a different manner. For the body-weight comparison the weights of the organs and parts of the .5-pound birds, the lightest birds for which complete dissection of the parts was made, are taken

TABLE 22.—RELATIVE INCREASE IN WEIGHT OF PARTS OF CARCASSES OF WHITE LEGHORN PULLETS WITH INCREASE IN BODY WEIGHT
(Expressed in percentage)

Approximate slaughter weight	.5 lb.	1 lb.	1.5 lbs.	2 lbs.	3 lbs.	4 lbs.
Age in days	44	58	72	100	159	233
Offal						
Feathers	100	288	411	572	745	709
Blood	100	226	304	382	610	705
Head	100	159	197	237	325	382
Shanks and feet	100	219	304	359	436	462
Total offal	100	226	310	397	537	564
Viscera						
Heart	100	164	201	245	369	484
Liver	100	177	236	280	386	502
Kidneys	100	165	213	254	337	400
Pancreas	100	176	193	247	315	317
Spleen	100	243	326	449	749	614
Lungs	100	163	228	319	402	447
Digestive tract	100	185	244	319	489	595
Total viscera[1]	100	181	238	305	454	523
Dressed carcass						
Skin	100	197	277	390	684	896
Neck	100	207	280	365	478	529
Legs above hock	100	253	376	511	784	953
Wings	100	233	330	443	599	675
Torso	100	228	345	494	858	1 149
Total dressed carcass	100	230	339	471	760	966
Total bone in dressed carcass	100	209	311	378	506	601
Total flesh and fat in dressed carcass	100	256	382	565	947	1 220
Total flesh, skin, fat, and edible viscera	100	232	339	489	809	1 039

[1]Exclusive of reproductive organs.

TABLE 23.—AVERAGE WEIGHTS OF PARTS OF CARCASSES OF WHITE LEGHORN PULLETS KILLED AT DIFFERENT WEIGHTS, EXPRESSED IN PERCENTAGES OF CORRESPONDING WEIGHTS FOR THE COCKERELS

Approximate slaughter weight	.5 lb.	1 lb.	1.5 lbs.	2 lbs.	3 lbs.	4 lbs.
Offal						
Feathers	118	111	101	119	115	73
Blood	104	97	92	97	95	75
Head	90	88	80	71	61	64
Shanks and feet	94	93	93	84	67	63
Total offal	101	99	93	97	87	70
Viscera						
Heart	79	86	83	83	84	85
Liver	90	89	94	88	100	93
Kidneys	96	88	100	94	110	101
Pancreas	105	94	94	112	102	83
Spleen	113	120	104	98	116	80
Lungs	103	91	93	111	85	70
Gizzard	109	101	103	123	120	101
Digestive tract	96	94	96	110	126	117
Total viscera[1]	97	93	95	104	117	101
Dressed carcass						
Skin	97	95	94	102	112	108
Neck	99	93	98	100	83	76
Legs above hock	98	102	97	97	92	87
Wings	102	104	102	105	91	85
Torso	112	102	104	110	125	123
Total dressed carcass	104	100	100	104	107	103
Total bone in dressed carcass	95	91	106	95	83	80
Total flesh and fat in dressed carcass	112	107	100	108	115	110
Total flesh, fat, edible viscera, and skin	107	103	100	107	114	108

[1]Exclusive of reproductive organs.

as 100, and all later weights are expressed as percentages of these. For the sex comparison the weights of organs and anatomical parts of the pullets are expressed as percentages of the corresponding parts of the cockerels.

Sex Differences. Table 23 brings out in a particularly clear way the sex differences in anatomical makeup. The consistently greater weights of head (including comb and wattles), shanks and feet, and heart in the cockerels and the generally greater weights of blood and bones in the dressed carcasses are clearly evident. On the other hand, the females consistently exceeded the males in weights of gizzard, dressed carcass, and flesh and fat, and generally in weights of feathers. At the higher body weights, i.e., 2, 3, and 4 pounds, the weights of total digestive tract, total viscera, and skin were greater in the females than in the males.

In a general way the relations just discussed, involving weights of organs and parts of carcasses of White Leghorn chickens, are similar to those found by Latimer[9*] in his study of the post-natal growth of this species. The Illinois studies, however, reveal a greater percentage weight of skeleton and digestive tract for the higher body weights, and a smaller percentage weight of skin at all body weights. The increase in the percentage weight of the heart, starting at a body weight of about 1,400 grams, as noted by Latimer,[9*] is not clearly evident in the Illinois data, tho the cockerels showed some increase in this respect after a body weight of 1,677 grams.

Variability of Organ Weights. The variability of the individual weights of organs and parts, as measured by the coefficient of variation, is given in Table 24 for the cockerels and in Table 25 for the pullets (page 110). This value was not calculated for many of the organs of the 2-day chicks; unfortunately many of the smaller organs in this group were not weighed to two significant figures. The small variability in empty weight simply testifies to the restricted selection of birds in taking samples of 10. The great variability in spleen weight is noteworthy. In average variability at all weights, the pullets exceeded the cockerels except with respect to gizzard weights, weights of bones in the dressed carcass, and weights of feathers.

CHEMICAL COMPOSITION OF BIRDS AT DIFFERENT BODY WEIGHTS

Composition of Chemical Samples. Each sample of 10 chickens was analyzed in 4 composite samples consisting of (1) the feathers, (2) the total bones in the dressed carcass, (3) the total flesh and fat in the dressed carcass plus the skin and the edible viscera, including

TABLE 24.—COEFFICIENTS OF VARIATION OF INDIVIDUAL WEIGHTS OF ORGANS AND PARTS OF CARCASSES FOR WHITE LEGHORN COCKERELS

	2 days old	.5 lb.	1 lb.	1.5 lbs.	2 lbs.	3 lbs.	4 lbs.	5 lbs.	Average
Empty weight	7.5	5.6	2.1	1.8	1.8	1.7	1.7	4.9	3.39
Feathers	....	14.7	8.6	11.7	13.6	10.7	6.6	8.2	10.61
Blood	43.3	22.5	12.8	11.4	12.0	7.1	9.1	10.6	16.11
Pancreas	....	9.7	11.6	14.8	12.6	17.6	12.8	16.4	14.34
Spleen	....	27.3	16.7	34.1	16.6	24.1	20.3	39.9	29.35
Kidneys	21.2	13.9	8.5	6.7	7.6	5.0	10.3	8.4	10.20
Lungs and trachea	13.5	10.0	6.3	7.4	14.7	8.0	7.9	10.4	9.77
Esophagus and proventriculus	....	11.6	11.4	6.7	6.2	10.1	9.5	9.5	9.29
Intestines	13.6	6.5	4.1	4.6	12.6	10.3	6.3	14.2	9.04
Skin	....	6.5	4.3	9.0	7.5	6.8	8.5	11.7	7.75
Heart	19.3	14.5	5.7	20.5	8.2	10.6	8.2	11.3	12.29
Liver	....	8.4	7.2	4.4	12.2	8.0	4.1	15.1	8.49
Gizzard	14.0	10.4	12.5	14.3	10.9	13.5	5.8	17.5	12.36
Flesh in dressed carcass	....	12.1	7.2	3.7	4.8	4.8	3.9	8.1	6.37
Bones in dressed carcass	....	19.3	9.0	9.2	9.0	10.9	10.3	7.7	10.77
Testicles	....	33.8	32.4	42.8	68.3	38.3	91.7	87.5	56.40

TABLE 25.—COEFFICIENTS OF VARIATION OF INDIVIDUAL WEIGHTS OF ORGANS AND PARTS OF CARCASSES FOR WHITE LEGHORN PULLETS

	2 days old	.5 lb.	1 lb.	1.5 lbs.	2 lbs.	3 lbs.	4 lbs.	Average
Empty weight	7.5	6.5	4.1	1.4	1.6	1.8	7.5	4.34
Feathers	....	9.8	11.6	12.7	12.0	9.2	5.7	10.18
Blood	43.3	15.9	14.6	11.8	8.2	36.9	10.7	20.20
Pancreas	....	9.3	10.9	14.5	20.7	15.0	18.6	15.47
Spleen	....	37.4	18.6	22.7	46.0	46.6	18.3	35.07
Kidneys	21.2	12.6	8.4	9.7	9.2	12.1	10.0	11.90
Lungs and trachea	13.5	13.6	7.3	19.3	25.7	9.1	7.7	13.74
Esophagus and proventriculus	....	11.4	12.5	9.0	7.5	10.3	8.9	9.93
Intestines	13.6	10.5	6.0	9.1	8.5	10.7	10.8	9.88
Skin	....	14.2	5.8	9.4	8.1	5.8	20.8	10.68
Heart	19.3	12.7	13.7	8.6	19.0	11.3	9.7	13.41
Liver	....	9.5	7.9	10.0	7.0	9.6	15.4	9.90
Gizzard	14.0	11.4	10.4	9.8	6.6	8.0	15.0	10.74
Flesh in dressed carcass	....	12.2	5.9	3.1	4.4	4.7	20.1	8.40
Bones in dressed carcass	....	9.0	8.0	6.0	8.4	10.0	12.6	9.01
Ovaries	....	....	....	....	....	11.3	55.9	33.58

TABLE 26.—CHEMICAL COMPOSITION OF FEATHERS OF WHITE LEGHORN CHICKENS

Approximate body weight	Dry substance	Crude protein	Ether extract	Ash	Calcium	Gross energy per gram
Cockerels						
lbs.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*gm. cals.*
.5	59.16	54.41	2.18	1.91	.110	3 248
1	59.19	55.28	1.55	1.65	.160	3 206
1.5	76.84	69.38	1.71	2.03	.251	4 194
2	65.38	62.12	1.32	1.49	.136	3 084
3	65.66	64.64	1.02	1.26	.090	3 138
4	60.64	58.38	1.07	1.03	.107	3 040
5	77.16	70.65	1.38	1.28	.123	3 866
Pullets						
.5	61.65	57.43	2.20	1.76	.090	3 358
1	60.56	57.49	1.45	1.42	.103	3 222
1.5	58.92	54.53	1.45	1.45	.116	2 791
2	62.71	60.58	1.13	1.11	.110	3 077
3	72.49	68.08	1.05	.90	.125	3 608
4	84.66	74.62	1.06	1.25	.212	4 065

liver, heart, and gizzard from which the inner membrane had been removed, and (4) the offal, including blood, head, shanks and feet, and all viscera not included in the preceding sample. The results of the chemical analysis of these samples are summarized in Tables 26 to 29.

TABLE 27.—CHEMICAL COMPOSITION OF BONE SAMPLES OF WHITE LEGHORN CHICKENS

Approximate body weight	Dry substance	Crude protein	Ether extract	Ash	Calcium	Calcium in ash	Gross energy per gram
				Cockerels			
lbs.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*gm. cals.*
.5	38.29	19.77	3.67	13.12	4.71	35.9	1 465
1	38.65	20.37	3.28	13.95	5.12	36.7	1 437
1.5	43.02	20.25	5.17	15.43	5.60	36.3	1 666
2	46.86	20.96	7.77	16.47	6.20	37.6	1 860
3	48.39	20.43	9.83	16.09	6.43	40.0	1 982
4	49.87	20.74	10.30	16.17	6.97	43.1	2 080
5	51.30	22.74	8.52	18.78	7.13	38.0	2 078
				Pullets			
.5	40.13	21.11	4.13	13.87	5.07	36.6	1 553
1	39.88	20.20	3.57	14.81	5.35	36.1	1 427
1.5	42.87	19.91	5.06	14.61	5.55	38.0	1 746
2	48.00	20.12	9.51	16.74	6.45	38.5	1 978
3	53.74	21.19	11.64	19.74	7.75	39.3	2 181
4	53.44	19.41	14.97	18.01	7.58	42.1	2 479

TABLE 28.—CHEMICAL COMPOSITION OF SAMPLES OF FLESH AND EDIBLE VISCERA OF WHITE LEGHORN CHICKENS

Approximate body weight	Dry substance	Crude protein	Ether extract	Ash	Calcium	Gross energy per gram
			Cockerels			
lbs.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*gm. cals.*
.5	29.85	21.21	4.42	1.31	.041	1 588
1	25.00	21.29	2.81	1.39	.029	1 444
1.5	27.42	22.02	4.17	1.17	.032	1 651
2	32.06	22.51	6.40	1.14	.024	1 766
3	29.75	22.17	6.34	1.07	.025	1 760
4	29.23	22.25	6.20	1.06	.026	1 814
5	28.87	23.30	4.20	1.09	.024	1 723
			Pullets			
.5	28.54	21.97	4.62	1.38	.042	1 694
1	25.21	21.97	2.59	1.36	.031	1 459
1.5	27.37	21.33	4.54	1.17	.032	1 627
2	30.72	21.08	7.06	1.07	.030	1 832
3	35.56	20.26	13.61	.99	.022	2 350
4	43.89	16.69	24.32	1.00	.018	3 259

The greater fat content of all pullet samples except the feathers, for all body weights above 1.5 pounds, is noteworthy. Also, in the pullet samples exclusive of the feathers the fat content increased with increasing body weight, the increase being the more rapid at the higher weights. The cockerel samples did not show such an increase above a body weight of about 2 pounds.

TABLE 29.—CHEMICAL COMPOSITION OF OFFAL SAMPLES OF WHITE LEGHORN CHICKENS

Approximate body weight	Dry substance	Crude protein	Ether extract	Ash	Calcium	Gross energy per gram
			Cockerels			
lbs.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*gm. cals.*
.5	23.53	16.47	2.97	2.87	.672	1 239
1	22.32	17.20	2.66	2.56	.590	1 214
1.5	24.61	17.19	3.95	3.09	.760	1 320
2	26.40	17.51	4.96	3.00	.770	1 415
3	27.54	17.44	5.15	3.43	.960	1 490
4	27.39	18.24	5.50	3.59	1.010	1 512
5	25.45	18.28	3.72	2.95	.892	1 432
			Pullets			
.5	23.86	16.73	2.86	2.70	.618	1 277
1	23.64	17.38	3.04	2.98	.740	1 278
1.5	24.65	16.89	3.95	3.25	.818	1 323
2	27.79	16.44	7.29	2.97	.775	1 530
3	31.13	17.44	11.63	3.28	.870	1 989
4	37.50	14.18	20.19	1.67	.377	2 743

Composition of the Birds. From the relative weights of the different samples for each group of chickens and from their chemical composition, the composition of the live birds was calculated. The results of these calculations are given in Table 30. From these results the percentage composition of the birds has been calculated on the live-weight, empty-weight, and fat-free (protoplasmic) bases, and the percentages have been summarized in Table 31. The more rapid fattening of the pullets as compared with the cockerels is clearly evident from this table. The cockerels generally contained a greater concentration of ash and calcium even on the fat-free basis.

TABLE 30.—AVERAGE CHEMICAL COMPOSITION OF WHITE LEGHORN CHICKENS

Approximate body weight	Average live weight	Dry substance	Crude protein	Ether extract	Ash	Calcium	Gross energy
				Cockerels			
lbs.	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	*cals.*
.07	31.1	6.61	4.77	1.29	.59	.14	39
.5	218.4	60.34	41.77	7.13	7.48	2.03	302
1	477.2	128.1	99.29	11.95	16.92	4.65	663
1.5	677.8	209.1	154.6	25.22	24.36	6.77	1 121
2	874.8	292.1	198.1	47.92	33.22	9.80	1 473
3	1 317.0	431.7	295.4	77.49	50.33	15.89	2 275
4	1 719.0	563.1	393.4	101.86	63.36	21.09	3 082
5	2 136.0	716.1	528.0	89.76	82.61	25.46	3 813
				Pullets			
.07	31.1	6.61	4.77	1.29	.59	.14	39
.5	223.5	61.10	44.10	7.51	7.64	2.10	323
1	468.1	130.7	102.39	11.83	16.82	4.56	675
1.5	668.7	197.5	141.8	25.79	23.85	6.94	1 032
2	890.0	297.2	197.3	57.59	31.65	9.56	1 588
3	1 367.0	512.5	303.1	153.3	49.57	15.37	3 020
4	1 716.0	741.3	321.1	335.4	52.06	16.58	4 982

TABLE 31.—PERCENTAGE COMPOSITION OF WHITE LEGHORN CHICKENS AT DIFFERENT LIVE WEIGHTS

Approximate body weight	Dry substance	Crude protein	Ether extract	Ash	Calcium	Gross energy per gram
			Live-weight basis (Cockerels)			
lbs.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*gm. cals.*
.07	21.24	15.32	4.14	1.90	.44	1 253
.5	27.66	19.10	3.26	3.42	.93	1 399
1	26.84	20.81	2.50	3.55	.97	1 390
1.5	30.84	22.80	3.68	3.59	1.00	1 654
2	33.39	22.64	5.48	3.80	1.12	1 684
3	32.78	22.44	5.88	3.82	1.21	1 725
4	32.76	22.89	5.92	3.69	1.23	1 793
5	33.52	24.72	4.20	3.87	1.19	1 785
			(Pullets)			
.07	21.24	15.32	4.14	1.90	.44	1 253
.5	27.34	19.73	3.36	3.42	.94	1 445
1	27.93	21.87	2.53	3.59	.98	1 442
1.5	29.53	21.21	3.86	3.57	1.04	1 543
2	33.39	22.16	6.47	3.56	1.07	1 784
3	37.50	22.18	11.22	3.63	1.12	2 210
4	43.20	18.71	19.55	3.03	.97	2 904
			Empty-weight basis (Cockerels)			
.07	23.99	17.29	4.68	2.14	.50	1 415
.5	28.90	19.95	3.40	3.57	.97	1 445
1	27.81	21.56	2.59	3.67	1.01	1 440
1.5	31.81	23.52	3.79	3.70	1.03	1 706
2	34.21	23.20	5.61	3.89	1.15	1 725
3	33.60	23.00	6.03	3.92	1.24	1 768
4	33.58	23.46	6.07	3.78	1.26	1 838
5	34.51	25.45	4.33	3.98	1.23	1 838
			(Pullets)			
.07	23.99	17.29	4.68	2.14	.50	1 415
.5	28.75	20.75	3.53	3.60	.99	1 520
1	28.85	22.59	2.61	3.71	1.01	1 489
1.5	30.44	21.86	3.98	3.68	1.07	1 591
2	34.31	22.77	6.65	3.65	1.10	1 833
3	38.46	22.74	11.50	3.72	1.15	2 266
4	44.20	19.15	20.00	3.10	.99	2 971
			Fat-free basis (Cockerels)			
.07	20.26	18.14	....	2.25	.52	.....
.5	26.30	20.65	....	3.59	1.00	.....
1	25.89	22.13	....	3.77	1.04	.....
1.5	29.12	24.45	....	3.85	1.07	.....
2	30.30	24.58	....	4.12	1.22	.....
3	29.34	24.48	....	4.17	1.32	.....
4	29.29	24.98	....	4.02	1.34	.....
5	31.55	25.56	....	4.16	1.29	.....
			(Pullets)			
.07	20.26	18.14	....	2.25	.52	.....
.5	29.23	24.10	....	4.17	1.15	.....
1	26.94	23.20	....	3.81	1.04	.....
1.5	27.56	22.77	....	3.83	1.11	.....
2	29.63	24.39	....	3.91	1.18	.....
3	30.46	25.69	....	4.20	1.30	.....
4	30.25	23.94	....	3.87	1.24	.....

Percentage Distribution of Nutrients Among Chemical Samples. The percentage distribution of the dry matter, crude protein, ether extract, gross energy, ash, and calcium among the four composite

TABLE 32.—PERCENTAGE DISTRIBUTION OF DRY SUBSTANCE AND CRUDE PROTEIN AMONG COMPOSITE SAMPLES ANALYZED IN WHITE LEGHORN CHICKENS OF DIFFERENT WEIGHTS AND SEX

Approximate body weight	Dry substance				Crude protein			
	Flesh	Bone	Offal	Feathers	Flesh	Bone	Offal	Feathers
Cockerels								
lbs.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*
.5	43.7	21.5	22.4	12.4	44.8	16.0	22.6	16.6
1	40.9	22.7	20.0	16.4	44.9	15.4	19.9	19.8
1.5	41.8	19.7	17.9	20.6	45.4	12.5	17.0	25.1
2	46.8	21.1	17.4	14.7	48.5	13.9	17.0	20.6
3	45.8	22.5	18.3	13.4	49.8	13.9	16.9	19.4
4	46.5	21.8	17.3	14.4	50.7	12.9	16.5	19.9
5	44.3	21.3	15.1	19.3	48.5	12.8	14.7	24.0
Pullets								
.5	43.1	22.1	21.4	13.4	45.9	16.1	20.7	17.3
1	41.7	21.0	19.1	18.2	46.3	13.6	17.9	22.2
1.5	43.9	22.1	17.2	16.8	47.6	14.3	16.5	21.6
2	47.2	20.0	16.3	16.5	48.8	12.6	14.5	24.1
3	52.5	17.4	15.7	14.4	50.5	11.6	14.9	23.0
4	57.5	14.2	17.2	11.1	50.5	11.9	15.0	22.6

samples analyzed is shown in Tables 32 to 34. From these tables it is interesting to note that the edible meat of the heavier birds, i.e., birds weighing from 3 to 5 pounds, contained from 45 to 57 percent of the total dry matter, about 50 percent of the crude protein, from 51 to 70 percent of the fat, but only 14 to 18 percent of the ash, and only a little over 1 percent of the calcium in the entire carcass. The feathers contained one-fifth or more of the crude protein in the total carcass. In the heavier cockerels the bones contained about one-fourth of the fat in the body, but in the heavier pullets they contained a much

TABLE 33.—PERCENTAGE DISTRIBUTION OF ETHER EXTRACT AND GROSS ENERGY AMONG COMPOSITE SAMPLES ANALYZED IN WHITE LEGHORN CHICKENS OF DIFFERENT WEIGHTS AND SEX

Approximate body weight	Ether extract				Gross energy			
	Flesh	Bone	Offal	Feathers	Flesh	Bone	Offal	Feathers
Cockerels								
lbs.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*
.5	54.8	17.4	23.9	3.9	46.3	16.5	23.5	13.5
1	49.2	20.7	25.5	4.6	45.5	16.2	20.9	17.1
1.5	52.7	19.6	23.9	3.8	46.9	14.2	17.9	20.8
2	56.9	21.3	20.0	1.8	51.1	16.5	18.5	13.7
3	54.3	25.4	19.1	1.2	51.4	17.4	18.8	12.4
4	54.5	24.8	19.3	1.4	52.7	16.5	17.4	13.2
5	51.4	28.2	17.6	2.8	49.6	16.1	15.9	18.1
Pullets								
.5	56.7	18.5	20.9	3.9	48.3	16.1	21.7	13.9
1	47.3	20.7	27.1	4.9	46.7	14.5	20.0	18.8
1.5	55.8	19.9	21.2	3.1	49.9	17.2	17.7	15.2
2	56.0	20.4	22.0	1.6	52.6	15.4	16.8	15.2
3	67.1	12.6	19.6	.7	58.8	12.0	17.0	12.2
4	70.4	8.8	20.5	.3	63.5	9.8	18.8	7.9

TABLE 34.—PERCENTAGE DISTRIBUTION OF ASH AND CALCIUM AMONG THE COMPOSITE SAMPLES ANALYZED IN WHITE LEGHORN CHICKENS OF DIFFERENT WEIGHTS AND SEX

Approximate body weight	Ash				Calcium			
	Flesh	Bone	Offal	Feathers	Flesh	Bone	Offal	Feathers
				Cockerels				
lbs.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*
.5	15.4	59.2	22.0	3.2	1.78	78.5	19.0	.69
1	17.1	61.9	17.3	3.4	1.31	82.8	14.5	1.23
1.5	15.3	60.6	19.3	4.6	1.51	79.3	17.1	2.07
2	14.6	65.0	17.4	2.9	1.04	82.9	15.1	.91
3	14.1	64.1	19.5	2.2	1.04	81.1	17.3	.50
4	14.9	62.6	20.1	2.1	1.11	81.1	17.0	.68
5	14.5	67.5	15.1	2.7	1.04	83.2	14.9	.87
				Pullets				
.5	16.6	60.9	19.3	3.0	1.86	81.4	16.1	.57
1	17.4	60.4	18.7	3.3	1.47	80.5	17.1	.90
1.5	15.5	62.2	18.8	3.4	1.46	81.3	16.2	.94
2	15.4	65.4	16.3	2.7	1.43	83.5	14.1	.90
3	15.1	65.9	17.0	1.8	1.08	83.4	14.6	.83
4	18.6	68.0	10.9	2.3	1.06	89.9	7.7	1.24

smaller proportion. However, from 62 to 68 percent of the ash and from 81 to 89 percent of the calcium in both cockerels and pullets were found in the bones of the dressed carcass.

Total Digestible Nutrients in Birds of Different Ages and Sex. The total edible nutrients in White Leghorn chickens of different weights have been calculated and the results collected in Table 35. The outstanding feature of this table is the demonstration of the superiority of pullets at weights of 2 pounds or more in their content of edible dry matter, fat, and energy, unaccompanied by any inferi-

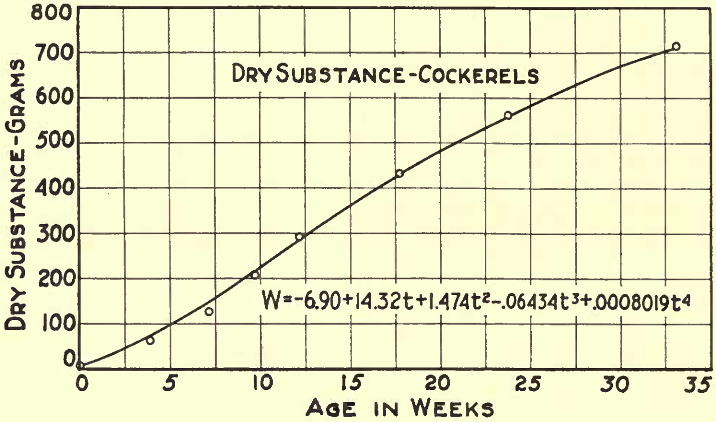
TABLE 35.—EDIBLE NUTRIENTS IN WHITE LEGHORN COCKERELS AND PULLETS AT DIFFERENT WEIGHTS

Approximate body weight	Weight of edible flesh	Dry substance	Crude protein	Crude fat	Ash	Calcium	Gross energy
				Cockerels			
lbs.	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	*cals.*
.5	92	27.4	19.4	4.1	1.2	.04	145
1	199	49.7	42.4	5.6	2.8	.06	287
1.5	320	87.7	70.5	13.3	3.7	.10	528
2	442	142	99.6	28.3	5.0	.11	781
3	686	204	152	43.5	7.3	.17	1 207
4	946	276	210	58.6	10.0	.25	1 715
5	1 167	337	272	49.0	12.7	.28	2 011
				Pullets			
.5	94	26.7	20.5	4.3	1.3	.04	158
1	209	52.8	46.0	5.4	2.8	.07	305
1.5	322	88.2	68.7	14.6	3.8	.10	524
2	465	143	98.1	32.9	5.0	.14	852
3	753	268	152	102.5	7.4	.17	1 769
4	1 027	451	171	249.7	10.3	.19	3 346

ority in the content of edible protein up to a body weight of 3 pounds. At the 4-pound weight the White Leghorn cockerel supplies about one-fourth more edible protein than the White Leghorn pullet.

MATHEMATICAL ANALYSIS OF THE CHEMICAL DATA

One of the main purposes of the chemical analysis of the birds slaughtered in this experiment was to secure data on the rate at which nutrients are deposited in the bodies of growing White Leghorn pullets



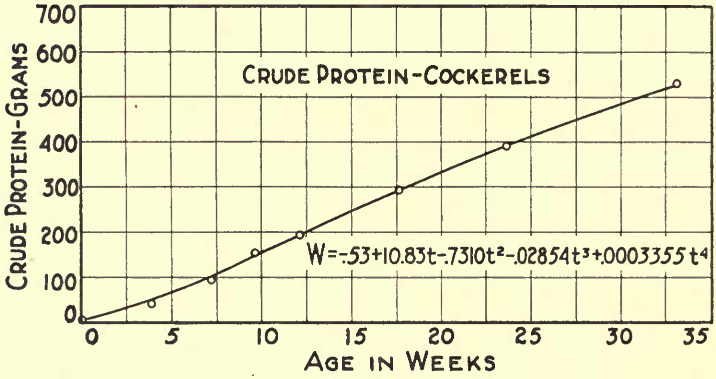


FIG. 3.—OBSERVED AND CALCULATED DRY SUBSTANCE AND CRUDE PROTEIN FOR WHITE LEGHORN COCKERELS

and cockerels. These rates of deposition of nutrients are fundamental data in the exact estimation of the food requirements for growth of this species. There is, however, no good method of obtaining these rates of growth in terms of individual nutrients directly from the original data, since they were obtained from small groups of birds. The irregularity of these data, reflecting the operation of uncontrolled factors possessing no significance for the problem at hand, offers a

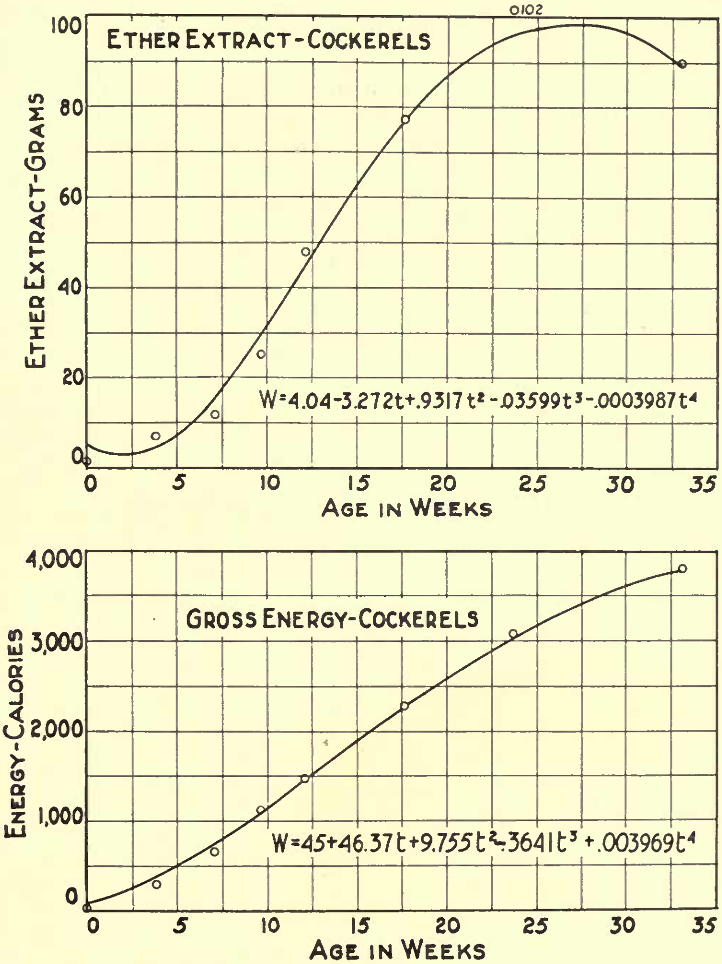


FIG. 4.—OBSERVED AND CALCULATED ETHER EXTRACT AND GROSS ENERGY FOR WHITE LEGHORN COCKERELS

serious obstacle to any simple and direct method of obtaining the desired information.

This error, inherent in all biological investigations on growth, may be overcome by fitting to each group of data a mathematical equation capable of describing them in a satisfactory manner. The closeness of description is, of course, measured by the deviations between the observed data and the estimations obtained from the fitted equation by

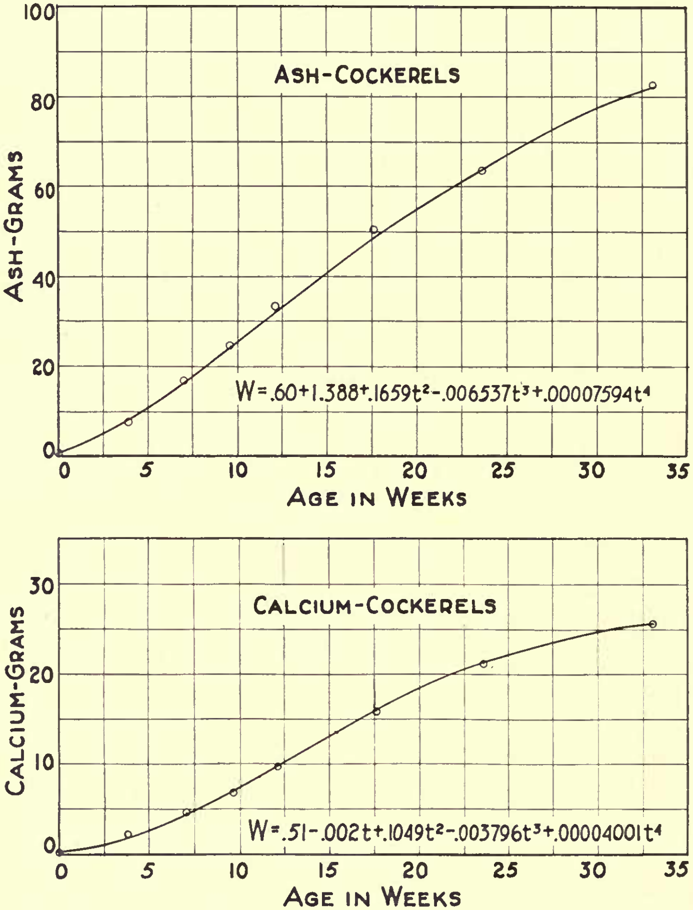


FIG. 5.—OBSERVED AND CALCULATED ASH AND CALCIUM FOR WHITE LEGHORN COCKERELS

solving for one of the variables, using properly assigned values of the other. Obviously such estimated values will show a regular variation of one variable on the other, capable of graphical description by a smooth curve.

In performing this mathematical analysis, the fourth-degree equation used for the age-body-weight data was used thruout. The age of each sample of birds submitted to chemical analysis, however, was determined by substituting in the growth equations (Nos. 2 and 3) the average body weight of the group (W) and solving for time (t).

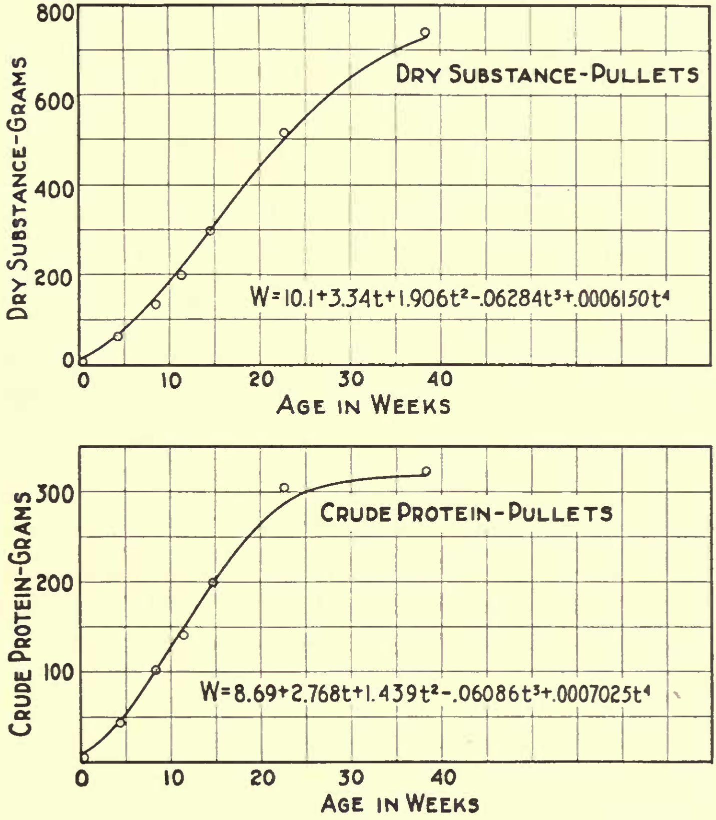


FIG. 6.—OBSERVED AND CALCULATED DRY SUBSTANCE AND CRUDE PROTEIN FOR WHITE LEGHORN PULLETS

The fourth-degree equation was then fitted in turn to each set of data relating to the weights of each nutrient in successive groups of birds (Table 30), using as the time variable the estimated age of each group. The method of least squares was used thruout. The resulting equations were as follows:

Cockerels

Dry substance: $W = -6.90 + 14.32t + 1.474t^2 - .06434t^3 + .0008019t^4$ (6)

Protein: $W = -.53 + 10.83t + .7310t^2 - .02854t^3 + .0003355t^4$ (7)

Ether extract: $W = 4.04 - 3.272t + .9317t^2 - .03599t^3 + .0003987t^4$ (8)

Gross energy:	$W = 45 + 46.37t + 9.755t^2 - .3641t^3 + .003969t^4$	(9)
Ash:	$W = .60 + 1.388t + .1659t^2 - .006537t^3 + .00007594t^4$	(10)
Calcium:	$W = .51 - .002t + .1049t^2 - .003796t^3 + .00004001t^4$	(11)

Pullets

Dry substance:	$W = 10.1 + 3.34t + 1.906t^2 - .06284t^3 + .0006150t^4$	(12)
Protein:	$W = 8.69 + 2.768t + 1.439t^2 - .06086t^3 + .0007025t^4$	(13)
Ether extract:	$W = -6.00 + 3.88t - .2373t^2 + .02500t^3 - .0004025t^4$	(14)
Gross energy:	$W = 112 - 24.6t + 15.11t^2 - .4776t^3 + .004899t^4$	(15)
Ash:	$W = .45 + .867t + .1991t^2 - .008827t^3 + .0001031t^4$	(16)
Calcium:	$W = .42 + .037t + .08132t^2 - .003298t^3 + .00003747t^4$	(17)

NOTE: In each case W is the weight in grams of the constituent and t is the age in weeks.

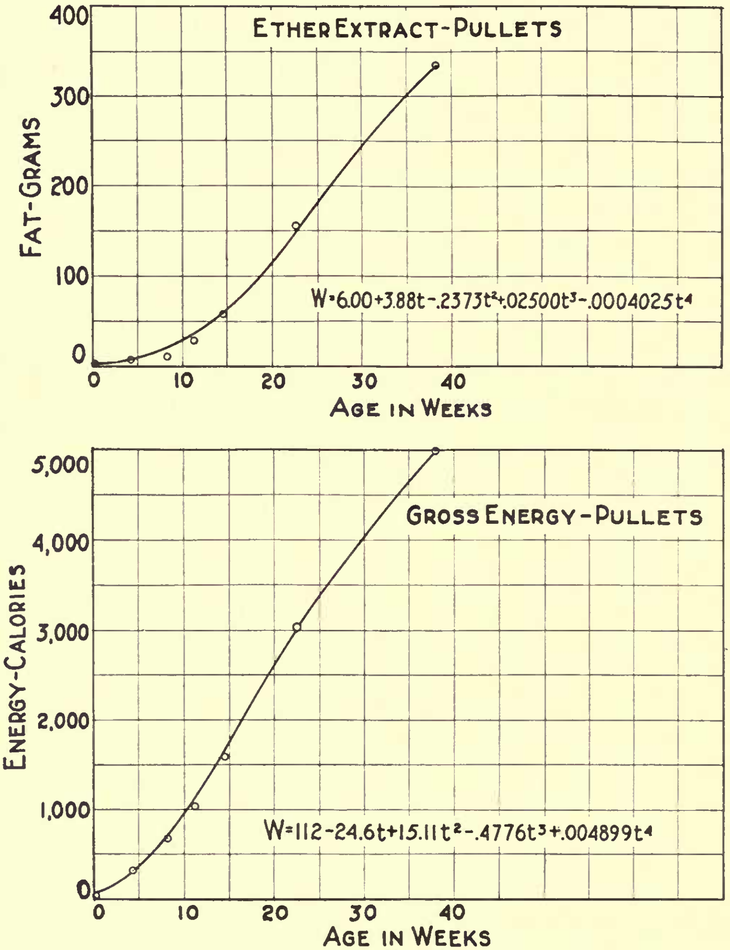
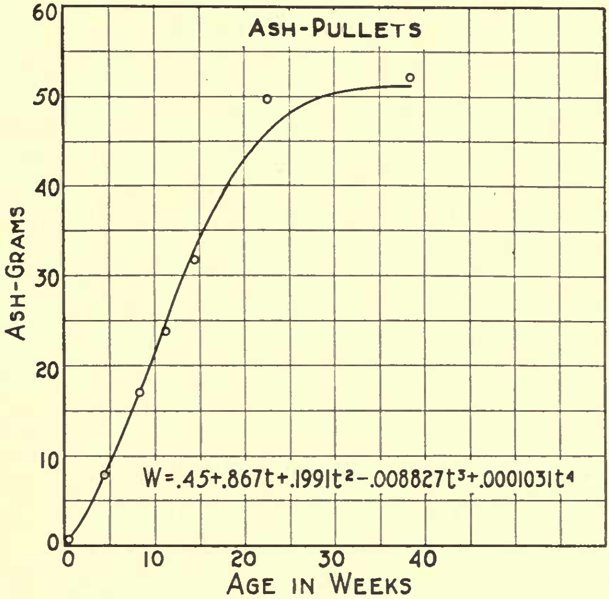


FIG. 7.—OBSERVED AND CALCULATED ETHER EXTRACT AND GROSS ENERGY FOR WHITE LEGHORN PULLETS

The closeness with which these equations fit the observed data is shown numerically in Table 36 and graphically in Figs. 3 to 8. Judging by eye only, the agreement between observed and calculated



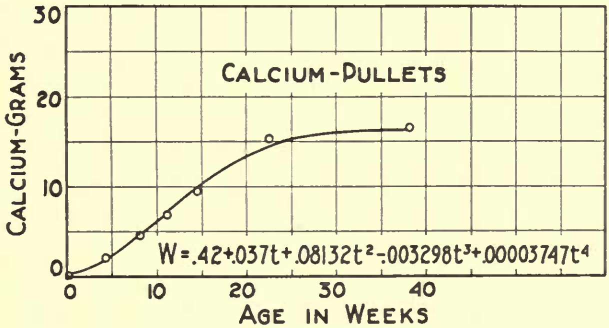


FIG. 8.—OBSERVED AND CALCULATED ASH AND CALCIUM FOR WHITE LEGHORN PULLETS

data is very good for ash, calcium, and crude protein, only fairly good for dry matter and gross energy, and rather poor for ether extract. A satisfactory estimation of the composition of newly hatched chicks was seldom possible by the use of these equations.

Perhaps the most serious objection that may be used against these

TABLE 36.—OBSERVED AND CALCULATED COMPOSITION OF THE SLAUGHTERED WHITE LEGHORN CHICKENS
(All weights in grams)

Average live weight	Corresponding age wks.	Dry substance		Crude protein		Ether extract		Gross energy in cals.		Ash		Calcium	
		Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
Cockerels													
31.1	0	6.6	....	4.8	....	1.29	....	39	34	.59	.46	.14	.15
218	3.87	60.4	67.0	41.8	50.6	7.13	3.50	302	348	7.48	8.05	2.03	1.71
477	7.13	128	149	99	104	11.9	16.2	663	749	16.9	16.7	4.65	4.49
678	9.62	209	217	155	149	25.2	30.2	1 121	1 104	24.4	24.1	6.77	7.13
875	12.12	292	286	198	195	47.9	45.9	1 473	1 478	33.2	31.8	9.80	9.99
1 317	17.64	432	429	295	294	77.5	77.4	2 275	2 284	50.3	48.2	15.9	16.1
1 719	23.69	563	557	393	393	102	96.7	3 082	3 026	63.4	63.6	21.1	21.4
2 136	33.04	716	711	528	526	90	90	3 813	3 807	82.6	82.3	25.5	25.6
Pullets													
31.1	.26	6.6	9.7	4.8	....	1.29	....	39	...	.59	....	.14	....
223	4.40	61.1	56.4	44.1	43.6	7.51	8.56	323	265	7.64	7.24	2.10	1.89
468	8.38	131	138	102	101	11.8	22.6	675	712	16.8	17.0	4.56	4.69
669	11.35	197	212	142	148	25.8	37.3	1 032	1 161	23.8	24.7	6.94	7.13
890	14.60	297	298	197	198	57.6	59.6	1 588	1 706	31.6	32.8	9.56	9.74
1 367	22.51	512	492	303	287	153	143	3 020	3 007	49.6	46.7	15.4	14.5
1 716	38.35	741	727	321	319	335	334	4 982	4 978	52.1	51.3	16.6	16.5

applications of a fourth-degree equation containing 5 constants to be evaluated from rather small groups of data is that the equation is too flexible, so that, for example, variations of the observed values at the higher ages have an undue effect upon the form of the curve. Thus, in Fig. 2, the fitted curve describing the growth in the body weights of the pullets attains a maximum at about 36 weeks, and then slowly

TABLE 37.—ESTIMATED CHEMICAL COMPOSITION AND ENERGY CONTENT OF WHITE LEGHORN CHICKENS AT EVEN WEIGHTS

Body weight	Age	Dry substance	Crude protein	Ether extract	Ash	Calcium	Gross energy
			Cockerels				
lbs.	*wks.*	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	*cals.*
.5	4.0	70	53	3.8	8.4	1.81	363
1	6.9	142	100	14.9	16.0	4.2	715
1.5	9.7	218	149	30	24	7.2	1 109
2	12.5	297	202	48	33	10.4	1 537
3	18.2	443	304	80	50	16.7	2 364
4	25.4	588	419	98	68	22.6	3 204
5	36.9	783	583	83	90	26.5	4 066
			Pullets				
.5	4.5	57	44	8.7	7.4	1.92	269
1	8.2	133	97	21.7	16.4	4.5	682
1.5	11.5	216	151	38	25	7.3	1 189
2	14.9	304	202	62	33	9.9	1 749
3	22.4	489	286	141	47	14.4	2 988
4	44.9	814	381	329	61	19.8	6 153

bends downward, indicating a trend which larger groups of birds at these ages would not show. A similar objection applies to the curve for ether-extract content of cockerels (Fig. 4). Under these conditions the equations given above cannot be used safely in predicting values much beyond the range of time observed, and in some cases predictions within this range approximating the highest observed age are probably not significant.

Solving these equations for even weights, rather than for the actual average slaughter weights, gives the results summarized in Table 37, which results may be used in preference to those in Table 30 in predicting the average composition of White Leghorn chickens at even weights. The data in Table 37 may also be used to good advantage in computing the absolute and percentage composition of gains between even weights, and in computing the percentage composition of the birds at even weights. The results of this latter computation are contained in Table 38.

The age of the 4-pound pullets could not be obtained from Equation 3 for reasons already explained. For the purpose of obtaining such a prediction, Brody's curve of diminishing increments[2*] was fitted to the growth data of pullets from 16 to 40 weeks of age. This equation, in its logarithmic form, is: log (1900 − W) = 3.54345 − .03586t. For weights of 2, 3, and 4 pounds, the ages are 15.4, 22.6,

TABLE 38.—ESTIMATED PERCENTAGE COMPOSITION AND ENERGY CONTENT OF WHITE LEGHORN CHICKENS AT EVEN WEIGHTS

Body weight	Dry substance	Crude protein	Ether extract	Ash	Calcium	Gross energy per gram
			Cockerels			
lbs.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*gm. cals.*
.5	30.9	23.2	1.7	3.7	.80	1 600
1	31.3	22.0	3.3	3.5	.93	1 576
1.5	32.0	21.9	4.5	3.6	1.05	1 630
2	32.7	22.2	5.3	3.6	1.15	1 694
3	32.5	22.3	5.9	3.7	1.23	1 738
4	32.4	23.1	5.4	3.7	1.25	1 766
5	34.5	25.7	3.7	4.0	1.17	1 793
			Pullets			
.5	25.3	19.5	3.8	3.2	.85	1 187
1	29.3	21.4	4.8	3.6	1.00	1 504
1.5	31.8	22.2	5.6	3.7	1.07	1 747
2	33.5	22.3	6.8	3.7	1.10	1 928
3	36.0	21.0	10.4	3.4	1.06	2 196
4	44.9	21.0	18.1	3.3	1.09	3 391

and 44.9 weeks. The last value is used in the computations of the composition of 4-pound pullets contained in Tables 37 and 38.

MINIMUM NUTRITIVE REQUIREMENTS OF WHITE LEGHORN CHICKENS FOR GROWTH

By the differentiation of Equations 6 to 17 equations are obtained from which for each constituent the instantaneous rate of deposition $\left(\frac{dW}{dt}\right)$ may be computed for any age (t). The rates obtained in this way from Equations 6 to 17 would be expressed in grams per week. Dividing by 7, the rates will be reduced to grams per day. These reduced differential equations are given below:

DIFFERENTIAL EQUATIONS, SHOWING RATE OF GAIN PER DAY

Cockerels

Dry substance: $$\frac{dW}{dt} = 2.05 + .4213t - .02757t^2 + .0004582t^3 \quad (18)$$

Protein: $$\frac{dW}{dt} = 1.55 + .2089t - .01223t^2 + .0001917t^3 \quad (19)$$

Ether extract: $$\frac{dW}{dt} = -.47 + .2662t - .01542t^2 + .0002278t^3 \quad (20)$$

Gross energy: $$\frac{dW}{dt} = 6.6 + 2.787t - .1560t^2 + .002268t^3 \quad (21)$$

Ash: $$\frac{dW}{dt} = .198 + .0474t - .002802t^2 + .00004339t^3 \quad (22)$$

Calcium: $\frac{dW}{dt} = -.0003 + .02997t - .001627t^2 + .00002286t^3$ (23)

Pullets

Dry substance: $\frac{dW}{dt} = .48 + .545t - .02693t^2 + .0003514t^3$ (24)

Protein: $\frac{dW}{dt} = .40 + .411t - .02608t^2 + .0004014t^3$ (25)

Ether extract: $\frac{dW}{dt} = .55 - .0678t + .01071t^2 - .0002300t^3$ (26)

Gross energy: $\frac{dW}{dt} = -3.5 + 4.32t - .2047t^2 + .002800t^3$ (27)

Ash: $\frac{dW}{dt} = .124 + .0569t - .003783t^2 + .0000589t^3$ (28)

Calcium: $\frac{dW}{dt} = .005 + .0232t - .001413t^2 + .00002141t^3$ (29)

Solving these differential equations for any age in weeks (t) will give the daily rate of depositions in grams of the constituents in question. The daily increments in chemical constituents and gross energy of White Leghorn chickens for ages at which body weights of .5, 1, 1.5, 2, 3, 4, and 5 pounds are attained, according to our own growth data, are summarized in Table 39. At a body weight of 2 pounds and an age of 12.5 weeks the cockerels were gaining in body weight at a rate of 11.8 grams per day, and were depositing in their bodies daily, on the average, 3.91 grams of dry matter, 2.63 grams of crude protein, .437 gram of ash, .165 gram of calcium and 21.5 calories of gross energy. The latter values represent the actual minimum need of nutrients by these birds for growth only, tho obviously they must be provided with larger amounts to allow for the food requirements of maintenance and activity, and for the wastage of food nutrients in digestion and metabolism. These additional factors in the food requirements of growing birds must be evaluated separately by methods other than those used in this study.

The estimated requirements for growth of 2-pound pullets (14.8 weeks old) gaining at the slower rate of 9.6 grams daily are 3.78 grams of dry matter, 2.06 grams of protein, .328 gram of ash, .108 gram of calcium, and 24.8 calories of energy per day. The larger energy requirement of the pullet is an expression of its greater rate of fattening, represented at a weight of 2 pounds by a daily deposition of 1.15 grams of fat as compared with .90 gram in the cockerel of the same weight.

For reasons already given, the estimated daily increments for the 5-pound cockerel and the 4-pound pullet cannot be accorded the same degree of accuracy as the estimates at the lower weights, within the range of experimental observation. The increments given in Table 39

TABLE 39.—CALCULATED DAILY INCREMENTS IN CHEMICAL CONSTITUENTS AND GROSS ENERGY OF WHITE LEGHORN CHICKENS DURING GROWTH AT DIFFERENT BODY WEIGHTS

Body weight	Age	Daily increments in—						
		Body weight	Dry substance	Crude protein	Ether extract	Ash	Calcium	Gross energy
Cockerels								
lbs.	*wks.*	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	*cals.*
.5	4.01	[illegible].9	3.33	2.20	.36	.346	.095	15.4
1	6.87	11.2	3.79	2.47	.70	.406	.136	19.0
1.5	9.65	11.9	3.96	2.60	.86	.433	.158	21.0
2	12.51	11.8	3.91	2.63	.90	.437	.165	21.5
3	18.23	10.5	3.35	2.46	.64	.394	.144	19.3
4	25.44	7.4	2.47	2.10	.07	.305	.085	13.8
5[1]	33.04	5.0	2.40	2.01	−.28	.270	.038	10.2
Pullets								
.5	4.45	7.9	2.41	1.75	.44	.307	.082	11.8
1	8.17	9.4	3.32	2.24	.58	.368	.113	19.6
1.5	11.52	9.8	3.73	2.28	.84	.367	.117	23.4
2	14.85	9.6	3.78	2.06	1.15	.328	.108	24.8
3	22.38	7.2	3.13	1.04	1.81	.162	.056	22.1
4[2]	38.35	...	1.59	.44	.73	.064	.024	19.0

[1]Calculations are for 2,136 grams, the weight of the last group of cockerels studied, rather than 2,268 grams (5 pounds even).
[2]Calculations are for 1,716 grams, the weight of the last group of pullets studied, rather than 1,814 grams (4 pounds even).

TABLE 40.—COMPARISON OF THE DAILY INCREMENTS DURING GROWTH IN PROTEIN, ASH, AND ENERGY FOR WHITE LEGHORN AND WHITE PLYMOUTH ROCK CHICKENS

Body weight	White Leghorns			White Plymouth Rocks					
				Submaximal growth[1]			Maximal growth[2]		
	Protein	Ash	Energy	Protein	Ash	Energy	Protein	Ash	Energy
Cockerels									
lbs.	*gms.*	*gms.*	*cals.*	*gms.*	*gms.*	*cals.*	*gms.*	*gms.*	*cals.*
.5	2.20	.346	15.4	1.42	.23	10.5	1.57	.26	11.6
1	2.47	.406	19.0	....	...	....	....	....	....
1.5	2.60	.433	21.0	1.88	.32	15.9	3.68	.63	31.1
2	2.63	.437	21.5	....	...	....	....	....	....
2.5	....	....	....	2.39	.43	22.5	6.21	1.11	58.5
3	2.46	.394	19.3	....	...	....	....	....	....
3.5	....	....	....	2.65	.49	27.3	4.26	.79	43.9
4	2.10	.305	13.8	....	...	....	....	...	....
4.5	....	....	....	2.34	.44	25.9	4.28	.81	47.5
5	2.01	.270	10.2	....	...	....	....	...	....
5.5	....	....	....	1.28	.25	15.2	3.71	.72	43.9
Pullets									
.5	1.75	.307	11.8	1.24	.21	9.6	1.52	.26	11.8
1	2.24	.368	19.6	....	...	....	....	...	....
1.5	2.28	.367	23.4	1.69	.27	17.5	3.66	.59	37.9
2	2.06	.328	24.8	....	...	....	....	...	....
2.5	....	....	....	2.06	.32	26.0	2.96	.45	37.4
3	1.04	.162	22.1	....	...	....	....	...	....
3.5	....	....	....	1.56	.23	22.9	3.38	.49	49.5
4	.44	.064	19.0	....	...	....	....	...	....
4.5	....	....	....	....	...	....	2.70	.38	44.3

[1]Estimates based on Illinois growth data; see Ill. Agr. Exp. Sta. Bul. 278. [2]Estimates based on the more rapid growth of White Plymouth Rock chickens observed at the Purdue Station; see Ill. Agr. Exp. Sta. Bul. 278.

therefore refer to the ages and weights of the last groups of cockerels and pullets actually studied, i.e., 33.04 weeks and 2,136 grams for the cockerels, and 38.35 weeks and 1,716 grams for the pullets. These weights are slightly less than 5 pounds (2,268 grams) and 4 pounds (1,814 grams) respectively.

The estimated daily increments in protein, ash, and energy for White Leghorn chickens are smaller than those obtained by a different method of mathematical analysis for the maximum growth of White Plymouth Rock chickens as reported in Bulletin 278 of this Station.[10*] For the slower growth actually observed in the Illinois flock of birds, however, the rates are much closer. These comparisons are made in Table 40.

The data contained in Tables 39 and 40, and the equations from which they have been obtained, are thus the most important data of the entire investigation. Their practical use in the formulation of scientific feeding standards must wait upon the satisfactory evaluation of maintenance requirements and requirements for muscular activity, and the satisfactory measurement of the wastage of food in digestion and metabolism.

TENTATIVE FEEDING STANDARDS FOR GROWING WHITE LEGHORN AND WHITE PLYMOUTH ROCK CHICKENS

In the absence of satisfactory evaluations and measurements it may be permissible, on the basis of available data and upon what may seem to be reasonable assumptions, to set up a tentative series of estimates of the nutritive requirements of growing White Leghorn and White Plymouth Rock chickens with reference to digestible crude protein, calcium, and net energy.

Protein Requirements. The requirements for protein relate to maintenance and growth. The preponderance of experimental evidence indicates that muscular activity does not, in the presence of adequate amounts of nonprotein nutrients, increase appreciably the breakdown of body protein or the need for food protein. This subject has been reviewed recently by Mitchell and Kruger[13*] and by Mitchell and Hamilton,[14*] so that the basis of the conclusion stated above need not be investigated here.

The study reported in this bulletin and that relating to White Plymouth Rock birds reported in Bulletin 278[10*] afford information of the protein requirements for growth but not of those for maintenance. In estimating the maintenance requirements, the investigation of Ackerson, Blish, and Mussehl[1*] of the Nebraska Agricultural Experiment Station on the endogenous metabolism of hens and capons has been consulted. In the publication describing this work, the nitrogenous output of birds of different ages while subsisting upon a nitrogen-free diet is given. This wastage of body nitrogen may be considered as a measure of the minimum maintenance requirement for protein since, for the attainment of nitrogenous equilibrium, this wastage must be covered by dietary nitrogen supplied in practical nutrition by dietary protein. Data for birds younger than 5 to 6 months of age are not included; for birds of these ages a rough extrapolation of the curve for capons, upon which the most complete data were obtained, has been made. On this basis it has been assumed that at one month of age the daily endogenous loss of nitrogen is 375 mgms. per kilogram of body weight, and that this ratio decreases along an *S*-shaped curve (as shown on page 195 of the report[*1]). Altho it is possible that sex differences exist in this respect, the Nebraska data afford no basis for this assumption, and in a large number of similar experiments on rats at the Illinois Station no sex differences of this character have been observed. In the computations of the maintenance requirements for protein given in Tables 42 and 43, therefore, the endogenous nitrogen per unit of body weight has been obtained by this approximate method from the Nebraska data; multiplication by the body weight gives the total endogenous wastage per bird, and multiplication of this value by the conventional factor of 6.25, the corresponding crude protein. These values are minimum values, and are of the same significance as the values for growth based upon the crude protein content of the daily gains. They may therefore be added together to give a total minimum protein requirement.

The total protein requirements obtained in this way would represent the requirements for digestible dietary protein only when the biological value of the dietary protein is equal to 100, indicating no wastage of digestible protein in the synthesis of body protein. But in practical nutrition the biological values of the proteins of feeds range from 50 to 85. Assuming a value of 50 as a safe average permits the statement of the minimum protein requirements in terms of digestible crude protein. The values in Tables 42 and 43 under this heading are therefore twice the minimum values contained in the column to the left.

Calcium Requirements. For calcium, as for protein, the Illinois investigations provide information on growth requirements but not on maintenance requirements. Sherman's studies[16*] on the calcium requirement of man afford some basis for computing the calcium requirement of chickens from their maintenance requirement for protein. According to Sherman, an adult man requires about 1 gram of calcium in maintenance for each 100 grams of digestible protein. But his protein requirement for maintenance upon which this ratio was based, i.e., 44 grams daily for an average man of 70 kilograms body weight, is probably about twice as high as the minimum requirement, as indicated, for example, by Hindhede's many investigations. In the Illinois investigations, digestible protein, for purposes of estimating nutrient requirements, has been assigned a biological value of 50, a conservative value to use in view of published results obtained at the Illinois Station. Hence it seems fair to assume that the calcium requirement is equal to 4 percent of the minimum crude protein requirement for maintenance, and for Tables 42 and 43 it has been so calculated. The sum of the calcium requirements for maintenance and growth is taken as the total calcium requirement since muscular activity is not known to affect the calcium metabolism. The total calcium requirements thus obtained are minimal in their significance; they allow for no wastage of calcium in either digestion or metabolism. With calcium supplements added to a calcium-poor ration, Forbes and his associates[6*] have obtained with growing pigs percentage retentions of calcium of 50 or better. If these values may be applied to poultry, the dietary calcium requirements may be taken as twice the minimum calcium requirements as given in the tables.

The experiments on White Plymouth Rocks[10*] did not involve calcium analyses but only ash analyses. However, the analysis of White Leghorns shows that the calcium content of the total ash approximates rather closely to 30 percent. Hence the growth requirements of calcium for the former species were assumed to equal 30 percent of their ash requirements.

Net Energy Requirements. The net energy requirements of growing birds may be factored into three components—the requirement for maintenance, the requirement for muscular activity, and the requirement for growth. Only the latter requirement is involved in the present study of White Leghorn chickens and n the study of White Plymouth Rocks reported in Bulletin 278.[10*] The basal heat production of chickens, however, has been the object of two experiments by Mitchell, Card, and Haines,[11*] reported in 1927. The basal metabolism of both White Leghorn and White Plymouth Rock chickens of different sex and ages was measured and expressed in calories per day per square meter of skin area exclusive of the area of the shanks and feet. In the calculations made for Tables 42 and 43, sex differences were not considered. Altho in the adult chicken (Rhode Island Red) the basal metabolism of pullets averages almost

TABLE 41.—MAINTENANCE EXPERIMENTS WITH RHODE ISLAND RED COCKERELS

Bird No.	Initial body weight	Final body weight	Average body weight	Feeding period	Corn eaten daily	Net energy intake	Surface area of birds	Basal heat production	Excess heat produced	
	gms.	gms.	gms.	wks.	gms.	cals.	sq. cms.	cals.	cals.	perct. of basal
443	3 045	3 125	3 029	10	89	249	2 062	166	83	50
471	3 150	3 225	3 136	10	91	255	2 110	170	85	50
816	2 885	3 010	2 888	10	84	235	1 998	161	74	46
474	3 265	3 245	3 211	7	94	263	2 144	173	90	52
174	2 560	2 560	2 521	10	76	213	1 825	147	66	45
624	3 085	3 000	3 006	10	89	249	2 052	165	84	51
552	2 915	3 020	2 952	10	85	238	2 027	163	75	46
458	2 960	3 250	3 101	10	86	241	2 095	169	72	43

TABLE 42.—ESTIMATED DAILY NUTRIENT REQUIREMENTS OF GROWING WHITE LEGHORN CHICKENS

Body weight	Crude protein				Calcium			Net energy				
	Mainte-nance	Growth	Total[1]	Digestible protein[2]	Mainte-nance	Growth	Total	Mainte-nance	Activity	Growth	Total	Equivalent weight of corn
Cockerels												
lbs.	gms.	gms.	gms.	gms.	gms.	gms.	gms.	cals.	cals.	cals.	cals.	gms.
.5	.5	2.2	2.7	5.4	.02	.09	.11	37	18	15	70	25
1	1.0	2.5	3.5	7.0	.04	.14	.18	55	27	19	101	36
1.5	1.5	2.6	4.1	8.2	.06	.16	.22	59	29	21	109	39
2	2.0	2.6	4.6	9.2	.08	.16	.24	72	36	21	129	46
3	2.8	2.5	5.3	10.6	.11	.14	.25	94	47	19	160	57
4	3.6	2.1	5.7	11.4	.14	.08	.22	114	57	14	185	66
5	2.5	2.0	4.5	9.0	.10	.04	.14	133	66	10	210	75
Pullets												
.5	.5	1.7	2.2	4.4	.02	.08	.10	37	18	12	67	24
1	1.0	2.2	3.2	6.4	.04	.11	.15	55	27	20	102	36
1.5	1.5	2.3	3.8	7.6	.06	.12	.18	59	29	23	111	40
2	2.0	2.1	4.1	8.2	.08	.11	.19	72	36	25	133	48
3	2.8	1.0	3.8	7.6	.11	.06	.17	94	47	22	163	58
4	1.4	.4	1.8	3.6	.06	.02	.08	114	57	19	190	68

[1]Total minimum requirement of protein. [2]Assuming a biological value of 50.

TABLE 43.—ESTIMATED DAILY NUTRIENT REQUIREMENTS OF GROWING WHITE PLYMOUTH ROCK CHICKENS, MAXIMUM GROWTH

Body weight	Crude protein				Calcium			Net energy				
	Maintenance	Growth	Total[1]	Digestible protein[2]	Maintenance	Growth	Total	Maintenance	Activity	Growth	Total	Equivalent weight of corn
Cockerels												
lbs.	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	*cals.*	*cals.*	*cals.*	*cals.*	*gms.*
.5	.5	1.6	2.1	4.2	.02	.08	.10	32	16	12	60	21
1.5	1.6	3.7	5.3	10.6	.06	.19	.25	63	31	31	125	45
2.5	2.5	6.2	8.7	17.4	.10	.33	.43	89	44	58	191	68
3.5	3.5	4.3	7.8	15.6	.14	.24	.38	111	55	44	210	75
4.5	4.5	4.3	8.8	17.6	.18	.24	.42	131	65	47	243	87
5.5	5.4	3.7	9.1	18.2	.22	.22	.44	150	75	44	269	96
Pullets												
.5	.5	1.5	2.0	4.0	.02	.08	.10	32	16	12	60	21
1.5	1.6	3.7	5.3	10.6	.06	.18	.24	63	31	38	132	47
2.5	2.5	3.0	5.5	11.0	.10	.13	.23	89	44	37	170	61
3.5	3.5	3.4	6.9	13.8	.14	.15	.29	111	55	49	215	77
4.5	4.4	2.7	7.1	14.2	.18	.14	.32	131	65	44	240	86
5.5	4.3	1.3	5.6	11.2	.17	.05	.22	150	75	24	249	89

[1]Total minimum requirement of protein. [2]Assuming a biological value of 50.

13 percent lower than that of cockerels (Mitchell and Haines),[12*] the data on any one breed are not sufficiently extensive to determine when this sex difference first appears and at what rate it approaches this adult value. On the other hand, from the results of Mitchell, Card, and Haines,[11*] it appears that the basal metabolism of the growing White Leghorn chicken, after 3 months of age at least, is appreciably less intense per unit of skin area than that of the White Plymouth Rock. For the purposes of these calculations the basal metabolism of the .5-pound birds of both breeds is taken as 1,200 calories per day per square meter of skin area, and that of the 1-pound birds as 900 calories on the same basis. For older Plymouth Rocks the average value of 828 calories per square meter is used, and for White Leghorns the value of 741 calories. The skin area of the White Rocks was determined from the formula $S = 9.85\ W^{.667}$ and that of the White Leghorns from the formula $S = 10.39\ W^{.667}$.

The basal heat productions calculated in this way represent the net energy requirements for physiological maintenance, and thus involve no activity factor. The assessment of the energy requirement for muscular activity, except on the basis of a unit of work or of horizontal locomotion accomplished, must always be an arbitrary and somewhat unsatisfactory undertaking. In the present calculations advantage was taken of an experiment performed a number of years ago at the Illinois Station for the purpose of determining the amount of a ration composed largely of corn that is required to maintain constant weight in adult chickens.[a]

Eight Rhode Island Red cockerels weighing around 3,000 grams were individually fed a ration of ground yellow corn in amounts varied in such a way as to induce constancy of body weight. A daily supplement of 3 grams of calcium carbonate, 1 gram of sodium chlorid, and 4 cc. of cod-liver oil was given each bird. Each cockerel was confined in a cage with a floor space of 4 square feet. After a variable period of adjustment each of the cockerels, with one exception, was maintained at practically constant weight on constant feed for 10 weeks. In the one exception the maintenance period was only 7 weeks. The results of the experiment are summarized in Table 41. The daily feed consumption has been expressed in terms of corn by adding the approximate isodynamic equivalent of the daily dosage of 4 cubic centimeters of cod-liver oil, i.e., 9 grams, to the corn actually consumed. The net energy value of the corn consumed daily has been computed on the basis of an average value of 280 calories per 100 grams of corn with a

[a]Acknowledgment is made to W. T. Haines for the feeding and care of the birds in this experiment.

moisture content of 10 percent.[12]* The skin areas of the birds and their basal heat production, at the rate of 806 calories per day per square meter, have been calculated.

On a maintenance ration the net energy consumed by adult cockerels would be used for two purposes only, i.e., for basal metabolism and for muscular activity. Hence in this experiment the energy expenditure in muscular activity may be estimated as the difference between the net energy intake and the basal heat production. From 66 to 90 calories were expended daily by the birds in this experiment in supporting their muscular activity. This was equivalent to 43 to 52 percent of their expenditures in the basal metabolism.

The energy expenditures for activity relate, in this experiment, to rather close confinement. They may be compared with similar calculations based on an experiment concerned with the indirect determination of the maintenance requirements of White Leghorn chickens reported recently by Titus.[18]* In this case the chickens were fed in groups of 10 in pens measuring about 11 feet by 7 feet with an adjoining yard of approximately the same dimensions. Both the pens and the yards had concrete floors, and no litter was used. By the use of a mathematical method of analyzing data obtained in an experiment in which maintenance of body weight was neither attempted nor realized, Titus estimated that the gross maintenance requirement of White Leghorn hens, 16 months old and weighing on an average 1,632 grams, was covered by a daily consumption per bird of 64 grams of the ration offered. This ration was a complex one, containing corn, wheat, oatmeal, and a number of protein concentrates and mineral supplements. It contained about 10 percent moisture and about 18 percent crude protein. The nonmineral portion of the 64-gram requirement was 61.1 grams. Assuming that this possessed a net energy value as high as that of corn of like moisture content, i.e., 280 calories per 100 grams, these birds were consuming 171 calories in net energy daily in maintenance. The surface (skin) area of a 1,632-gram White Leghorn chicken may be estimated at 1,440 square centimeters, and its basal metabolism (741 calories per square meter) as 107 calories. Hence 64 calories (171-107) were being expended daily in muscular work. This number of calories is equivalent to almost exactly 60 percent of the basal heat production. But the net energy value of this ration is, in all probability, less than that of corn, because of its higher protein content. For example, in unpublished experiments summarized briefly in the 41st Annual Report of the Illinois Station, wheat was found to have a greater heating effect on chickens than corn (63 calories per 100 grams as compared with 50 calories), and pure protein (casein) proved to be the most potent stimulant to heat production of the three main classes of nutrients (137 calories per 100 grams). If the net energy intake of the chickens in Titus' experiments[18*] was appreciably less than 171 calories, which seems probable, the expenditure in muscular activity would be less than 60 percent of the basal metabolism. The energy cost of muscular activity, expressed as a percentage of the basal heat production, therefore, was probably no greater in the group feeding experiment of Titus than in the individual feeding experiment above described, altho the confinement was much more severe in the latter case.

On the basis of these two experiments it has been assumed, in making the computations of the net energy requirements of growing chickens, that the energy cost of the muscular activity characteristic of chickens is equal to 50 percent of the basal heat production.

Growth, the third factor in the energy requirement of chickens, has been evaluated directly in the experiment reported in this bulletin and in the study of the growth of White Plymouth Rocks reported in Bulletin 278.[10*] This factor is measured by the daily deposition of gross energy in the growing chicken, i.e., by the gross energy value of the new tissue added daily during growth.

The total requirement of net energy is equal to the sum of the three factors separately evaluated and has been expressed in the last column of figures in Tables 42 and 43 in terms of corn, a net energy value of 280 calories per 100 grams being assumed for corn containing 10 percent of moisture.[12*]

Illustration of Use of Tentative Standards. The requirements of protein (nitrogen) and calcium for growth approximate or even exceed those for maintenance, but the requirement of net energy for growth is generally less than half the maintenance requirement, and at the larger weights, even tho growth is still proceeding actively, the net energy requirement is a still smaller fraction of the basal requirement (Tables 42 and 43). The activity quota of energy is generally considerably larger than the growth quota.

A 2-pound White Leghorn pullet, according to Table 42, requires 4.1 grams of crude protein daily, which in ordinary farm practice should be met by not more than 8.2 grams of digestible protein. Its net energy requirement is computed at 133 calories a day, 54 percent of which is needed for physiological maintenance (the basal metabolism), 27 percent for muscular activity, and 19 percent for growth. This amount of net energy would be provided by 48 grams of a good grade of corn. The estimated requirement for calcium is .19 gram, which would probably be met fully by .38 gram of dietary calcium, assuming a utilization of 50 percent. The deficiencies of a corn ration are indicated in this case by the fact that 48 grams of corn, sufficient to cover the energy requirements of a day, would contain less than half the required digestible protein and a mere fraction of the calcium needed. On the other hand, 48 grams of corn would furnish .12 gram of phosphorus, which may very well approximate the daily phosphorus requirement.

Extension to Egg Production. The calculations described above can be extended very simply to cover egg production. Analyses made at the Illinois Station show that an egg of average weight, say 58 grams, contains 7.45 grams of crude protein, 1.98 grams of calcium, and 95 calories of gross energy. If a pullet is producing one egg a day, obviously these amounts of nutrients must be added to her minimum physiological requirements. If she is producing an average of an egg every other day, one-half of these amounts of nutrients must be provided daily.

Titus found, in the investigation referred to,[18*] that the production of one egg appeared to require an allowance of 40 grams of his complex ration, or approximately 38 grams if the mineral supp'ements are deducted. This amount of corn, according to the work of Mitchell and Haines,[12*] would contain 106 calories of net energy, but it is probable, as explained above, that the ration was appreciably lower than corn in net energy value. It is not improbable, therefore, that 38 grams actually contained no more than 95 calories of net energy, the actual gross energy content of an egg of average size.

SUMMARY

Increases in the body weights of a flock of Single Comb White Leghorn chickens numbering initially about 1,000 birds were followed for a period of 40 weeks. The biweekly weights of the cockerels and the pullets were fitted to polynomial equations of the fourth degree for purposes: (1) of concise description, (2) of predicting for any age the most probable body weight, and (3) of computing the rates of gain in body weight at any given time. The growth curves obtained in this phase of the investigation approximate closely those previously reported for the same breed of birds from the Kentucky[3*] and the Connecticut (Storrs) Stations.[4*]

Samples of birds were removed from this flock as growth proceeded in order to follow by measurement of the carcass, dissection and weight of the individual organs and anatomical parts, and chemical analysis of the entire bird and its edible portion, the growth changes in White Leghorn chickens of both sexes. A total of 150

birds were thus measured individually and were analyzed in 15 groups of 10 birds each. Each group of birds was analyzed in four composite samples: (1) edible flesh and viscera, (2) bones in dressed carcass, (3) feathers, and (4) offal.

The birds increased in size in such a manner that their conformation, exclusive of feathering, did not change materially. This seems to be a proper interpretation of the fact that, at any weight, all the more important measurements taken were approximately the same percentages of the corresponding measurements of the lightest sample of birds measured.

The dimensional differences between pullets and cockerels were not marked, except that when the body weights were greater than 2 pounds, the leg measurements of the cockerels were larger than those of the pullets. In breadth at hips the pullets averaged consistently larger than the cockerels, and they averaged larger in midcircumference except at the 4-pound weight, at which weight the heaviest sample of pullets was taken.

The skin area of each bird was determined after the skin was removed from the body. After the conclusion of the experiment a more satisfactory method of determining surface area was worked out with a group of 25 White Leghorn birds ranging in weight from 109 to 2,142 grams, which involved the fitting of a cloth mold to the picked carcass. The areas obtained were related to the body weights in a fairly satisfactory manner by means of the equation: $S = 8.19W^{.705}$, in which S is the surface area in square centimeters and W the body weight in grams.

The weights of all organs and anatomical parts increased progressively in absolute value as the body weight increased, but the relative (percentage) weights, with reference to the empty body weight, cannot be so simply described.

The percentage weights of the offal parts—feathers, blood, head, shanks, and feet—remained fairly constant in the case of the cockerels after a body weight of .5 to 1 pound was reached, but with the pullets the offal parts, with the exception of the blood, decreased in percentage weights at the higher body weights.

The percentage weights of viscera (with the exception of the spleen) showed a general tendency to decrease with age in both sexes, tho frequently in an irregular manner. This decrease was most marked for the younger ages. The cockerels were clearly distinguished from the pullets by a more rapid decrease in the percentage weight of the digestive tract.

The percentage weight of the dressed carcass increased slowly with increasing body weight in the case of the cockerels, and appreciably faster for the pullets.

Sex differences in weights of organs and parts of carcasses at approximately equal body weights may be summarized as follows. For the cockerels there was consistently evident a greater weight of head (including comb and wattles), shanks, feet, and heart, and generally a greater weight of blood and bones in the dressed carcass. For the pullets there was a consistent superiority in the weights of gizzard, dressed carcass, and flesh and fat, and generally in the weight of feathers. At weights of 2 pounds and over, the females excelled the males in the weights of digestive tract, total viscera, and skin.

Variability in the weights of all organs and separated parts within the sample groups was greater for the pullets than for the cockerels, except for gizzard weights and weights of bones in the dressed carcass. Of all organs the spleen showed by far the greatest variability as measured by the coefficient of variation.

Chemical analysis of the four samples into which all carcass parts were separated disclosed higher fat percentages for the pullets in case of all samples except the feathers and for all body weights above 1.5 pounds. The carcasses of the pullets fattened more rapidly and continuously than those of the cockerels which, after a weight of 2 pounds, showed no further tendency to fatten. At 4 pounds body weight the pullets contained an average of 19.55 percent of fat as compared with only 5.92 percent for the cockerels.

The edible meat in the birds weighing 3 to 5 pounds contained from 45 to 57 percent of the total dry matter in the entire carcass, from 51 to 70 percent of the total fat, about 50 percent of the total protein, but only 14 to 18 percent of the total ash and a little over 1 percent of the total calcium. The feathers contained one-fifth or more of the crude protein in the total carcass. In the heavier cockerels the bones contained about one-fourth of the fat in the body, but in the heavier and fatter pullets they contained a much smaller proportion. However, from 62 to 68 percent of the ash and from 81 to 89 percent of the calcium in both sexes were contained in the bones of the dressed carcass.

At weights of 2 pounds and over the pullets exceeded the cockerels in content of edible dry matter, fat, and energy, and only at the 4-pound weight were they inferior to the cockerels in content of edible protein.

The chemical data of this investigation were submitted to an extensive mathematical analysis, mainly for the purpose of obtaining equations from which the rate of deposition of nutrients during growth can be estimated at any age. These rates of deposition are fundamental data in the exact estimation of the food requirements for growth and cannot be obtained satisfactorily by any other method of analysis. In performing this mathematical analysis, the fourth-degree polynomial equation, used for the age-weight relation, was used thruout.

To illustrate, it may be computed that at a body weight of 2 pounds and an age of 12.5 weeks, the cockerels were gaining in body weight at a rate of 11.8 grams daily and were depositing in their bodies daily 3.91 grams of dry matter, 2.63 grams of protein, .90 gram of fat, .437 gram of ash, .165 gram of calcium, and 21.5 calories gross energy. At the same body weight but at an age of 14.8 weeks, the pullets were gaining daily 9.6 grams in total weight, 3.78 grams of dry matter, 2.06 grams of protein, 1.15 grams of fat, .328 gram of ash, .108 gram of calcium, and 24.8 calories of gross energy.

On the basis of these data and of data and approximations afforded by other investigations, the total nutrient requirements of growing White Leghorn chickens have been computed for different body weights. Using the data previously published in Bulletin 278 on White Plymouth Rock chickens,[10]* similar calculations have been made for this breed. The results are summarized in Tables 42 and 43.

LITERATURE CITED

1. ACKERSON, C. W., BLISH, M. J., and MUSSEHL, F. E. The endogenous metabolism of hens and capons. Poultry Sci. 2, 189-198. 1923.
2. BRODY, S. Growth and development with special reference to domestic animals. III. Growth rates, their evaluation and significance. Missouri Agr. Exp. Sta. Res. Bul. 97. 1927.
3. BUCKNER, G. D., WILKINS, R. H., and KASTLE, J. H. The normal growth of White Leghorn chickens. Amer. Jour. Physiol. 47, 393. 1918.
4. CARD, L. E., and KIRKPATRICK, W. F. Rearing chickens. Conn. (Storrs) Agr. Exp. Sta. Bul. 96. 1918.
5. COWGILL, G. R., and DRABKIN, D. L. Determination of a formula for the surface area of the dog together with a consideration of formulae available for other species. Amer. Jour. Physiol. 81, 36. 1927.
6. FORBES, E. B., and associates. The utilization of calcium compounds in animal nutrition. Ohio Agr. Exp. Sta. Bul. 347. 1921.
7. GRAY, J. The kinetics of growth. Brit. Jour. Expt. Biol. 6, 248-274. 1929.
8. HANSON, F. B., and HEYS, F. Differences in the growth curves of albino rats born during the four seasons of the year under uniform laboratory conditions. Anat. Rec. 35, 83. 1927.
9. LATIMER, H. B. Postnatal growth of the body, systems, and organs of the Single-Comb White Leghorn chicken. Jour. Agr. Res. 29, 363-397. 1924.
10. MITCHELL, H. H., CARD, L. E., and HAMILTON, T. S. The growth of White Plymouth Rock chickens. Ill. Agr. Exp. Sta. Bul. 278. 1926.
11. ———— ———— and HAINES, W. T. The effect of age, sex, and castration on the basal heat production of chickens. Jour. Agr. Res. 34, 945-960. 1927.
12. ———— and HAINES, W. T. The basal metabolism of mature chickens and the net energy value of corn. Jour. Agr. Res. 34, 927-943. 1927.
13. ———— and KRUGER, J. H. The effect of muscular work upon the endogenous catabolism of the tissues. Jour. Biol. Chem. 76, 55-74. 1928.
14. ———— and HAMILTON, T. S. The biochemistry of the amino acids. Amer. Chem. Soc. Monograph 48, Chemical Catalogue Co., New York. 493-502. 1929.
15. ROBERTSON, T. B. The chemical basis of growth and senescence. J. B. Lippincott Co., Philadelphia and London. 1923.
16. SHERMAN, H. C. Calcium requirement of maintenance in man. Jour. Biol. Chem. 44, 21-27. 1920.
17. TITUS, H. W., and JULL, M. A. The growth of Rhode Island Reds and the effect of feeding skim milk on the constants of their growth curves. Jour. Agr. Res. 36, 515-540. 1928.
18. ———— The gross maintenance requirement of White Leghorns. Poultry Sci. 8, 80-84. 1929.