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MAINTENANCE REQUIREMENTS OF CHICKENS AND PRODUCTIVE ENERGY OF FEEDS AS RELATED TO AGE

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Differences in weight and sex had no effect upon the maintenance requirements of young chickens per day per 100 grams. Chickens receiving rations high in protein had much lower maintenance requirements than those receiving rations low in protein. With rations averaging 31 per cent protein the average maintenance requirements was 12.4 calories of productive energy compared with 15.8 calories per day per 100 grams with rations averaging 16.2 per cent protein. In one experiment, chickens in the period from 12 to 18 weeks had an average maintenance requirement of 7.12 calories of productive energy per day per 100 grams compared with an average of 13.6 calories for chickens in the period of 7 to 28 days. The average maintenance requirements of the young chickens ranged from 5 to 10.8 grams of rations per day per 100 grams. Chickens 6 to 18 weeks old utilize the metabolizable energy of feed for production of fat and flesh equally as well as younger chickens. Hydrogenated cottonseed oil with an iodine value of 68 had a productive energy value equal to cottonseed oil, but the hydrogenated oil with an iodine value of 10 had a low digestibility and the digested portion had about 70 per cent of the productive energy of cottonseed oil.

The weight basis was more suitable for calculating maintenance requirements of chickens up to 18 weeks old, just as it was found to be for young chickens in previous work. Differences found in the productive energy values of the same feed in two experiments are sometimes due to differences in the maintenance requirements between the groups being compared.

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MAINTENANCE REQUIREMENTS OF CHICKENS AND THE EFFECT OF AGE OF CHICKENS ON THE PRODUCTIVE ENERGY OF FEEDS

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This publication is a part of a comprehensive investigation of the energy values of feeds and foods as measured by the storage of fat and flesh by growing chickens. Various aspects of the problem have been presented in previous publications. The energy values of 62 kinds of feed were measured in 192 tests on young growing chickens (7). Wide differences were found in the energy values of different kinds of feeds and foods, but these differences were found to be due chiefly to differences in digestibility. The ability of the chickens to utilize the digested material from different feeds, on the average, is usually uniform. The energy values per unit of the nutrients of many different feeds are usually within 10% of that of corn meal. Similar results were found in experiments with rats (8).

The report discusses the variations in maintenance requirements of chickens. It also presents measurements of productive energy made with chickens appreciably older than those used in previous work (4, 6, 7). A few experiments with younger chickens not previously reported are included.

Definitions of Terms

The percentage of effective organic constituents of a feed is the sum of the percentage of the protein, the nitrogen-free extract and the fat or ether extract multiplied by 2.25. Crude fiber is disregarded since it is digested only to a very small extent by chickens, while ash and water have no energy values.

The percentage of effective digestible nutrients of a feed is the sum of the percentages of digestible protein, the digestible nitrogen-free extract and the digestible ether extract multiplied by 2.25. In other words, the effective digestible nutrients is that portion of the effective organic constituents which can be digested by the animal.

Metabolizable energy is the energy of the food less the energy in the excrement, both fecal and urinary and, in case of ruminants, in gases produced by fermentation. It includes all the energy of the food which can be used by the animal. The metabolizable energy of chicken feeds can be calculated by methods previously developed (5). For the purpose of this work, metabolizable energy values for maintenance were obtained in calories per 100 grams by multiplying grams of effective digestible nutrients by 4.2. When part of the protein is retained, as in growing chickens, the metabolizable energy is higher than for maintenance experiments because the total energy content of protein is higher than its metabolizable energy.

Productive energy is the energy stored up as fat and protein by the chicken from that portion of the ration eaten which exceeds the quantity used for all maintenance purposes. The productive energy is expressed as calories per gram or per 100 grams of live weight.

Cost of utilization of a feed is the difference between the metabolizable energy and the productive energy of the feed. It consists of the energy consumed in digesting and utilizing the digested nutrients and in storing the protein and fat in the animal. If the productive energy is 72% of the metabolizable energy, the remaining 28% is considered to be the cost of utilization.

Maintenance requirement is that portion of the energy of the feed used in the life processes of the animal, including keeping the body warm, and movements of the body. The bodily activities consume energy, which in this work is included in the energy of maintenance.

The productive energy used for maintenance is the difference between the productive energy of the quantity of food eaten and the calories of energy stored up in fat and flesh. For the work here presented it is calculated from the data secured with the corn meal ration.

The maintenance requirements in terms of productive energy were calculated according to the equation No. 1:

$$M = \frac{FP - G}{WD}$$

In this equation, M is the maintenance requirement in calories per day per gram, F is the grams of the ration eaten, P is the productive energy of the ration in calories per gram, G is the gain of calories in fat and flesh, W is the average weight of the chicken in grams during the period of the experiment, and D is the period of the experiment in days. M is usually converted to calories per 100 grams, to avoid the sue of small fractions. The maintenance requirement in our experiments is usually calculated from the standard corn meal ration, in which the effective digestible nutrients are considered to have the productive energy of 2.78 calories per gram (4).

The productive energy is calculated by the equation No. 2:

$$P = \frac{MWD + G}{F}$$

P is the calories of productive energy per gram of the ration, and M is the maintenance requirement per day per gram secured from the corn meal ration fed at the same time and under the same conditions as the rations whose productive energy is being calculated. The other symbols correspond to those given for equation No. 1.

Methods

The method of experiment has been fully described (4, 6, 7). The baby chickens were fed a corn meal ration for approximately one week and then divided into groups of equal weight, usually of 6 chickens each. The digestibilities of the rations fed were measured by means of the chickens left over. The chickens in one group were killed, prepared for analysis (10) and analyzed for protein and fat, and the others were fed the experimental rations individually, in battery brooders. At the end of the experimental period, the chickens were killed and analyzed for protein and fat. The gains in energy were calculated from the composition of the chickens at the beginning and at the end of the experiment. The consumption of feed was ascertained for each chicken. In the first series of experiments (4) the corn meal ration was limited for one group to about half the amount eaten by another group fed unlimited amounts. By substitution of the data from the two groups in two equations No. 1 and algebraic solution, the values for the unknowns M, maintenance, and P, productive energy, were ascertained. In subsequent experiments (6, 7) the corn meal was partly replaced by other feeds in order to compare their productive energy values, while the maintenance requirements were calculated from the data of the corn meal ration fed to another group at the same time.

Maintenance Requirements of Chickens Less Than 4 Weeks Old

Little work has been reported on the exact measurement of the maintenance requirements of chickens, other than reported by us incidental to the determination of the productive energy of rations and feeds. It may be calculated from the work of Titus (18) that laying White Leghorn pullets require 42 grams of feed per day per kilogram of body weight. According to the work of Brody, Fork and Kemster (2) laying hens require 46.5 grams of feed per day per kilogram. The basal heat production of chickens, according to Mitchell and Haines (16) depends on their ages and may range from 146 calories per kilogram per day for chickens 5 days old, to 62 calories per kilogram per day for cockerels weighing 2728 grams. Barrot, et al. (1) have also reported data on the basal metabolism of chickens. Fraps and Carlyle (4) report as the average of a number of experiments that the maintenance requirements are 13.4 calories of productive energy per day per 100 grams during periods of 21 to 42 days for chickens weighing approximately 100 to 500 grams at the end of the period. This was equivalent to 74.8 grams of the feed mixture used, per day per kilogram. Fraps and Carlyle (6) also reported productive energy for maintenance ranging from 10.50 to 16.30 and averaging 12.49 calories per day per 100 grams in 20 tests, and (7) from 9.40 to 20.58 with an average of 14.12 calories per day per 100 grams in 51 experiments and an average of 13.60 for 70 experiments. If the ration has the quantity of a productive energy of 1.9 calories per gram, the quantity required for maintenance of chickens up to the age of about 4 weeks ranged from 50 to 108 grams, with an average of 72 grams of feed per day per kilogram live weight. On account of the wide range of maintenance requirements, from 9.42 to 20.48 calories per day per 100 grams, the data was studied further with respect to the factors which might influence the maintenance requirements.

The corn meal ration fed to ascertain the maintenance requirements was not the same in all the experiments, but followed the same general pattern. The corn meal ration used in 13 experiments marked A in Table 2 contained, in percentages, corn meal 59.8, wheat gray shorts 16.3, dried skim milk 10.0, yeast 6.0, alfalfa leaf meal 4.0, oyster shell 1.5, tricalcium phosphate 1.0, salt 1.0, cod liver oil 0.2 and manganese sulphate 0.2 %, and contained 16 per cent protein. Another corn meal ration marked B in Table 3 contained 10 per cent casein in place of 10 per cent of the corn meal in the above ration but was otherwise the same. In a third series, Table 5, 20 per cent of casein replaced 20 per cent corn meal in rations otherwise the same as the ration above.

The maintenance requirements were calculated to the average weight of the chickens for the period of the experiment, usually 3 weeks. The calories of productive energy consumed in the ration fed less the calories of energy stored in the chicken give the calories of productive energy used for maintenance, and with use of the length of the feeding period and the average weight of the ckickens, the data was converted to calories of productive energy used per day per 100 grams of live weight.

Effect of Individuality, Weight and Sex Upon Maintenance Requirements

There are decided differences in the maintenance requirements of different chickens in the same group, fed on the same ration at the same time and under the same conditions. In experiments with 6 groups of young chickens (4) the average maintenance requirements of productive energy per 100 grams per day was 13.7 calories, the average of the maximum for each group was 14.3 calories, the average for the minimum was 11.97 and the average of the standard deviations of the various groups was 1.0. If all the maxima and minima are considered separately the variations are still wider.

Ritzmen and Benedict (17) have reported variations of from 20 to 80 per cent in the basal metabolism of the same cow or steer. Winchester (19) reports variations in heat productions in laying hens as large as 40 per cent of the maximum heat production. Forbes, et al. (12) point to wide differences in the basal metabolism of individual rats in the same group of experimental animals. Fraps and Carlyle (4) give an average standard deviation of 1.0 calories for 6 experiments with young chickens in which the average maintenance requirement was 13.5 calories per day per 100 grams.

Individual variations in maintenance requirements will usually be equalized when groups of sufficient size are fed at the same time, but this equalization may not always occur. In such cases, differences in maintenance requirements between the groups will cause differences in productive energy which may not actually be correct.

In order to ascertain the effect of differences in weight on maintenance requirements the chickens in each test were divided into three groups: (1) those appreciably heavier than the average, (2) those approximately average in weight, and (3) those appreciably lighter in weight than the average. The maintenance requirements were then averaged for each group, and then averages were made for all the tests. The results are given in Table 1. The average difference in maintenance requirements per 100 grams between the chickens heavier than the average and those lighter than the average is 0.8 calories, for the 17 tests; this difference is small and not statistically significant. In the limits of the weights compared, the weight had no effect on the maintenance requirements per day per 100 grams.

Each group was divided according to sex, and the maintenance requirements averaged for each group. All the groups were then averaged, with the results shown in Table 1. The experiments were divided into groups, one in which

Table 1. Average effect of weight and sex on maintenance requirements

	Maintenance requirements cal./day/100 gm.
Effect of weight	
Number of tests, 16	
High weight, average 133 gm.	14.3
Low weight, average 104 gm.	15.1
Effect of sex	
Maintenance requirements 15 calories or more per day per 100 gm.	
Number of tests, 11	
Male	16.1
Female	15.9
Maintenance requirements 12 calories or less per day per 100 gm.	
Number of tests, 9	
Male	11.2
Female	10.9

the maintenance requirement was 15 calories or more, the other 12 calories or less, per day per 100 grams. As an average of 11 experiments, no differences in maintenance requirements were shown as due to sex. This applies only to the young chickens studied, which were less than 30 days old. According to results published by other workers, sex may cause some differences with older chickens.

According to Ritzman and Benedict (17) some factors connected with the season affected the maintenance requirements of cows. The data for chickens were examined but no relation could be found between the maintenance requirements and the season of the year.

Relation of Maintenance Requirements to Protein Content of Ration

In order to ascertain the relation of the maintenance requirements of the chickens to the protein contents of the ration, the data were tabulated in 4 groups—(1) protein content less than 18%, (2) protein content 18.1 to 21%, (3) protein content 21.1 to 24%, and (4) protein content over 30%. The constituents of the rations have been given (6, 7). Three sets of rations differed only in the percentages of corn meal and casein. In Ration B, 10% of the corn meal in Ration A was replaced by 10% casein, and in Ration C, 20% corn meal was replaced by 20% casein. The period of experiment was 3 weeks.

The data are given in Tables 2, 3, 4, and 5, and summarized in Table 6. On an average, the maintenance requirements are related to the protein content of the ration, being high when the ration was low in protein and low when the ration was high in protein.

The chickens which received rations containing over 30 per cent of protein had an average maintenance requirement of 12.4 calories per day per 100 grams with a standard deviation of 0.8 compared with 15.9 calories with a standard deviation of 1.9 for chickens which received a ration containing less than 18% of protein. The maintenance requirements of the group receiving rations

Table 2. Relation of maintenance requirements to protein in rations containing 18% or less protein

No.	Date begun	Prod. energy used for maintenance per day, per 100 grams, Cal.	Prod. energy of ration, Cal./gm.	Live weight at end, gm.	Fat in chickens, %	Energy in chickens, calories per 100 gm.	Protein in rations %
1-31	December 9, 1930	20.48	1.980	80.9	8.76	193.2	17.10
1-32	January 13, 1931	14.91	1.984	148.1	11.11	218.5	17.06
1-33	January 13, 1931	15.14	1.984	147.8	8.10	191.4	17.06
1-34	February 11, 1931	15.14	1.984	139.0	14.19	242.7	17.06
5	June 1, 1937	14.34	1.948	156.8	9.92	195.6	17.38
37	September 23, 1940—A	16.79	1.925	141.8	8.98	194.4	16.76
38	October 8, 1940—A	16.37	1.964	139.7	10.18	205.1	16.58
42	December 17, 1940—A	15.59	1.917	209.5	10.49	204.9	16.37
48	April 7, 1941—A	16.09	1.909	215.0	9.59	205.3	16.50
53	October 7, 1941—A	15.40	1.937	132.6	8.36	195.5	16.39
54	September 21, 1941—A	15.28	1.937	210.7	11.83	224.7	16.40
56	November 13, 1941—A	17.05	1.869	157.2	9.92	208.7	16.20
57	November 11, 1941—A	16.85	1.894	161.5	10.33	209.5	16.45
59	January 20, 1942—A	17.09	1.979	154.5	8.80	188.0	16.20
60	February 3, 1942—A	16.65	1.952	154.1	10.08	205.8	15.64
62	March 3, 1942—A	16.09	1.923	147.5	8.22	184.9	15.79
65	May 4, 1942—A	14.01	1.866	169.4	9.54	204.0	15.75
66	May 19, 1942—A	12.42	1.890	176.9	12.28	226.2	15.50
	Average (18)	15.87	1.936	157.9	10.04	205.5	16.12
	Average A (13)	15.82	1.920	167.0	9.89	204.4	16.19

Table 3. Relation of protein to maintenance requirements—Protein in ration containing 18 to 21% protein

No.	Date begun	Prod. energy used for maintenance per day, per 100 grams, Cal.	Prod. energy of ration, Cal./gm.	Live weight at end, gm.	Fat in chickens, %	Energy in chickens, calories per 100 gm.	Protein in rations %
1-38	March 30, 1931	9.72	1.973	284.3	12.23	228.4	19.73
1-39	April 3, 1931	11.59	1.973	368.3	12.49	236.2	19.73
1-41	April 22, 1931	9.42	1.973	276.7	14.65	253.6	19.73
1-42	April 29, 1931	10.97	1.973	407.7	13.12	240.2	19.73
1-62	March 6, 1934	16.48	1.799	138.4	8.69	195.3	18.80
1-63	January 21, 1935	13.32	1.747	205.4	9.12	202.0	18.85
1-64	March 11, 1935	17.72	1.846	205.3	7.24	180.4	18.78
1-66	(28 days) June 22, 1936	14.43	1.672	211.7	7.75	189.6	18.13
1	January 4, 1937	16.37	1.909	118.6	6.52	183.5	19.15
2	February 17, 1937	15.35	1.909	147.9	7.80	182.1	19.33
3	March 17, 1937	15.00	1.919	240.2	7.15	183.8	19.50
4	April 28, 1937	12.75	1.877	236.9	8.96	193.8	18.78
19	April 17, 1939	12.34	1.828	187.3	8.30	193.7	20.10
21	October 3, 1939	13.13	1.923	209.7	8.71	199.1	20.85
22	October 17, 1939	12.78	1.933	199.1	9.29	203.1	20.30
25	December 12, 1939	15.35	1.767	192.3	5.44	169.3	19.89
33	April 16, 1940	13.58	1.800	201.7	7.51	188.7	19.36
	Average (17)	13.55	1.872	219.5	9.12	201.3	19.46

Table 4. Relation of maintenance requirements to protein in rations containing 21.1—24% protein

No.	Date begun	Prod. energy used for maintenance per day, per 100 grams, Cal.	Prod. energy of ration, Cal./gm.	Live weight at end, gm.	Fat in chickens, %	Energy in chickens, calories per 100 gm.	Protein in rations %
1-65	April 22, 1935	14.05	1.991	274.3	6.50	181.8	22.13
6	October 19, 1937	11.10	1.961	191.7	8.81	196.1	21.80
7	November 23, 1937	10.21	1.892	167.7	8.37	192.4	21.55
8	January 25, 1938	10.20	1.980	209.7	8.04	190.3	22.71
9	February 22, 1938	12.60	1.979	216.5	6.66	183.7	22.81
10	March 22, 1938	11.79	1.925	188.9	7.18	182.2	22.81
11	May 3, 1938	10.50	1.876	212.6	7.38	187.7	22.75
12	May 31, 1938	10.79	1.899	190.5	7.55	189.6	22.08
13	October 11, 1938	10.78	1.909	185.2	8.14	189.2	21.40
15	December 20, 1938	10.90	1.972	178.7	8.96	195.6	21.92
16	January 17, 1939	11.46	1.952	188.4	8.65	192.8	21.94
17	February 14, 1939	11.64	1.970	176.7	8.41	195.1	22.09
18	March 13, 1939	10.93	1.962	164.6	8.95	196.2	22.25
30	November 5, 1940—B	12.19	1.838	218.0	5.50	174.8	23.55
41	November 19, 1940—B	15.57	1.914	195.5	5.82	173.4	23.69
43	January 21, 1941—B	13.99	1.924	219.9	6.22	173.8	22.95
44	February 4, 1941—B	13.84	1.904	226.6	5.95	178.4	23.71
46	March 4, 1941—B	13.04	1.865	212.4	6.21	177.8	23.40
47	March 24, 1941—B	15.86	1.950	207.3	4.75	168.6	23.54
52	September 23, 1941—B	13.49	1.900	202.8	6.56	179.9	22.87
55	October 10, 1941—B	12.99	1.863	217.0	6.99	185.2	23.38
61	February 16, 1942—B	15.47	1.888	184.4	4.36	158.3	23.09
63	March 30, 1942—B	15.52	1.875	229.4	5.09	166.1	23.08
	Average (23)	12.56	1.921	202.6	7.00	183.0	22.68
	Average B (10)	14.20	1.892	211.3	5.75	173.6	23.33

Table 5. Relation of maintenance requirements to protein in ration containing over 30% protein

No.	Date begun	Prod. energy used for maintenance per day, per 100 grams, Cal.	Prod. energy of ration, Cal./gm.	Live weight at end, gm.	Fat in chickens, %	Energy in chickens, calories per 100 gm.	Protein in rations %
23	October 31, 1939—C	12.93	1.878	215.6	4.99	171.5	30.71
24	November 28, 1939—C	12.45	1.798	188.5	4.46	164.3	30.26
26	January 1, 1940—C	12.76	1.871	210.6	5.35	166.1	31.61
27	January 23, 1940—C	13.73	1.911	181.6	4.25	160.7	31.38
28	February 6, 1940—C	11.89	1.926	213.9	4.68	166.3	31.26
29	February 20, 1940—C	13.01	1.889	196.2	4.39	159.2	30.77
30	March 5, 1940—C	13.06	1.896	171.8	3.67	155.4	30.81
31	March 19, 1940—C	11.75	1.884	207.7	4.83	170.6	30.74
32	April 2, 1940—C	11.73	1.892	236.5	4.91	167.8	31.80
34	April 30, 1940—C	12.62	1.825	203.8	4.07	165.7	30.15
35	May 14, 1940—C	10.87	1.816	224.2	4.81	167.0	31.24
36	May 28, 1940—C	11.46	1.885	194.0	4.87	166.5	30.80
	Average C (12)	12.36	1.873	203.7	4.61	165.1	30.96

Table 6. Relation of protein content of ration to maintenance requirements, live weight, and fat content of chickens

	Protein less than 8%	Protein 18.1 to 21%	Protein 21.1 to 24%	Protein over 30%
Number of comparisons averaged	18	17	23	12
Maintenance requirements, calories of productive energy per day per 100 gm.				
Average	15.8	13.6	12.6	12.4
Maximum	20.5	17.7	15.9	13.4
Minimum	12.4	9.4	10.2	10.9
Standard deviation	1.7	2.5	2.0	0.8
Live weight at end, gm	157.9	219.5	202.6	203.7
Fat in chickens, per cent	10.0	9.1	7.0	4.6
Protein in ration, average per cent	16.2	19.5	22.7	31.0
Groups on rations in which casein replaced corn meal but otherwise the same.				
Protein in ration, per cent	16.2	....	23.3	31.0
Number averaged	15	....	10	12
Average maintenance requirement	15.8	....	14.2	12.4

containing 30% protein were uniformly low, while those receiving a ration containing less than 18% protein were uniformly high with the exception of experiment 66, in which it was lower than the others.

The maintenance requirements of the two intermediate groups, where the rations contained 18 to 21 and 21 to 24% protein, averaged 13.6, and 12.6 calories per day per 100 grams, and were thus between the high and the low protein rations. The maintenance requirements were, however, more variable in these intermediate groups than in the groups which received the rations containing 30% protein, the standard deviations being 2.45 and 1.97 respectively. The maintenance requirements in the group receiving 18-21% protein ranged from 9.42 to 17.72 calories per day and 100 grams, and for those receiving 21-24% protein it ranged from 10.20 to 15.86 calories. The range of maintenance requirements in the two intermediate groups overlaps the maintenance requirements of the group receiving the high protein rations, and those of the group receiving the low protein ration. Although there is apparently some relation between the protein content of the rations and the maintenance requirements of chickens, it is clear that other factors affected the maintenance requirements of the chickens receiving rations with nearly the same protein content.

Similar results are secured with the chickens receiving the rations which differed only in quantities of corn meal and casein marked A, B and C in Tables 2, 3, 4, 5. The averages for the entire group and the thirteen tests which received the same ration were nearly the same with the chickens in the group fed 18% protein. The two sets of averages are different in the groups in which 21 to 24% protein was fed, the average maintenance requirements in the entire group being 12.56 calories, and in the sub-group, 14.20 calories. There is nothing in the data to indicate the reason for the differences in these two sub-groups.

The data indicate clearly that the protein content of the ration may affect the maintenance requirements of young chickens. The chickens receiving the ration containing 30 per cent of protein had uniformly low maintenance requirements averaging 12.4 calories of productive energy per day per 100 grams, equivalent to 6.5 grams of a ration furnishing 1.9 calories of productive energy per gram. The chickens receiving rations containing less than 17 per cent of protein had high average requirements of 15.8 calories of productive energy per day per 100 grams, equal to 8.4 grams of ration.

This effect of protein is contrary to the idea that protein has a specific dynamic power which increases the heat eliminated by animals. Low maintenance requirements are accompanied by decreased elimination of heat. The observed increase in elimination of heat which comes within a short time after the ingestion of protein evidently does not represent the action of the protein over the entire day.

While the maintenance requirements were uniformly low with chickens receiving rations containing more than 30 per cent of protein, and usually high with those receiving less than 17 per cent of protein, the maintenance requirements varied widely with the chickens receiving 18 to 21 and 21 to 24 per cent of protein. They also varied with individual chickens fed on the same ration at the same time. That is, there are wide variations in maintenance requirements not due to percentages of protein but due to causes which are not yet accounted for.

Comparison of the averages in Table 6 shows that the chickens receiving the ration containing averages of 30 per cent protein had an average live weight at the end of 203.7 grams, compared with 157.9 grams for those receiving the rations containing less than 18% protein, and an average fat content of 4.6 compared with 10.0%. A ration of high protein content produces chickens of larger size and containing much less fat than the rations containing 16% protein (9).

The experiments cited above were made at different times of the year and so do not involve direct comparisons of the effect of protein on maintenance requirements. Forbes and associates (14) have conducted a series of 6 experiments with rats in which the effect of different percentages of protein was tested. From the data summarized by them, (14) the maintenance requirements of rats were approximately calculated as shown in Table 7. The period of experiment was 70 days. For the purpose of this calculation, the productive energy of the ration was estimated to be 0.7 of the metabolizable energy and the average weight was assumed to be the same as the initial and final weights divided by 2. Neither of these assumptions is exactly correct but the error is not sufficient to invalidate the calculations.

The results summarized in Table 8 show that the maintenance requirements for the young growing rats decreased as the protein content of the ration increases, up to 25%. The decrease is greatest between 10% and 15% protein in the ration and is small above 15%. The results are remarkably uniform in the 5 experiments. With mature rats the protein content of the ration had little if any effect upon the maintenance requirements, in the single experiment made with such animals.

Table 7. Effect of percentage of protein on maintenance requirements of rats

Experiment No. and reference to publication	Live weight of rats gm.	Protein in diets %	Body gain of energy cal.	Metabolized energy cal.	Average weight gm.	Productive energy cal.	Prod. energy for maintenance cal.	Maintenance per 100 gm. per day cal.
Exp. 1	40–126	10	224	1933	87.0	1353.1	1129.1	18.5
J. Nutri. 10	48–155	15	263	1931	101.5	1351.7	1088.7	15.3
(1935), 461	48–168	20	296	1939	103.0	1357.3	1061.3	14.7
	47–167	25	302	1928	107.0	1349.6	1047.6	14.0
Exp. 2	48–115	10	226	1858	81.5	1300.6	1074.6	18.8
J. Nutr. 10	47–142	15	259	1860	94.5	1302.0	1043.0	15.8
(1935), 461	48–150	20	267	1957	99.0	1299.9	1032.9	14.9
	48–152	25	270	1848	100.0	1293.6	1023.6	14.6
Exp. 3	47–162	25	332	2001	104.5	1400.7	1068.7	14.6
J. Nutr. 15	47–159	30	320	1984	103.0	1388.8	1068.8	14.8
(1938), 285	48–159	35	311	1970	103.5	1379.0	1068.0	14.7
	47–151	45	285	1934	99.0	1353.8	1068.8	15.4
Exp. 4	49–173	10	364	2739	111.0	1917.3	1553.3	20.0
J. Nutr. 18	50–218	25	480	2698	134.0	1888.6	1408.6	15.0
(1939), 47	50–220	35	423	2648	135.0	1853.6	1430.6	15.1
	50–207	45	415	2577	128.5	1803.9	1388.9	15.4
Exp. 5	385–391	10	113	3619	388.0	2533.3	2420.3	8.9
J. Nutr. 20	388–401	25	124	3579	394.5	2505.3	2381.3	8.6
(1940), 47	390–388	45	5	3407	389.0	2384.9	2379.9	8.7
Exp. 6	34–146	10	323	2179	90.0	1525.3	1202.3	19.1
J. Nutr. 28	33–202	25	387	2157	117.5	1509.9	1122.9	13.7
(1944), 194	33–180	45	334	2028	106.5	1419.6	1085.6	14.6

Table 8. Effect of protein in ration on maintenance requirements of rats as calculated from the work of Forbes, et al. Maintenance requirements in calories per 100 grams per day

Protein in rations	Exp. 1 Cal.	Exp. 2 Cal.	Exp. 3 Cal.	Exp. 4 Cal.	Exp. 5* Cal.	Exp. 6 Cal.
10%	18.5	18.8	....	20.0	8.9	19.1
15%	15.3	15.8	....	....	....	....
20%	14.7	14.9	....	....	....	....
25%	14.0	14.6	14.6	15.0	8.6	13.7
30%	....	....	14.8	15.1	....	....
35%	....	....	14.7	15.4	....	....
45%	....	....	15.4	....	8.7	14.6

*Experiment 5 was made with mature rats weighing about 390 grams.

Maintenance Requirements of Chickens to Age of 8 to 18 Weeks

The work discussed in the preceeding pages was based on experiments to ascertain the productive energy of foods with chickens up to the age of about 4 weeks. In the work now to be discussed the experiments were continued to ages of 9, 13, and 19 weeks. The methods used have already been described. The chickens were about 1 week old when placed on experiment, and the experimental period lasted 6, 12, or 18 weeks.

The corn meal ration used in Experiments 45, 49, 51 and 58 consisted, in percentages, of corn meal 60, wheat gray shorts 16.3, dried skim milk 10, yeast 6.0, alfalfa leaf meal 4.0, calcium carbonate 1.5, tricalcium phosphate 1.0, salt 1.0, and fortified cod liver oil 0.2. The protein content of this ration was about 16.8%. The corn meal rations used in Experiments 125, 131, 139, 145 were the same except that they contained 2% less corn meal and 2 per cent more alfalfa leaf meal. The corn meal rations used in Exp. 20 were similar to those used in Exp. 45, except that 10% cottonseed meal and 15% cottonseed oil replaced 25% corn meal (protein in the ration, 18.5%); in Experiment 64, 30% casein replaced 30% corn meal (protein 37.7%). The corn meal ration in Experiment 14 contained, in percentages, corn meal 56.8, wheat gray shorts 20.0, casein 12.0, yeast 2.0, alfalfa leaf meal 6.0, calcium carbonate 1.0, tricalcium phosphate 1.0, salt 1.0, fortified cod liver oil 0.2 (protein in ration 21.9%). In experiments numbered above 47, 0.2 gm. manganese sulphate replaced 0.2 gm. wheat gray shorts. The quantities of the experimental feeds which replaced the corn meal are shown in the tables. The percentage composition of the feeds are given in Table 9. The effective organic constituents of the rations are given in Tables 14 and 15. Table 9 also contains the chemical composition of the corn meal rations used in the experiments made for 12 to 18 weeks. Digestion experiments were made on the rations and the effective digestible constituents were calculated from the digestion coefficients and the analyses of the ration.

The average live weights, percentages of protein and fat and calories per 100 grams of chicken, as well as other data, are given in Table 10. The data from each individual chicken were calculated separately in all the work, but only the averages are presented.

Table 9. Percentage composition of feeds and cornmeal rations, and of feathers

Name of feed sample	Protein %	Ether extract %	Crude fiber %	Nitrogen free extract %	Water %	Ash %
Albumen, blood	70.60	.73	.17	5.64	10.11	12.75
Albumen, egg	79.97	.19	.24	5.44	9.11	5.05
Casein, Exp. 45	82.83	.32	.15	3.79	8.93	3.98
Casein, Exp. 49	82.69	.75	.17	3.54	8.81	4.04
Casein, Exp. 51	81.43	.25	.24	5.99	8.62	3.47
Corn meal, Exp. 14	10.45	3.40	1.02	73.45	10.46	1.22
Corn meal, Exp. 20	10.81	3.28	.96	73.99	9.69	1.27
Corn meal, Exp. 45	10.00	3.58	1.10	73.25	11.04	1.03
Corn meal, Exp. 50	9.93	4.27	1.35	70.40	12.10	1.45
Corn meal, Exp. 51	10.19	4.20	1.49	71.09	11.62	1.41
Corn meal, Exp. 58	8.55	3.69	1.51	73.67	11.39	1.19
Corn meal, Exp. 64	9.38	3.96	1.51	73.19	10.66	1.30
Corn meal, Exp. 125–131	9.93	4.85	2.12	69.66	11.86	1.58
Cottonseed meal, Exp. 58	42.98	5.79	10.13	26.95	7.85	6.30
Gelatine*	93.98	.05	.15	.00	14.32	1.89
Oat hulls, Exp. 50 and 58	3.45	1.27	30.04	50.40	7.37	7.47
Wheat bran, Exp. 58	19.28	2.84	10.57	49.64	10.56	7.11
Wheat bran, Exp. 125–131	19.15	3.66	8.40	52.89	10.66	5.24
Corn meal ration, Exp. 14	21.91	3.22	2.05	57.17	9.58	5.47
Corn meal, cottonseed oil ration, Exp. 20	18.51	17.18	3.56	47.29	6.83	6.63
Corn meal ration, Exp. 45	16.83	3.10	1.91	62.82	9.71	5.63
Corn meal ration, Exp. 49	16.28	3.82	2.48	60.46	10.84	6.12
Corn meal ration, Exp. 51	16.16	3.46	2.65	60.78	10.40	6.55
Corn meal ration, Exp. 50	23.65	3.24	2.34	53.55	10.70	6.52
Corn meal ration, Exp. 58	15.76	3.35	2.55	62.58	9.74	6.02
Corn meal ration, Exp. 64	37.73	2.08	2.50	41.62	8.81	7.26
Corn meal ration, Exp. 125–131	16.09	3.91	2.95	60.62	10.17	6.26
Corn meal ration, Exp. 139–145	17.08	3.89	3.32	58.81	10.35	6.55
Feathers, Exp. 51	71.60	4.26	1.98	8.39	7.12	6.15
Feathers, Exp. 58	78.58	2.53	1.90	3.58	9.34	4.07

*The factor 6.25 is too high for the nitrogen of gelatine.

Table 10. Average composition, weights and calories per 100 grams of chickens

Number of experiment and name of ration	Number averaged	Live weight at beginning gm.	Live weight at end gm.	Empty weight at end gm.	Per cent empty weight of live weight	Weight after preparation gm.	Protein %	Fat %	Calories per 100 gm. empty weight
Experiment 125									
Preliminary chicks									
Calories per 100 gm									
Corn meal ration	7	73.7	490.2	469.6	95.7	451.1	22.86	7.48	199.4
Wheat bran ration	8	74.4	344.0	323.6	94.1	308.1	23.86	2.38	150.2
Experiment 139 and 145									
Preliminary chicks	6		73.5	64.5	87.9	61.1	18.20	8.73	184.5
Calories per 100 gm			162.2						
Experiment 145									
Corn meal ration	6	71.3	331.5	313.7	94.6	304.4	23.57	5.21	182.1
Wheat bran ration	6	74.3	201.8	188.8	93.3	174.1	25.33	1.42	145.3
Experiment 131									
Preliminary chicks									
Calories per 100 gm									
Corn meal ration	7	54.4	794.5	766.8	96.5	746.0	23.19	7.83	204.5
Wheat bran ration	7	54.4	505.6	469.3	92.8	458.9	24.11	1.64	151.8
Experiment 45									
Preliminary chicks	5		54.5	52.3	96.1	50.4	18.36	6.86	164.3
Calories per 100 gm			158.0						
Corn meal ration	6	54.5	925.4	908.6	98.2	875.6	22.37	12.25	241.2
Wesson oil ration	6	54.9	643.0	625.6	97.1	591.5	20.94	16.74	275.0
Casein ration	6	55.3	991.4	977.8	98.6	942.0	25.07	5.10	189.6
Casein and Wesson oil ration	6	55.3	1088.1	1071.3	98.4	1019.3	23.13	6.97	196.1
Experiment 51									
Preliminary chicks	6		46.2	43.8	94.8	39.7	17.38	7.15	165.2
Calories per 100 gm			156.6						
Corn meal ration	6	45.6	862.7	838.5	97.2	809.7	22.56	12.96	248.8
Cottonseed oil ration	6	46.5	483.7	456.9	94.0	441.4	20.37	15.15	257.0
Casein ration	6	46.5	991.1	959.0	96.7	915.1	25.01	5.75	195.3
Casein and cottonseed oil ration	5	46.4	1025.4	981.2	95.6	937.9	23.38	9.40	220.2
Experiment 58									
Preliminary chicks	6		45.7	43.4	94.9	41.1	17.44	7.64	170.1
Calories per 100 gm			161.4						
Corn meal ration	6	46.7	1001.3	977.3	97.6	947.9	21.71	11.98	235.0
Oat hulls ration	6	46.4	1004.2	976.2	97.2	939.8	24.52	6.42	198.8
Cottonseed meal ration	5	47.2	1003.1	966.3	96.2	924.7	24.18	4.61	179.9
Wheat bran ration	4	47.7	754.5	730.3	96.8	698.0	25.01	4.61	184.6

Table 10. Average composition, weights and calories per 100 grams of chickens—Continued

Number of experiment and name of ration	Number averaged	Live weight at beginning gm.	Live weight at end gm.	Empty weight at end gm.	Per cent empty weight of live weight	Weight after preparation gm.	Protein %	Fat %	Calories per 100 gm. empty weight
Experiment 139									
Corn meal ration	8	67.6	1233.3	1197.8	97.1	1161.8	25.16	12.60	248.5
Wheat bran ration	6	67.5	678.1	648.3	95.6	626.1	26.18	2.03	167.2
Experiment 14									
Preliminary	4	....	55.7	53.5	96.1	53.0	17.93	5.78	155.6
Calories per 100 gm.	....	....	149.4	....	....	....	....	....	....
Corn meal ration	6	56.0	178.1	173.8	97.5	170.6	20.37	8.10	191.0
Wesson oil ration	5	56.7	135.7	130.8	96.4	128.9	19.11	14.16	240.6
Hydrogenated oil ration	6	56.3	171.0	166.3	97.4	163.8	20.15	8.49	193.4
Hydrogenated oil ration	6	56.7	157.1	152.2	96.8	149.9	18.53	13.25	228.7
Experiment 20									
Preliminary chicks	4	....	51.5	47.8	92.8	49.5	16.78	7.25	162.8
Calories per 100 gm.	....	....	151.0	....	....	....	....	....	....
Cottonseed oil ration	6	52.0	154.1	150.5	97.7	148.0	18.42	13.46	230.1
Corn oil ration	5	51.4	136.3	132.4	97.0	131.1	18.71	12.18	219.8
Peanut oil ration	6	52.3	139.3	135.0	96.9	133.4	18.79	12.22	220.6
Soybean oil ration	6	51.6	139.1	134.7	96.9	133.5	18.60	12.38	221.0
Experiment 49									
Preliminary chicks	6	....	51.9	48.1	92.8	44.6	17.82	9.20	149.5
Calories per 100 gm.	....	....	138.7	....	....	....	....	....	....
Corn meal ration	6	51.8	194.3	187.7	96.6	180.3	19.95	10.83	214.2
Cottonseed oil ration	5	52.0	144.1	138.3	96.0	132.0	18.56	16.28	257.3
Casein ration	6	51.7	197.8	192.3	97.2	185.1	21.30	4.42	165.6
Casein and cottonseed oil ration	6	52.0	158.5	152.6	96.0	143.9	20.26	7.51	184.9
Experiment 50									
Preliminary chicks	6	....	50.6	46.9	92.6	44.0	18.41	5.41	154.8
Calories per 100 gm.	....	....	143.4	....	....	....	....	....	....
Corn meal ration	6	51.3	218.3	211.6	96.9	202.2	21.37	5.99	176.9
Wesson oil ration	6	51.6	146.3	140.0	95.6	133.6	19.38	12.32	224.9
Oat hull ration	6	50.7	179.8	173.2	96.2	166.1	22.30	2.52	149.7
Oat hull and Wesson oil ration	6	50.6	142.2	135.2	94.8	126.3	19.92	9.75	203.9
Experiment 64									
Preliminary chicks	6	....	57.6	54.0	93.7	54.7	18.08	6.50	163.1
Calories per 100 gm.	....	....	152.7	....	....	....	....	....	....
Corn meal ration	6	57.2	214.1	203.5	95.1	197.2	21.11	3.41	151.4
Gelatine ration	6	58.2	126.7	117.5	92.7	113.1	19.78	2.18	132.3
Egg albumen ration	6	57.9	171.0	160.5	93.9	155.9	22.17	2.22	146.3
Blood albumen ration	5	57.5	273.4	263.1	96.3	254.8	21.15	3.26	150.2

In the experiments lasting 12 to 18 weeks, the chickens moulted and the feathers were scattered around the room. The feathers collected averaged 17.4 gm. per chicken in Exp. 51, and 7.4 gm. each in Exp. 58. Composition of the feathers is given in Table 9. The energy content of the two samples of feathers was calculated to be 4.5 and 4.7 calories per gram and the total energy in the discarded feathers was approximately 78 and 35 calories. These quantities should be added to the energy gained by the chickens, and deducted from the energy used for maintenance, but such correction was not practical since the exact quantities shed by each group of chickens is not known. However, the total energy used for maintenance (Table 11) was over 4000 calories per chicken per period. The energy in the feathers was 1.8 and 0.9 per cent of 4000, so that the loss of the feathers would have very little effect upon the figures for maintenance requirements.

Average data from the calculation of the energy used for maintenance are given in Table 11. As in previous work (6, 7, 8), the productive energy of the effective digestible nutrients of the corn meal ration was taken to be 2.78 calories per gram. The maintenance requirements were calculated with use of the average weights per period. This has been shown to give more consistent results than the use of the average of the first and last weights and better in accord with the previous work of others than the use of the surface area (4). The productive energy of the feed eaten, less the energy gained by the chickens, gives the total productive energy used for maintenance, from which the maintenance requirement per day per 100 grams were calculated.

As shown in Table 11 the productive energy used for maintenance in the two experiments of 6 weeks each are 17.7 and 18.9 calories per 100 grams per day. These results are much higher than those secured in any of the experiments for 3 weeks previously reported (Tables 2, 3, 4, 5) except the 24.48 calories in Exp. 31 in Table 2. The quantities of productive energy used for maintenance in the four experiments for the periods of 12 weeks are close together, and their average of 13.1 calories per day per 100 grams is not far from the average of 13.7 calories found in 70 experiments for periods of 3 weeks mentioned on a preceding page.

The energy used for maintenance in the single experiment for 18 weeks was 10.1 calories per day per 100 grams. This is appreciably lower than the 13.1 calories for the four 12 weeks experiments, and lower than all except two experiments (A-38 and A-41) of the previous experiments for 3 weeks in Table 3. This indicates that the chickens from 13 to 18 weeks old have lower maintenance requirements per 100 grams than the younger chickens. This is in accordance with work reported by Mitchell and Haines (16), that the basal heat production of chickens weighing 2705 grams was 63 calories per kilogram of body weight, while for those weighing 1321 grams it was 81 calories per kilogram.

If the maintenance requirements of the chickens up to the age of 12 weeks in the 18 weeks experiment were considered to be 13.7 calories per 100 grams per day, the maintenance requirement calculated as shown in Table 12 for the period of from 12 to 18 weeks would be 7.2 calories per day per 100 grams. With a ration containing 1.9 calories of productive energy per gram, approx-

Table 11. Average data and calculation of maintenance requirements of chickens fed on the standard corn meal ration

Experiment number	Percentage of P. E. of ration found in gain	Period of experiment weeks	Number of chickens	Average weight by periods gm.	Initial energy content cal.	Final energy content cal.	Gain of energy cal.	Prod. energy of ration cal. per gm.	Ration eaten gm.	Prod. energy of feed eaten cal.	For maintenance: Total prod. energy cal.	For maintenance: Prod. energy per period per 100 gm. cal.	For maintenance: Prod. energy per day per 100 gm. cal.
125	31	6	7	253.5	111.3	938.6	827.3	1.92	1407.1	2697.4	1870.1	742.3	17.7
145	22	6	6	196.7	115.7	570.9	455.2	1.84	1103.5	2026.0	1570.8	795.3	18.9
131	26	12	7	399.4	82.2	1572.9	1490.8	1.92	3027.7	5804.1	4313.3	1084.5	12.8
45	34	12	6	382.3	86.1	2185.5	2099.5	1.95	3128.2	6093.8	3994.3	1043.8	12.4
51	33	12	6	348.6	71.4	2082.7	2011.3	1.92	3151.7	6063.9	4052.7	1164.4	13.9
58	34	12	6	366.1	75.3	2292.2	2216.8	1.96	3317.3	6498.6	4281.8	1170.2	13.9
139	25	18	8	668.8	109.7	2956.2	2846.5	1.84	6168.1	11324.5	8477.9	1269.1	10.1
14	48	3	6	110.7	83.7	332.4	248.7	1.98	262.4	518.6	269.9	247.2	11.8
20	51	3	6	104.6	78.5	353.1	274.6	2.32	231.3	536.7	262.1	252.7	12.0
49	47	3	6	127.4	71.8	405.1	333.3	1.94	380.7	707.1	403.8	318.3	15.2
50	44	3	6	136.7	73.6	374.8	301.2	1.88	365.9	587.5	386.3	282.6	13.5
64	40	3	6	128.1	87.4	309.1	221.7	1.84	308.3	558.0	336.3	263.0	12.5

Table 12. Energy for maintenance for the period of from 12 to 18 weeks

Average weight by periods to 12 weeks, grams	445
Energy used for maintenance, 18 weeks (A) calories	8478
Energy used for maintenance, 12 weeks (B)	5121
.137 × 445 × 84 = (B)	
Energy used for maintenance, 42 days, 12 to 18 weeks (A—B = C)	3354
Average weight by periods 12 to 18 weeks, grams	1113
Energy used for maintenance, calories per day per 100 gram = 100C ÷ (1113 ×42) = D	7.18

imately 37 grams of the ration per day and kilogram would be required for maintenance of the older chickens. This is not far from the 42 grams of feed per day per kilogram calculated from the results reported by Titus (18) for laying White Leghorn pullets, or the 46.5 gm. ration per day per kilogram calculated from the work of Brody, Fork, and Kempster (2) for laying hens. Laying hens could be expected to have somewhat greater maintenance requirements than growing chickens. Additional experiments are needed with chickens of from 12 to 18 weeks old or older, since a single experiment cannot be considered to give the exact value.

In the five experiments of 3 weeks duration here reported (Table 11), the maintenance requirements of the young chickens ranged from 11.8 to 15.2 calories per day per 100 grams, with an average of 13.0. The maintenance requirements were lower than usual for four of the 6 experiments.

Productive Energy Values of the Feeds with Chickens to the Age of 7 to 19 Weeks

The experiments included comparisons of the energy values of the experimental feeds with that of corn meal, as was done in previous work (6, 7). If part of the metabolizable energy not utilized as productive energy can be used for maintenance, there might be differences between productive values secured from chickens fed for 6 to 18 weeks, which might not be apparent in the shorter feeding periods of 3 weeks with smaller and younger chickens.

That portion of the productive energy of the ration used for maintenance averaged 52% of the productive energy fed in the experiments for 3 weeks, 73% in the experiments for 6 weeks, 68% in the experiments for 12 weeks, and 75% in the experiment for 18 weeks. If the heat of utilization could be used for maintenance purposes and thereby save productive energy, the productive energy of the ration should be appreciably greater in the experiments for 6, 12 or 18 weeks than in the experiments for 3 weeks. Apparently such was not the case.

The average maintenance requirements given in Table 11 were used to calculate the productive energy of the rations fed in the same experiments containing the feeds which were compared with corn meal, with the results given in Table 13. The method of procedure in each case is indicated by the

Table 13. Data and calculation for average productive energy of rations and effective digestible nutrients

Experiment number and name of ration	No. averaged	Average weight by periods gm.	Initial energy content cal.	Final energy content cal.	Gain of energy cal.	Ration eaten gm.	Used for maintenance cal.	For gain and maintenance cal.	Prod. energy of ration cal. per gm.	Effect digest. nut. of ration per 100 gm.
Experiment 125. 6 weeks										
Wheat bran	8	182.1	112.3	485.9	373.5	1401.2	1251.4	1724.9	1.231	49.2
Experiment 145. 6 weeks										
Wheat bran	6	139.7	120.6	273.6	153.0	974.9	1110.5	1263.5	1.174	41.8
Experiment 131. 12 weeks										
Wheat bran	7	277.3	82.2	713.4	631.2	3095.8	3007.5	3638.7	1.173	49.2
Experiment 45. 12 weeks										
Cottonseed oil	6	289.6	86.7	1799.7	1713.0	2312.1	3023.7	4736.7	1.998	88.9
Casein	6	431.5	87.4	1860.2	1772.8	3061.8	4654.9	6427.6	2.091	69.3
Casein and cottonseed oil	6	426.6	87.4	2092.0	2004.6	2537.6	4453.9	6458.5	2.510	91.8
Experiment 51. 12 weeks										
Cottonseed oil	6	214.6	72.8	1190.6	1117.8	1668.0	2498.6	3616.4	2.170	90.8
Casein	6	425.9	72.9	1865.9	1793.0	3015.7	4959.2	6752.2	2.257	68.1
Casein and cottonseed oil	5	383.3	72.7	2150.8	2078.1	2404.7	4463.6	6541.7	2.726	91.5
Experiment 58. 12 weeks										
Oat hulls	6	389.3	70.9	1945.2	1870.4	4689.6	4542.3	6412.7	1.364	47.1
Cottonseed meal	5	394.9	76.2	1737.6	1661.4	3989.8	4619.9	6281.2	1.575	51.4
Wheat bran	4	320.1	77.1	1347.9	1270.9	3994.7	3746.7	5017.5	1.251	45.3
Experiment 139. 18 weeks										
Wheat bran	6	398.5	109.5	1086.8	977.3	5663.3	5061.1	6038.4	1.064	41.8
Experiment 14. 3 weeks										
Cottonseed oil	5	97.4	84.7	321.0	236.3	203.9	240.7	477.0	2.372	88.2
Hydrogenated oil	6	110.0	84.1	321.8	237.7	288.9	271.6	509.3	1.767	67.4
Hydrogenated oil	6	106.1	84.8	347.7	263.0	225.7	262.2	525.1	2.342	89.5
Experiment 20. 3 weeks										
Corn oil	5	97.7	77.5	294.3	216.7	210.0	247.3	464.0	2.192	81.0
Peanut oil	6	97.1	79.0	299.8	220.9	206.4	245.8	466.7	2.260	81.0
Soybean oil	6	98.5	77.9	298.4	220.5	201.0	249.2	469.7	2.350	84.6
Experiment 49. 3 weeks										
Cottonseed oil	5	109.6	72.2	360.2	288.0	288.0	348.4	636.4	2.190	87.5
Casein	6	128.7	71.7	318.5	246.9	308.0	409.1	656.0	2.128	67.3
Casein and cottonseed oil	6	108.4	72.2	283.3	211.2	205.2	344.8	556.0	2.737	87.1
Experiment 50. 3 weeks										
Cottonseed oil	6	106.7	73.9	314.9	241.0	238.8	301.9	542.9	2.287	90.2
Oat hulls	6	122.4	72.7	260.6	187.8	416.0	346.3	534.1	1.279	45.9
Oat hulls and cottonseed oil	6	103.7	72.5	280.1	207.6	270.8	293.4	501.0	1.825	66.4
Experiment 64. 3 weeks										
Gelatine	6	86.2	88.8	156.8	67.9	204.9	226.7	294.6	1.465	65.4
Egg albumen	6	115.4	88.5	235.1	146.7	313.9	303.5	450.2	1.434	56.1
Blood albumen	5	159.7	87.9	394.5	306.6	398.4	420.1	726.7	1.829	63.4

Table 14. Productive energy in terms of feed, effective organic constituents, effective digestible nutrients, and metabolizable energy

Name of Feed	Length of period, weeks	Experimental feed					Productive energy of experimental feed			
		Percent of ration	Effective organic constituents %	Effective digestible nutrients %	Metabolizable energy Cal. per 100 gm.	Total feed Cal. per 100 gm.	Effective organic constituents Cal. per 100 gm.	Effective digestible nutrients Cal. per 100 gm.	Rank with effective digestible nutrients of corn meal as 100	In percentage of metabolizable energy
Casein, Exp. 45	12	30	87.3	77.8	327	289	331	372	124	89
Casein (with oil), Exp. 45	12	30	87.3	89.9	378	412	472	458	153	110
Casein, Exp. 51	12	30	87.9	76.0	319	351	399	462	154	110
Casein (with oil), Exp. 51	12	30	87.9	81.9	344	423	481	516	172	123
Casein (average)	12	...	...	...	...	369	421	452	151	108
Casein (average), 3 weeks	3	...	...	...	...	224	256	317	105	76
Cottonseed oil, Exp. 45	12	20	225.0	174.5	733	266	264	175	58	36
Cottonseed oil (with casein), Exp. 45	12	20	225.0	192.8	809	451	200	234	78	56
Cottonseed oil, Exp. 51	12	20	225.0	188.0	789	363	161	193	64	46
Cottonseed oil (with casein), Exp. 45	12	20	225.0	196.9	827	474	211	241	80	57
Cottonseed oil (average)	3	...	...	...	...	467	208	237	79	57
Cottonseed meal, Exp. 58	12	50	83.0	41.8	176	163	197	390	130	93
Cottonseed meal (average)	3	...	...	...	...	130	152	280	93	67
Oat hulls, Exp. 58	12	50	56.7	1.9	8	45	...	...	100	...
Oat hulls (average)	...	...	...	...	...	13	24	...	...	...
Wheat bran, Exp. 125	18	50	80.3	40.1	168	102	127	254	85	61
Wheat bran, Exp. 145	6	50	80.3	31.1	131	107	133	343	114	82
Wheat bran, Exp. 58	12	50	75.3	29.6	124	98	131	331	110	79
Wheat bran, Exp. 131	12	50	80.3	40.1	168	90	112	205	75	54
Wheat bran, Exp. 139	18	50	80.3	31.1	131	85	106	272	91	65
Wheat bran (average)	6, 12, 18	...	...	...	...	96	121	280	95	68
Wheat bran (average)	3	...	...	...	...	100	125	273	91	65

Table 15. Productive energy in terms of feed, effective organic constituents, effective digestible nutrients, and metabolizable energy. 3 weeks

Name and laboratory number of feed	Percent of ration	Effective organic constituents %	Effective digestible nutrients %	Metabolizable energy Cal. per 100 gm.	Productive energy: Total feed Cal. per 100 gm.	Productive energy: Effective organic constituents Cal. per 100 gm.	Productive energy: Effective digestible nutrients Cal. per 100 gm.	Productive energy: Rank of effective digestible nutrients with those of corn meal as 100	Productive energy: In percentage of metabolizable energy
Corn meal, Exp. 14		90.9	79.9	336	240	264	300	100	71
Cottonseed oil	15	225.0	192.0	806	499	222	260	87	62
Hydrogenated oil, B	15	225.0	53.7	226	95	42	177	59	42
Hydrogenated oil, A	15	225.0	200.9	844	479	213	238	79	57
Cottonseed oil, Exp. 20	15	225.0	215.1	903	475	211	221	100	53
Corn oil	15	225.0	199.1	836	390	173	196	89	47
Peanut oil	15	225.0	198.7	835	435	193	219	99	52
Soybean oil	15	225.0	222.6	935	495	220	222	100	53
Corn meal, Exp. 49	50	91.1	80.2	336	241	265	300	100	72
Casein	30	87.9	72.3	304	304	346	422	141	101
Casein (oil)	30	87.9	78.6	330	423	481	538	179	128
Cottonseed oil	20	225.0	169.7	712	368	164	217	72	52
Corn meal, Exp. 50	50	88.4	79.2	333	238	269	300	100	71
Cottonseed oil	20	225.0	192.2	807	442	196	230	77	55
Oat hulls	30	56.7	6.9	29	38	67	55	100	100
Cottonseed oil (with oat hulls)	20	225.0	181.7	763	510	227	281	90	67
Corn meal, Exp. 64	50	87.9	73.3	308	220	250	300	100	72
Gelatine	30	82.6	70.0	294	98	119	140	47	33
Egg albumen	30	85.9	39.0	164	83	97	213	71	51
Blood albumen	30	76.4	63.0	265	217	284	344	115	82
Cottonseed oil average, Exp. 14, 49, 50								81	59
Casein average, Exp. 49								160	115

headings of Table 13. The productive energy used for maintenance is calculated by multiplying the average weight in grams by periods by the calories used to maintain one gram of chicken as found by the use of the corn meal ration in the same experiment. The sum of the calories in the gain and the calories used for maintenance, divided by the grams of feed eaten, gives the calories of productive energy of one gram of the ration, as shown in Table 13. The calculations were made for each chicken separately and then averaged.

The productive energy values of the feeds were calculated from the productive energy of the rations by the procedures already described in detail (6, 7). The difference between the productive energy of one gram of the corn meal ration and one gram of the ration containing the feed to be compared gives the effect of the substitution. This difference added to the productive energy of the quantity of corn meal substituted gives the productive energy of the quantity of the feed which replaced the corn meal. The effective digestible nutrients of the feeds tested were calculated in a similar way from the digestion experiments and the composition of the feeds and rations.

The productive energy values of the various feeds as calculated for the periods of 6, 12, and 18 weeks are given in Table 14. For comparison of the longer experiments with those for three weeks, the average data for experiments on the same feeds already published (6, 7) are included. Since there are differences in digestibility, comparisons are best made of the values of the different feeds by means of the productive energy per unit of effective digestible constituents and in percentages of metabolizable energy.

Oat hulls had a higher value in the one 12 weeks experiment than the average of the experiment for 3 weeks previously reported, but the total productive energy value is so low that slight differences between the results secured with the entire rations would produce those differences. The digestibility of oat hulls is so low and variable that comparative energy values are not significant.

The productive energy value of the casein in three of the four experiments for 12 weeks is greater than the average value secured in the experiments for periods of 3 weeks previously reported. The relative productive energy of 100 grams of the effective digestible nutrients of the casein compared with that of corn as 100, averages 151, while the average for the 3 weeks experiments previously reported is 105. However, the rations fed in experiment 49, with younger chicks for 3 weeks, were the same as those fed in experiment 48 reported in Table 15 and the relative value of the casein is 149 and 179, which is likewise high. This indicates that the greater value of casein found in this work compared with previous work is not due to the age of the chickens but to other factors. In calculating the productive energy values, it is necessary to assume that the productive energy used for maintenance per 100 grams of live weight is the same for the experimental rations as for the standard corn meal ration fed in the same experiments. If there are differences in the energy used for maintenance by the different groups compared in the same experiment, the differences would cause differences in the values secured for the productive energy. As shown on a preceding page, the higher protein content of the casein ration may have caused lower maintenance requirements than those due to the corn meal ration. This may be the cause of the high value for productive energy secured in those experiments. The productive energy of the casein is greater than its metabolizable energy in three of the experiments in Table 14 and one in Table 15. Since the metabolizable energy is the entire quantity of energy which the animal can secure from the food, the productive energy should not exceed it, so that this evidence indicates that the values for the productive energy of the casein are too high in these experiments.

The relative value of the effective digestible nutrients of cottonseed oil, Table 14, averaged 61 (with corn meal as 100) in the two experiments of 12 weeks, compared with 79 as the average of the 3 weeks experiments previously reported (7) for cottonseed oil. In the other two of these experiments for 12 weeks in which casein was fed as 30% of the ration, the relative values for cottonseed oil were 78 and 80, practically the same as the average of 79 for the previous 3 weeks experiments. It would appear that the low value for cottonseed oil secured in the two experiments was probably due to differences in maintenance requirements between the experimental ration and the standard corn meal ration, and not to less efficient use of the oil by the older chickens than by the younger ones.

Only one experiment was made with cottonseed meal in the 12 weeks experiments. As was the case with the casein, the relative productive energy of the cottonseed meal was higher than the value secured for the younger chickens in the 3 weeks experiment.

With the wheat bran, two experiments of 6 weeks duration were made, two were made for 12 weeks, and one for 18 weeks. The average relative value of the effective digestible nutrients for the five experiments is 95, compared with corn meal as 100, with an average of 91 for the 3 weeks experiments previously reported. These averages are practically the same. The relative value was 91 in the 18 weeks experiment, which is the same as the average value secured in the 3 weeks experiment. The average for the two 12 weeks experiments is 98 and for the two 6 weeks experiments is 100. These are a little higher relative values than for the 3 weeks experiment, but the other work reported indicates that these values are too high.

The conclusion reached is that the chickens 6 to 18 weeks old utilize the metabolizable energy for production of fat and flesh as efficiently as the younger chickens less than 4 weeks old. These experiments attest the validity of the method of experiment used in comparing the productive energy values of various feeds with that of corn meal, since widely differing periods of time give nearly the same results. The work on chickens, together with that done on rats (8), indicates that the value of productive energy used for maintenance per day per 100 grams is usually the same with the corn meal ration as with rations in which other feeds are substituted for corn meal in the same experiment.

Productive Energy Experiments to the Age of About 4 Weeks

A summary of the results of the experiments of 3 weeks duration here reported is in Table 15. Two samples of hydrogenated cottonseed oil were used in experiment 14, one of which (A) was of the consistency used in human foods, while the other (B) was harder than is used for human foods unmixed with other oils or fats. Sample A had an iodine value of 65 and B, of 10. Sample A was slightly more digestible (11) than the cottonseed oil with which it was compared, and had about 10 per cent lower value in productive energy than the oil with which it was compared in the same experiment but its productive energy averaged about the same as the average of other experiments with cottonseed oil (7). The hard sample of hydrogenated oil had a low digestibility, and the oil digested from it had about 70 per cent of the productive energy of sample A.

Cottonseed oil, peanut oil and soybean oil had practically equal productive energy values in experiment 20. Corn oil had about 10% lower productive energy per unit of digested oil than the other oils used in the same experiment and the fat had slower digestibility, but one experiment is not sufficient to show that its value is lower than that of the others.

The productive energy of gelatine was low in experiment 64. Egg albumen had a higher value than gelatine, while blood albumen had a higher value than corn meal.

Productive Energy Where Maintenance Requirements of Older Chickens are Calculated on the Surface Area Basis Compared with Calculations on the Weight Basis

The method used to measure the productive energy of the corn meal ration was to feed one group of chickens on limited quantities of the ration, and another group on unlimited quantities of the same ration, and then calculate the productive energy of the ration, and productive energy used for maintenance from the data by an algebraic method from the equations given on a previous page. In order to make this calculation, it is necessary to assume that the calories of productive energy used for maintenance vary either in proportion to the weights or in proportion to the surface areas of the chickens. The results were calculated for both assumptions and the weight basis was found to give the more reasonable results (4). The results calculated on the weight basis were more consistent and better in accord with other published work than those calculated on the surface basis, and the weight basis has accordingly been used on the work subsequently reported. The results secured have indicated that this procedure is correct. The work was done with chickens up to a maximum age of 42 days except one experiment, in which older chickens were used, and this experiment indicated that the result might possibly be different with older chickens (4).

It is obvious that if there are only small differences between the final weight of the animals grown with the corn meal ration and those grown at the same time with another ration, in which the corn meal was replaced by the feed to be tested, it will make little difference whether the weight basis or the surface area basis is used. If the final weights differ, however, the two methods of calculation will give different results. The greatest differences in weights of the chickens compared in the work here discussed, were in experiment 139 which had been carried on for 18 weeks. The weights by periods were appreciably greater for the chickens which had received the standard corn meal ration than for those which received the ration in which corn meal was replaced by wheat bran. This experiment was selected to again compare the two methods of calculating the maintenance requirements.

The surface area was calculated for each weight of each chicken as was done in the work previously reported, by the formula of Southgate (4) $S = 9.3\ W^{.66}$ in which S is the surface and W the weight. The surface by periods was calculated from this data. The amount of calories used for maintenance was calculated for the corn meal ration both by weight and by surface and the productive energy was then calculated for the wheat bran ration. The average data are summarized in Table 16.

From Table 16, it is seen that the average surface area and the average weight of the chickens on the corn meal ration, as averaged by periods, are of equal magnitude. This results in almost the same number of calories of energy per unit of area or of weight. The surface areas of the smaller chickens, on the wheat bran ration, are proportionately larger than the weights. This results in an apparent use of 957 more calories of energy for maintenance per chicken by the surface area basis than by the weight basis. The result is that on the surface area basis, the wheat bran ration has a productive energy of 1.234 calories per gram, compared with 1.064 calories on the basis of the weight. When the productive energy of the wheat bran is calculated on the surface basis, its digestible nutrients have a value of 127 while on the weight basis they have a value of 91, compared with those of corn meal as 100. From our knowledge of the chemical composition of wheat bran it is unreasonable to assume that its digestible nutrients have higher values than those of corn meal. The value on a weight basis is reasonable and in accord with the values previously published (7). The value on the surface area basis is unreasonable because it is too high.

Table 16. Comparison of surface area basis with weight basis. Exp. 139—18 weeks

	Weight basis	Surface basis
Corn meal ration.		
Average weight in grams or surface in sq. cm. by periods (W)	669	682
Productive energy of feed eaten, calories (E)	11325	11325
Energy gained by chickens, calories (G)	2847	2847
Total productive energy used by chickens (E — G = N)	8478	8478
Productive energy used for maintenance per day per 100 gm. or cm. 100N ÷ DW = M (D is 126 days)	10.1	9.8
Wheat bran ration.		
Average weight or surface by periods, (V) wheat bran ration	399	485
Energy gained by chickens, calories (H)	977	977
Energy used for maintenance, calories (MVD ÷ 100 = K)	5061	6018
Productive energy of feed eaten (H + K = F)	6038	6995
Grams of ration eaten (R)	5663	5663
Productive energy of wheat bran ration, calories per gram F ÷ R	1.064	1.234
Productive energy of wheat bran, calories per 100 grams	85	119
Productive energy per 100 grams of effective digestible nutrients of wheat bran	272	381
Productive energy of effective digestible nutrients of wheat bran compared with that of corn meal as 100	91	127
Productive energy of 100 calories of metabolizable energy in wheat bran	65	90

For three of the other four experiments with wheat bran (Table 11) inspection shows that calculation by the surface basis instead of the weight basis would give too high results.

It would appear from the work here presented that for chickens up to 18 weeks old, the average weight by periods is a better basis than the surface area, for calculating the energy used for maintenance when the data is to be used to calculate the productive energy of the food.

Effect of Variations in Energy Used for Maintenance in the Same Experiment Upon the Measurements of Productive Energy

In order to calculate the productive energy of the feeds and rations, it is necessary to assume that the productive energy used for maintenance is the same per day per 100 grams live weight with the groups receiving the test feeds as with the group receiving the corn meal ration at the same time and under the same conditions. Differences in the quantities of productive energy used for maintenance between the two groups being compared would result in incorrect results for the productive energy calculated. As stated on a preceding page there are differences (4) in the quantities of energy used for maintenance between individual chickens fed on the same feed at the same time. It is too much to expect that these differences will always be averaged out for each group in all experiments. In some experiments, the energy used in maintenance will not be the same in the groups compared and incorrect values for productive energy will occur. These errors can be eliminated only by repetition of the work on a sufficient number of times. Differences in productive energy used for maintenance may also occur if there are wide differences in protein content. Differences in maintenance requirements may occur between chickens fed at different times, for reasons which remain to be ascertained.

Since variations in energy used for maintenance may occur in the same experiment, the differences in productive energy already reported in some cases may be due chiefly to differences in energy used for maintenance of the animals rather than differences in productive energy of the feeds. It seems more logical to conclude that variations in maintenance requirements between the groups of chickens compared are more likely to occur than differences in the productive energy secured by the animal from the same chemical compounds.

The unreasonably high values for casein in the work just reported (Tables 14, 15) may be due to differences in energy used for maintenance rather than to differences in the productive value of casein. To test this possibility the energy used for maintenance was calculated on the assumption that the digestible constituents of casein per unit had the same productive energy as those of corn meal. The results are given in Table 17. Table 17 shows that comparatively small differences in the energy used for maintenance between the groups compared would account for the high productive value of the casein.

Several experiments were selected in which too high values were obtained for the productive energy of the feed. Table 18 shows the results secured when, on the one hand, the maintenance requirements are assumed to remain constant per day per 100 grams, and the productive energy is calculated; and

Table 17. Maintenance requirements when productive energy is constant. Exp. 51

	Cal/day /100 gm.
Corn meal ration	13.9
Corn meal and casein ration	11.2
Difference	2.7
Assumed productive energy of casein in per cent of metabolizable energy	72
Found productive energy of casein assuming that maintenance requirements are constant	110

Table 18. Maintenance requirements calculated on the assumption that productive energy is constant, compared with productive energy calculated on the assumption that maintenance requirements are constant and equivalent to those of the corn meal ration

	Protein in ration %	Maintenance requirements		Relative productive energy of digestible nutrients, corn meal as 100
		Per day per 100 gm. calories	Corn meal as 100	
Exp. 37. Corn meal ration	16.8	16.99	100	100
Linseed oil meal	30.4	17.27	102	105
Soy bean oil meal	34.5	13.41	79	124
Fish meal	43.8	15.02	88	125
Exp. 38. Corn meal ration	16.6	16.36	100	100
Corn gluten feed	23.5	14.77	90	131
Corn gluten meal	33.3	13.54	83	136
Peanut meal	31.3	14.34	88	124
Exp. 57. Corn meal ration	16.5	16.84	100	100
Cottonseed flour	38.8	18.21	108	93
Linseed oil meal	29.7	14.72	87	146
Exp. 59. Corn meal ration	16.2	18.32	100	100
Sweet potatoes	13.3	18.62	102	93
Dried beef	32.0	12.96	71	166
Liver meal	43.9	12.41	68	137

when, on the other hand, the productive energy is assumed to be equal for equal quantities of digestible nutrients, and the maintenance requirements are calculated. An examination of the data shows that the high values secured for productive energy may really be due to differences in the energy used for maintenance in the groups compared, although they were assumed to be equal for the purpose of calculating the productive energy. The differences for maintenance shown in the tables are not unreasonable, and even greater differences have been found to occur between different groups of animals fed at different times. Some of the differences in energy used for maintenance are not wider than have been found between individual chickens fed on the same feed at the same time.

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SUMMARY

The maintenance requirements of chickens from about 7 to 28 days old in 70 experiments ranges from 9.4 to 20.5 calories of productive energy per day per 100 grams with an average of 13.6. Expressed in terms of a ration having a productive energy of 1.9 calories per gram, the maintenance requirements are ranged from 5.0 to 10.8 grams per day per 100 grams of live weight with an average of 7.2 grams.

Maintenance requirements for individual chickens fed the same ration under approximately the same conditions at the same time varied to a considerable extent, the standard deviation averaging 1.01 for 6 groups of chickens requiring an average of 13.7 calories of productive energy per day per 100 grams of live weight.

Differences in weight and in sex had no effect on maintenance requirement of the young chickens. Chickens receiving rations high in protein had much lower maintenance requirements than those receiving rations low in protein. With a ration which averaged 31.0 per cent protein, the average maintenance requirements were 12.4 calories of productive energy per day per 100 grams with a standard deviation of 0.8 while with rations averaging 16.2 per cent protein, the maintenance requirements were 15.8 calories per day per 100 grams with a standard deviation of 1.7.

The effect of protein on growing chickens is contrary to the idea that protein has a specific dynamic action which increases the heat eliminated by animals. While there is some relation between the protein content of the ration and the maintenance requirements, other factors as yet unknown caused wide differences.

The maintenance requirements ranged from 9.4 to 17.7 calories of productive energy per day per 100 grams live weight with chickens fed rations containing 18 to 24 per cent protein.

Chickens up to the age of 12 weeks had approximately the same maintenance requirement per day per 100 grams as the younger chicks. In one experiment, chickens from 12 to 18 weeks required only 7.12 calories of productive energy per day per 100 grams, which is much lower than the average of 12.6 calories for the younger chickens.

Chickens 6 to 18 weeks old utilize the metabolizable energy of food for production of fat and flesh as efficiently as younger chickens.

Hydrogenated cottonseed oil with an iodine number of 65 had about the same digestibility and productive energy value as cottonseed oil. Hydrogenated oil with an iodine value of 10 had a low digestibility and the digested portion had about 70 per cent of the productive energy of cottonseed oil.

When the maintenance requirements were calculated on the surface area basis in an experiment lasting 18 weeks, the productive energy calculated for wheat bran was unreasonably high. The weight basis is more suitable for calculating maintenance requirements for the older chickens, just as it was found to be for young ones in previous work.

In calculating the productive energy of rations or feeds, it is necessary to assume that the productive energy required for maintenance per day per 100 grams averages the same for animals on the experimental rations as on the

standard corn meal ration with which they are compared. Unusually high or low values for productive energy sometimes occur when this assumption is not correct, and when there are appreciable differences in maintenance requirement between the groups being compared.

REFERENCES

1. Barott, Herbert G., Fritz, James C., Pringle, Emma M., and Titus, Harry W., 1937. Heat Production and Gaseous Metabolism of Young Male Chickens. Jour. Nutrition. 15:145-167.

2. Brody, Samuel, Fork, E. M., and Kemster, H. L., 1938. Energetic Efficiency of Egg Production and Influence of Live Weight Thereon. Research Bul. 278, Missouri Agr. Exp. Station, 59 pages.

3. Dukes, H. H., 1937. Studies on the Energy Metabolism of the Hen. Jour. Nutrition. 14:341-353.

4. Fraps, G. S., and E. C. Carlyle, 1939. The Utilization of the Energy of Feed by Growing Chickens. Tex. Agri. Exp. Sta. Bul. 571.

5. Fraps, G. S., E. C. Carlyle and J. F. Fudge, 1940. Metabolizable Energy of Some Chicken Feeds. Tex. Agr. Exp. Sta. Bul. 589.

6. Fraps, G. S. and E. C. Carlyle, 1941. Productive Energy of Corn Meal, Alfalfa Leaf Meal, Dried Buttermilk, and Casein as Measured by Production of Fat and Flesh in Growing Chickens. Tex. Agr. Exp. Sta. Bul. 600.

7. Fraps, G. S., and E. C. Carlyle, 1942. Productive Energy of Some Feeds as Measured by Gains of Energy of Growing Chickens. Tex. Agr. Exp. Sta. Bul. 625.

8. Fraps, G. S., 1943. Productive Energy of Certain Feeds as Measured by Production of Fat and Flesh by Growing Rats. Tex. Agr. Exp. Sta. Bul. 632.

9. Fraps, G. S., 1943. Relation of the Protein, Fat and Energy of the Ration to the Composition of the Chickens. Poultry Science 22 421-424.

10. Fraps, G. S., 1944. Preparation of Small Animals for Analysis. Jour. Asso. Off. Agr. Chem. 27 224-226.

11. Fraps, G. S., 1944. Digestibility of Feeds and Human Foods by Chickens. Tex. Agr. Exp. Sta. Bul. 663.

12. Forbes, E. B., R. W. Swift, Alex Black and O. J. Kahlenberg, 1935. The Utilization of Energy-Producing Nutriment and Protein as Affected by Individual Nutrient Differences. Jour. Nut. 10 461-479.

13. Forbes, E. B., and R. W. Swift, 1944. Associative Dynamic Effects of Protein, Carbohydrate and Fat. Jour. Nutr. 27 453-468.

14. Forbes, E. B., R. W. Swift, L. F. Marcy, and M. T. Davenport, 1944. Protein, Intake and Heat Production. Jour. Nutrition 28, 189.

15. Johnson, S. R., A. G. Hogan, and U. S. Ashworth, 1938. The Utilization of Energy at Different Levels of Protein Intake. Missouri Agr. Exp. Sta. Bul. 246.

16. Mitchell, H. H., and W. T. Haines, 1927. The Basal Metabolism of Mature Chickens and the Net Energy Value of Corn. Jour. Agr. Res. 34:927.

17. Ritzman, E. G., and F. G. Benedict, 1938. Nutritional Physiology of the Adult Ruminant. Carnegie Institution of Washington, Publication No. 494, Pages 128-9.

18. Titus, H. W., 1928. The Gross Maintenance Requirement of White Leghorns. Poultry Science 8, 80-84.

19. Winchester, C. E., 1940. Lability of Metabolic Processes in Laying Hens. Poultry Science 19 233-234.