EFFECTS OF NUTRITION ON VARIABILITY

IN THE GROWTH OF CHICKENS

By

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INTRODUCTION.

The chicken has long been known as one of the most variable of species. This high degree of variability has fundamental advantages and disadvantages. As it was pointed out by Jull (1932), the fact that there is great variation among fowls is of particular significance in inheritance. Progress in breeding would not be possible if it were not for the variation which makes the selection of superior individuals possible. On the other hand, the high degree of variability in chickens makes it difficult to interpret poultry nutrition experiments unless large numbers of individuals are used, or large differences between groups are obtained. There is also a very real possibility that certain types of unfavorable diets might skew the distribution of variability and thus cause misinterpretations of the data if the usual methods of statistical analysis were employed.

In broiler production variability in rate of growth presents some serious practical disadvantages. The slower chickens are often classed as culls. When the flock is sold without the culls it may bring as much as a cent per pound more than if these culls are left in the flock. Thus the slow growing members in a commercial broiler flock frequently cause the producer to loose as much as 5 percent on a deal. Nor is this the only disadvantage resulting from slow growing members of the flock, for they are frequently driven from the feeders by the larger chicks and practice coprophage to quench their appetites, as a result they incubate and spread any fecal borne infection that may be present. Furthermore, the smaller members of a flock are often identified with the beginning of outbreaks of cannibalism.

There are many factors that may contribute to the variability in the

rate of growth of the chickens. These may be divided into two main classes, native variability and acquired variability. Under native variability are found the chicks' initial variability, inherited potentialities, and congenital nutritive reserve.

The initial variability is due to differences in the weight of eggs from which the chicks hatched, differences in water loss during incubation due to shell structure and condition, and the differences due to the differences in weight of unabsorbed yolks. Chicks vary in their inherited potentialities in regard to adult body size, rate of growth, and glandular balance. The congenital nutritive reserve of chicks may vary because their dams were on different diets, were in different rates of lay, differed in their efficiency of assimulating nutrients of their diets, or differed in their efficiency of depositing assimulated nutrients into the egg.

Acquired variability may be caused by the level of feed intake, level of protein intake, efficiency of feed utilization, effect of previous live weight, or transient disturbances in growth. The level of feed intake may be due to either rationing, appetite, social opportunity, or the ability to ingest. The level of protein intake is influenced by rationing, feeding diets of different protein content or by selection. The efficiency of feed utilization can be effected by relative deficiencies of amino acids, vitamins, or minerals; excessive quantities of crude fiber, pentosans, insoluble grit or charcoal; the presence of excretory or moldy products; or the presence of organic or metallic poisons. It may also be effected by the degree of digestion, the degree of absorption or the rate of metabolism, factors which are influenced by inheritance as well as by the character of the feed. Previous live weight affects both the physical ability to ingest feed and the social status of the individual. Transient dis-

turbances such as disease, mechanical injury, or social oppression may cause the chick to develop less rapidly than either its inheritance or diet would permit.

REVIEW OF THE LITERATURE.

Jull (1923) called attention to an increase in variability in live weight in Barred Plymouth Rock chicks during the first 4 or 5 weeks of life. He found that after a period of high variability which lasted until the tenth week for males and the twelfth week for females, there was a general tendency toward decrease in variability in live weight for both sexes. Latimer (1924) found that the variability in live weight of White Leghorn chicks was greatest at 5 weeks of age. Jull and Quinn (1924) found no correlation between the weight or shape of an egg and the sex of the chicks that hatched from it, although the weight of the chick was closely related to the weight of the egg.

Schneider and Dunn (1924) showed that the inheritance of body weight in the domestic fowl is extremely complicated, for they found that body weight was 3 to 6 times as variable as bone measurements. Jull and Quinn (1931), using a cross between Barred Plymouth Rocks and Black Rose-Comb Bantams, found that F_1 progeny was intermediate in weight between and about as variable as the parent stocks. However, the F_2 generation, though still intermediate in weight between the parent stocks, was far more variable than either parent stock. Many other workers have since made contributions on this subject which only serve to emphasize the complicated nature of the inheritance of body size. The inheritance of the rate of growth appears to be nearly as complicated as that of body weight. Asmundsen and Lerner (1933) reported that there were genetic differences with respect to rate of growth within their strain of the White Leghorn breed, and that those differences were determined by multiple factors. Schnetzler (1936) found that fast growing chicks grow larger, lay larger eggs and beget faster growing offspring than slow growing chicks.

Titus and Jull (1928) pointed out that chicks that received skim milk did not increase in variability after the fourth week of age, whereas those that did not receive skim milk continued to increase in variability until the seventh or eighth week. Jull and Titus (1928) showed that growth of chickens is more closely related to feed consumption than to age. Parker (1929) found that early handicaps due to poisoning, starving, chilling, overheating, or removing the unabsorbed yolk had no significant effect on variability and but little effect on live weight at 20 weeks.

Hays and Sanborn (1929) reported that early hatched chicks were nearly 13 percent heavier at 2 weeks than late hatched chicks even though there was little difference in weight at hatching. Hale (1931) concluded that males and females should be considered separately and that the coefficient of variability should not exceed 15 percent unless experimental treatment or other conditions had seriously interfered with the rate of growth. He worked out and tabulated the smallest differences that would be significant at coefficients of variability of 15, 17.5, and 20 percent for groups of chickens from 10 to 100. Schroeder and Lawrence (1932) used large numbers of chicks in several replicate pens and found that large differences occured in mean live weight and variability. They found that variability reached a maximum by 6 weeks but that the occurrence of disease greatly increased variability. They presented a formula for determining the number of chicks it would be necessary to use to provide even mathamatical chances that the experiment could be approximately duplicated. Their formula was $N = \frac{2(s)^2}{Sd^2}$. They also compiled a table which gave the numbers of chicks of one sex that would be needed to demonstrate differences of 2.5, 5, 10, and 20 percent at coefficients of variability ranging from 10 to 24 percent by increments of 2 percent.

Mitchell, Card and Hamilton (1931) in their exhaustive study of growth in White Leghorn chicks determined the coefficients of variability for most of the parts and organs of the chickens' bodies as well as for their live weights. They found some of the parts to be more variable than the whole and the remainder to be about the same.

Keller (1933) observed that differences in the size of different breeds of chickens was due to different numbers of cells rather than to differences in size of cells.

Souba (1923), Latimer (1924), Upp (1928), and Funk, Knandal, and Calenbach (1930) made correlation studies of the growth of chickens. Although many significant correlations between the live weights at later stages were discovered those found before 4 weeks of age were not significant.

Several workers have noted the similarity in glandular appearance in experimental animals after starvation, vitamin E deficiency, or hypophysectomy. Verzar and Kokas (1931) suggested that the symptoms of vitamin E deficiency in the young rat were similar to those following hypophysectomy. Nelson (1933) showed that vitamin E deficiency involved the pituitaries. The pituitaries of male rats kept on E deficient diets for long periods exerted greater gonadotropic action than those of control animals. Rowlands and Singer (1936) found that E deficient female pituitary contains less lutenizing factor than normal glands. The results secured by Barrie (1937) with young rats born of E deficient does would indicate that E deficiency causes a simple pituitary deficiency. On the contrary, Drummond (1940) pointed out that E deficiency fails to respond to anterior lobe extracts or pituitary transplants although either treatment corrects genuine pituitary deficiency. He believed that the most promising field

for investigation is that E deficiency acts directly upon the gonads which act in turn upon the pituitary. Copping and Korenchevsky (1940) recorded the weights of all the endocrine glands of male and female rats on E deficient and complete diets. Although growth was considerably retarded in the E deficient rats the only glands that were noticably out of proportion were the thymus and spleens which were oversize in the E deficient rats. Vogt-Moller (1940) makes two interesting statements regarding vitamin E in human medicine which we quote partly because the second reflects our viewpoint as to one of the causes of variability in chickens. "To me there appears to be sufficient evidence for assuming that vitamin E acts directly or indirectly as a sort of morphogenic hormone .... I emphasized years ago and I emphasize in this paper that certain individuals may require greater amount of vitamin E than other individuals, so that the requirement of the central nervous system for vitamin E is not fulfilled when these persons are exposed to the damage of infections, intoxications, and so on." However, Dam, Glavind, Bernth, and Hagens (1938) showed that vitamin E cured encephalomalacia in chickens without influencing growth, hence the syndrome in young chicks may well differ in other symptoms from that found in rats.

It has frequently been noted that the thymus of rapidly growing chickens is large, whereas, that of slowly growing chickens is relatively very small. Ackert (1924) found that the thymus of chickens parasitized with Ascaridia perspicillum were smaller than those of non parasitized chickens. However, Riddle and Krizenecky (1931) reported that the removal of both the thymus and the bursa Fabricii from 17 common pigeons did not affect development or function of the reproductive organs. They suggested that other organs, that is lymph nodes, might have thymic function. Plagge(1941) has

concluded that the thymus gland of the male and female albino rat is definitely sensitive to varying concentrations of sex hormones as indicated by gross changes in the gland at puberty and by both gross and histological changes following castration or injections of sex hormones. Thymectomy does not affect the reproductive system of either sex. As the physiological relationship between the thymus and the reproductive system is not reciprocal his study offers no evidence to support the claim that the thymus is an organ of internal secretion. Phillips and Engle (1940) noted that a deficiency of riboflavin in chicken diets caused atrophy of the thymus. Smith and Ireland (1941) working with mice found that the principle change in thymus as a result of age was a constant increase in argyrophil fibers in the medulla. Rowntree and associates (1935) reported a striking series of experiments in which an acid extract of thymus was injected into rats daily from the third week through the reproductive period. After the third generation of inbreeding and treatment, the offspring became progressively more precocious, though they continued to be normal in other respects and stopped growing when they reached normal size. Mitchell (1938) suggests that possibly the thymus is a storage place for certain food materials that are useful in growth processes and are especially required during the period of the development of sexual maturity.

EXPERIMENTAL.

Preliminary experiments were undertaken in an attempt to find clues in gland or organ size that would be helpful in discovering the causes of variability. Chicks from relatively efficient progenies from the project recently reported by Hess, Byerly, and Jull (1941) were killed 12 hours after hatching, their endocrine glands and segments of empty digestive tract were removed and weighed on an analytical balance. The organic make-up of the chicks from matings producing efficient progeny was not measurably different from that of chicks from matings producing relatively inefficient progeny. However, great individual variation in the size of thymus glands was noted.

It seemed reasonable that these large thymus glands might either stimulate rapid growth or act as reservoirs for nutrients needed for rapid growth. Accordingly, a technique was developed by which the several lobes of the thymus of newly hatched chicks could be entirely removed. The thymus glands were removed from 8 newly hatched New Hampshire Red chicks and the operated chicks were placed in a battery brooder compartment with 8 comparable control chicks. Each week during a ten week test period the operated chicks weighed as much and were as variable as the control chicks.

In an experiment, to be reported in detail below, in which widely divergent types of diets were fed, the fastest and slowest growing chicks that had been fed each of 10 diets were selected for examination of glands and organs. The thymus, spleen, pancreas, liver, proventriculus, gizzard, duodenum, illeum, jejunum, ceca, and colon of each chick was weighed. Most of the organs were in proportion to body weight. There were, however, two interesting exceptions. The thymus

glands of the chicks that had grown rapidly were more than twice as large in proportion as those of chicks that had grown slowly. On the other hand, the proventriculuses of chicks that had grown slowly were about one and one half times as large in proportion as those chicks that had grown rapidly.

It was felt that the results, using chicks that had already established their rates of growth, might not yield as much information as if chicks were used during the early period when differences in rate of growth could first be definitely detected. Accordingly, the 2 heaviest and the 2 lightest chicks from a lot of 25 were selected for study at 16 days of age. The thymus of each heavy chick was 5 times as heavy in proportion as that of either light chick. The same was found to be true of the bursa Fabricius, a lymphatic organ attached to the cloaca. As in the previous experiment, the proventriculuses of the small chicks were larger in proportion than those of the large chicks. All other organs appeared to be normal and in proportion to body weight. To obtain more data of this nature 50 day old chicks were grown in a battery brooder to 14 days of age at which time the 5 heaviest, 5 average, and 5 lightest chicks were selected for study. The average weights of the thymus, pancreas, liver, proventriculus, gizzard, duodenum, illeum and jejunum, colon, ceca, and bursa Fabricius expressed as percent of live weight and the length of the duodenum, illeum and jejunum, ceca, and colon expressed as a ratio to live weight are tabulated in Table I. As in previous experiments the thymuses and bursas of the fast growing chicks were nearly 5 times as heavy in proportion as those of slow growing chicks. As before, the proventriculuses of slow growing chicks were heavier in proportion than those of fast growing chicks. Contrary

Table I. Average weights of parts of Barred Plymouth Rock chicks 14 days of age, expressed as percentage of empty live weight, and the average lengths of sections of the digestive tract, expressed as ratio to empty body weight.

(Each figure is an average for 5 chicks)

Average ratios of lengths of sections of digestive tract to live weight

Source of Material	Empty live weight	Duodenum	Illeum and Jejunum	Colon	Ceca
	Grams	Ratio	Ratio	Ratio	Ratio
Largest chicks	106.8	6.31	25.2	2.06	3.18
Average chicks	81.4	7.54	27.3	2.46	3.73
Smallest chicks	56.4	9.89	37.2	3.16	4.68

Average weights of parts

Source of Material	Gizzard	Duodenum	Illeum and Jejunum	Colon	Ceca
	Percent	Percent	Percent	Percent	Percent
Largest chicks	7.14	1.87	5.48	0.33	1.53
Average chicks	8.14	2.33	5.17	0.36	2.02
Smallest chicks	9.23	2.73	5.81	0.46	1.86

Average weights of parts

Source of Material	Thymus	Pancreas	Liver	Proven-triculus	Bursa Fabricius
	Percent	Percent	Percent	Percent	Percent
Largest chicks	0.39	0.54	3.82	1.07	0.32
Average chicks	0.26	0.52	3.47	1.20	0.16
Smallest chicks	0.10	0.66	3.77	1.37	0.07

to what had been found with older chicks, all sections of the digestive tract were in the same proportion as the proventriculuses although variability was much greater than among proventriculuses. As this field of endeavor did not appear to be particularly fruitful, attention was turned to a study of the effect of diet on variability.

Examination of the literature indicated that excellent unexploited data might be available that could not be duplicated without considerable expense. In only one instance, Parker (1929), was the data already in a form usable in this study. She had found that variability was not increased or decreased as a result of short early handicaps resulting from chilling, overheating, sublethal poisoning, starving, or removing the unabsorbed yolk. The data of Titus and Jull (1928) showed that the variability of chicks fed a good diet on range reached a maximum at 7 weeks and decreased thereafter but that the variability of chicks fed an excellent diet on range reached a maximum by 4 weeks and decreased thereafter. Data from the project reported on by Hammond (1934) offered the results of feeding a wide variety of diets under several experimental conditions. Coefficients of variability for each two week period from hatching to 20 weeks of age for cockerels fed more than 60 different diets were tabulated and examined. The most striking fact revealed by these data was that progressive stages of confinement influenced the degree of variability, the length of time required for the development of maximum variability and the rate at which variability decreased after reaching the maximum. Typical curves of coefficients of variability for cockerels fed the same diet with access to grass range, access to direct sunlight on concrete runyards, confined without sunlight, and confined without sunlight but supplied

with vitamin D from cod-liver oil are plotted in Figure 1. The chicks
that were deficient in vitamin D increased in variability continuously
until by the twentieth week the variability was twice as high as the
normal maximum encountered at 4 or 6 weeks.

The data for the chicks at 6 weeks of age from the level of feed
intake experiment reported by Titus, Hendricks, and Jull (1934) were
analyzed for variability. The results are tabulated in Table II.
Maximum variability was less when the level of feed intake was slight-
ly lower than ad libitum. Attainment of maximum variability was de-
layed in inverse order to the level of feed intake. Variability was
greater at 37.5 or 25 percent of normal feed intake than at ad libitum
feed intake.

The data of Hammond, Hendricks, and Titus (1938) for cockerels at
6 weeks of age were analyzed for variability. The results are tabulated
in Table III. It was found that the variability was least when 25 per-
cent protein was fed, slightly higher at 23 percent protein and again
higher at 21 percent protein. It remained constant over the range of
protein levels ordinarily fed, that is from 21 down to 15 percent, but
increased sharply when the protein level was dropped to 13 percent.

Another experiment with which the author had familiarity promised
considerable differences in variability due to diet. This experiment,
recently reported by Wilkie and Hammond (1940), involved the use of
diets which contained single cereal grains. The composition of the
diets used in this experiment together with the coefficients of vari-
ability at 6 weeks of age of the chicks to which these diets were fed
are tabulated in Table IV. The single cereals used in these diets
affected variability inversely to the way they affected growth. At
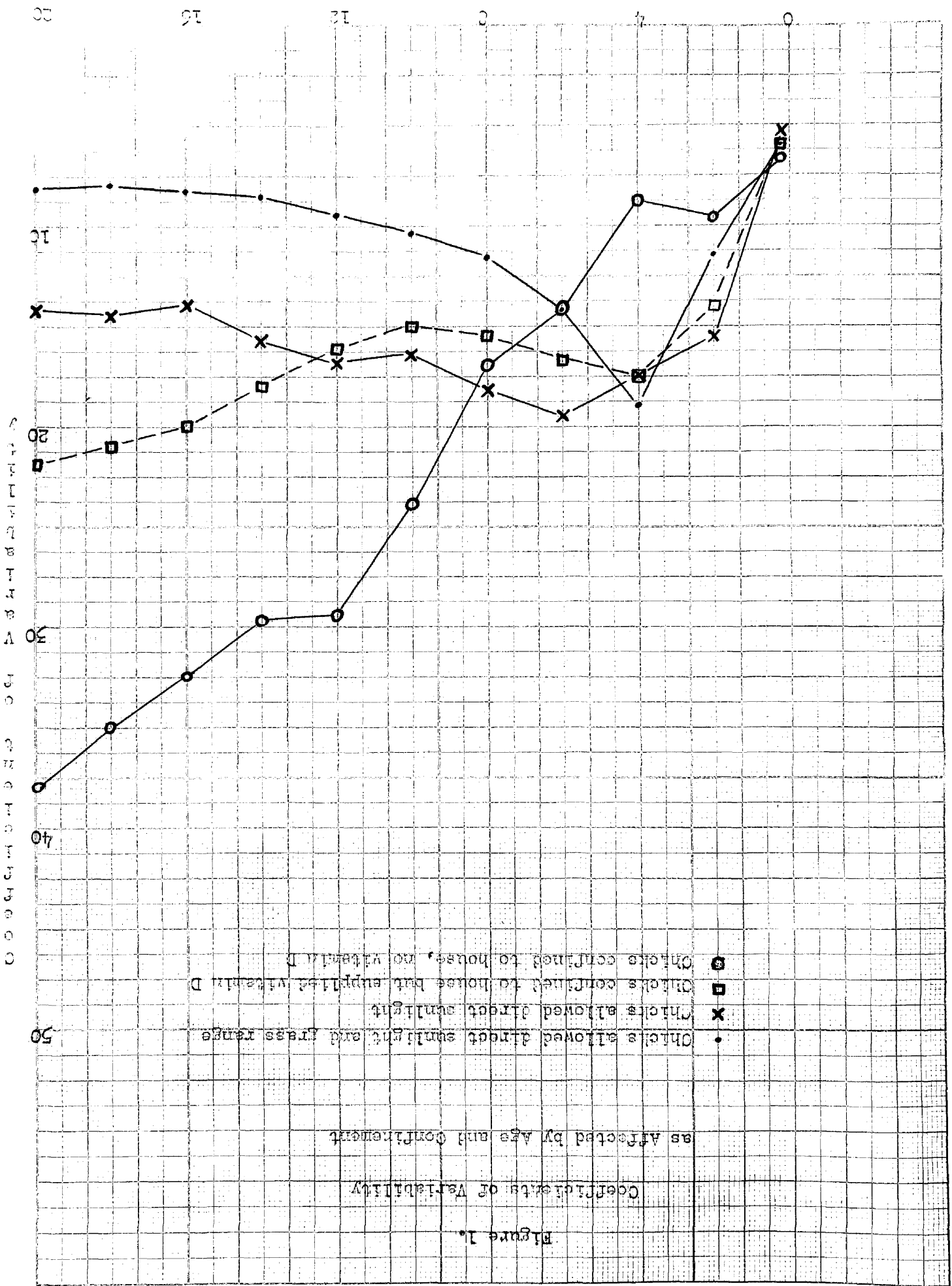
Table II. Coefficients of variability for cross bred cockerels at 6 weeks of age as influenced by the level of feed intake.

Level of feed intake		Average live weight		Coefficients of variability
Percent	:	Grams	:	
100	:	386.7	:	18.2
87.5	:	339.2	:	10.3
75	:	300.4	:	13.4
65.5	:	255.0	:	14.7
50	:	204.2	:	13.4
37.5	:	166.8	:	22.0
25	:	112.1	:	21.2

Table III. Coefficients of variability for cross bred cockerels at
6 weeks of age as influenced by the level of protein intake.

Crude protein in the diet	:	Average live weight	:	Coefficients of variability
Percent	:	Grams	:	
25	:	438.8	:	14.9
23	:	433.2	:	16.9
21	:	403.5	:	20.6
19	:	378.1	:	20.3
17	:	388.7	:	20.4
15	:	339.7	:	19.5
13	:	274.9	:	26.2

Table IV. Composition of simple cereal grain-dried buttermilk diets and the average live weights and coefficients of variability at 6 weeks of age for White Leghorn chicks fed those diets.

Ingredient	Parts, by weight, of diet No.—					
	412	413	414	415	416	417
Ground whole oats—	77					
Ground yellow corn			66 3/4			
Ground barley		74				
Ground wheat				77	49 1/4	59 7/8
Ground hulled oats						20
Ground oat hulls—					20	
Dried buttermilk—	21	24	31 1/2	21	29	18
Ground limestone—	1	1	1/2	1	5/8	1
Calcium phosphate-			1/4		1/8	1/8
Salt	1	1	1	1	1	1
Cod-liver oil	1	1	1	1	1	1
Total	101	101	101	101	101	101

Average live weight in grams

429.9	363.9	210.1	276.0	330.7	292.1

Coefficients of variability

11.5	15.8	32.7	23.5	20.6	17.5

Ingredient	Parts, by weight, of diet No.—				
	418	419	420	421	422
Ground whole oats			20	20	20
Ground yellow corn	42 1/2	52	49 1/4		
Ground barley					54 1/2
Ground wheat				57	
Ground hulled oats		20			
Ground oat hulls	20				
Dried buttermilk	36	26	29	21	23 1/2
Ground limestone	1/4	3/4	1/8	1	1
Calcium phosphate	1/4	1/4	5/8		
Salt	1	1	1	1	1
Cod-liver oil	1	1	1	1	1
Total	101	101	101	101	101

Average live weight in grams

288.5	295.0	278.7	326.6	425.9

Coefficients of Variability

22.5	20.8	24.4	17.3	14.0

6 weeks the variability of the group that received the diet containing oats was very low. It was followed in order by those that received barley, wheat, and corn. The variability of the chicks fed the diet that contained corn as the only grain was exceedingly high.

It was felt that three major problems concerning the effect of diet on variability remained to be investigated. They were the effect of the texture of the diet, the effect of relative attractiveness of the individual ingredients, or selection, and the effect of partial deficiencies of the several vitamins known to affect growth in chickens. Consequently, a series of 4 experiments was undertaken in an attack on these problems. In these experiments Barred Plymouth Rock chicks were obtained from a single hatchery flock. This flock was so small that an entire weeks' saving of eggs was required to produce enough chicks for each experiment. Thus, the genetic potentialities of the chicks on each of the four experiments probably was approximately equal. In all experiments the chicks were distributed by a modified random distribution system that results in approximately equal distribution of starting live weights and of the sexes in each lot. The chicks were brooded in electrically heated battery brooders in a steam heated battery room. With the exception of a lot of chicks in the fourth experiment that were fed by pipette, feed was kept before the chicks at all times. In all 4 experiments the chicks were weighed weekly between the hours of 5 and 7 P.M.

In the first experiment a study was made of the effect of diluting a basal diet with digestible and indigestible carbohydrates. The basal diet used in this experiment was one with which the author had had considerable previous experience and which supplied adequate quantities of

the vitamins according to the standards given by Titus (1939). In
color it was light brownish gray. The basal diet was composed of the
following ingredients:

Ground white corn	40 parts
Ground whole wheat	21
Soybean meal	10.8
Dried skim milk	10
Meat scrap	10
Dried whey	2
Ground oyster shell	3.0
Dried molasses	0.2
Dried brewers yeast	1.0
Manganized salt	1.0
Total	99.0

Straight cod-liver oil was fed at a level of 1 percent in all
diets.

The 10 lots of 25 chicks each were fed as follows:

Lot 1. Basal diet 99 percent, cod-liver oil 1 percent.

Lot 2. Basal diet 83 percent, cod-liver oil 1 percent, paper 16 percent

Lot 3. Basal diet 87 percent, cod-liver oil 1 percent, paper 12 percent

Lot 4. Basal diet 91 percent, cod-liver oil 1 percent, paper   8 percent

Lot 5. Basal diet 95 percent, cod-liver oil 1 percent, paper   4 percent

Lot 6. Basal diet 95 percent, cod-liver oil 1 percent, starch   4 percent

Lot 7. Basal diet 91 percent, cod-liver oil 1 percent, starch   8 percent

Lot 8. Basal diet 87 percent, cod-liver oil 1 percent, starch 12 percent

Lot 9. Basal diet 83 percent, cod-liver oil 1 percent, starch 16 percent

Lot 10. Basal diet 83 percent, cod-liver oil 1 percent, sucrose 16 percent

The paper was prepared by washing mimeograph paper, drying it and grinding it in a hammer mill to a consistancy resembling cotton linters. In order to convert this material into an edible diet it was necessary to mix it with the basal as a wet mash which was subsequently dried and reground before mixing the cod-liver oil with it. The starch was partially dextrinized by autoclaving, after which it was dried and ground. Remarkable differences in bulk were noted in the complete diets. The weight of 1000 cc. of each diet was recorded. These weights are tabulated in Table V. together with coefficients of variability at 2,4, and 6 weeks, the average live weights at 6 weeks, and the average efficiency of feed utilization to 6 weeks for each lot of chicks. Although the higher dilutions with both paper and starch decreased growth and appeared to delay the attainment of maximum variability they did not consistently increase variability.

The second experiment was conducted for the purpose of studying the effect of feeding a diet ground to different degrees of fineness and stained different colors, and to determine whether or not such treatments would prevent selection or stimulate feed consumption. The basal diet fed to Lots 15 through 20 was the same as that used in the previous experiment, and that fed to Lots 11 through 14 was identical except that yellow corn replaced white corn. As in the previous experiment 1 percent of straight cod-liver oil was mixed with each diet each week.

The 10 lots of 23 chicks each and an extra lot of 27 chicks in individual compartments were fed as follows:

Lot 11. The yellow corn diet made into chick size pellets. This was also fed to the chicks in individual compartments.

Table V. Coefficients of variability at 2, 4, and 6 weeks, average live weight, cumulative feed consumption and cumulative efficiency of feed utilization at 6 weeks for Barred Plymouth Rock chicks used in 4 experiments on variability.

Lot No.	Coefficients of Variability at 2 weeks	at 4 weeks	at 6 weeks	Average live weight at 6 weeks	Total feed consumption per chick to 6 weeks	Efficiency of feed utilization to 6 weeks	Weight of 1000 cc. of feed
				grams	grams		grams
1	11.7	17.8	19.7	353.5	709.1	.4459	605
2	9.2	18.4	23.8	290.1	775.6	.3256	348
3	10.7	18.9	22.6	296.1	736.4	.3513	370
4	11.9	21.8	24.2	325.4	917.7	.3140	408
5	26.3	23.9	20.7	385.7	912.1	.3823	525
6	23.3	12.3	13.6	367.1	849.8	.3988	605
7	17.2	27.5	28.5	319.2	725.9	.3883	610
8	11.8	14.3	15.5	297.0	649.6	.4012	620
9	10.8	22.2	24.9	253.4	571.2	.3797	625
10	18.3	25.6	24.3	310.3	763.0	.3583	625
11	16.7	26.0	25.0	349.9	938.0	.3303	
12	16.6	23.0	23.5	339.9	866.6	.3460	
13	20.5	22.4	22.3	358.8	795.2	.4009	
14	13.6	18.9	22.5	367.0	798.7	.4107	
15	13.1	22.1	20.6	392.3	861.7	.4100	
16	13.3	21.1	25.9	298.1	801.5	.3220	
17	16.9	25.7	30.9	230.7	478.1	.4031	
18	14.8	26.2	30.4	318.6	699.3	.4013	
19	12.4	23.1	27.4	304.0	701.4	.3792	
20	18.1	31.4	39.3	268.4	632.1	.3645	
11 b	12.5	14.0	20.7	252.7	682.7	.3138	
21	14.9	25.3	27.7	174.4	492.4	.2770	
22	21.6	26.7	20.2	373.9	915.9	.3667	
23	16.4	24.4	26.7	417.2	978.3	.3866	
24	18.8	23.4	25.9	343.3	775.0	.3939	
25	17.7	20.3	19.9	375.6	1027.4	.3276	
26	18.0	27.7	30.6	257.3	557.7	.3932	
27	12.0	15.4	18.1	88.5	237.1	.2130	
28	14.6	21.0	24.7	364.1	962.7	.3387	
29)	16.2	(21.0	19.8	385.0	871.3	.3983	
30)		(26.3	36.5	250.0	781.7	.2712	
31	15.4	17.8	19.3	371.2	899.6	.3719	
32	10.4	10.7	10.3	152.2	400.4	.2877	
33	18.4	21.0	20.2	439.0	966.7	.4148	
34	17.5	9.3	11.5	127.2	313.8	.2843	
35	17.9	30.3	34.1	349.3	902.6	.3449	
36	15.9	21.3	28.5	240.1	710.6	.2844	174
37	15.2	20.3	19.5	275.2	694.7	.3429	630
38	18.0	25.9	31.5	309.7	849.7	.3209	451
39	15.2	21.6	18.1	383.1	944.5	.3664	520
40	21.8	21.1	19.2	381.7	993.9	.3468	615

Lot 12. The yellow corn diet ground only fine enough to pass through
the 1/4 inch screen of a hammer mill.

Lot 13. The yellow corn diet ground fine enough to pass through the
1/8 inch screen of a hammer mill.

Lot 14. The yellow corn diet ground fine enough to pass through the
1/16 inch screen of a hammer mill.

Lot 15. The white corn diet 25 percent, the white corn diet stained
red 25 percent, the white corn diet stained blue 25 percent,
and the white corn diet stained orange 25 percent in a mixture.

Lot 16. The white corn diet.

Lot 17. The white corn diet stained green.

Lot 18. The white corn diet stained blue.

Lot 19. The white corn diet stained red.

Lot 20. The white corn diet stained orange.

The dyes used were water soluble coal tar colors from the Food and
Drug list approved for food, drug, and cosmetic uses (Federal Security
Agency (1940)). Information regarding identification and quantities of
the colors used is tabulated in Table VI.

Many of the results of this experiment were not anticipated and
invite speculation. The pertinent data are tabulated in Table V.
Variability increased with particle size even including pellets, which
form precluded the possibility of selection of ingredients taking place.
Growth rate increased as particle size decreased but was greatest in the
lot that received the multicolored diet. The chicks fed the green and
the orange diets ate sparingly of their feed and those fed the red and
blue diets ate more than the controls. However, all of the lots of chicks
fed the colored diets were highly variable. The lot of chicks in in-

Table VI. The colors, names, Color Index numbers, and quantities of the water soluble coal-tar colors used in the second experiment.

Color in feed	Food and Drug. designation	Former trade name	Color Index number	Quantity per kilo of feed
	F. D. & C. *			grams
Green	Green No. 3	Fast green	657	0.1
Blue	Blue No. 1	Brilliant Blue	855	0.2
Red	Red No. 2	Anaranth	184	0.2
Orange	Orange No. 1	Orange I	150	0.1

*Certified by the Federal Security Agency for use in foods, drugs, and cosmetics.

dividual compartments were noticably less variable than the comparable
lot fed the same diet.

The purpose of the third experiment was to study the effect of a
partial deficiency of each of several vitamins and manganese on the
variability in the growth of chickens. As the results of the second
experiment tended to indicate that the variability of chicks on a given
diet was at a minimum when the diet was finely ground, all of the diets
used in this experiment were ground to pass through the sixteenth inch
screen of a hammer mill. The basal diet used for Lots 22, 24, 25, 27,
28, 29, and 30 was the yellow corn basal that was fed to Lots 11
through 13. A fortified vitamin A and D feeding oil (400 A.O.A.C.
chick units of vitamin D and 3000 I.U. of vitamin A per gram) was used
in place of straight cod-liver oil in this experiment. It was fed a
level of 0.1 percent and mixed with the feed each week. The 10 lots
of 25 chicks each were fed as follows:

Lot 21. A diet low in riboflavin.

Ground yellow corn	42.0 parts
Ground whole wheat	21.0
Menhaden fish meal	10.0
Soybean meal	11.0
Feeding molasses	2.5
Ground oyster shell	2.5
Water extracted casein	10.0
Manganized salt	1.0
A and D feeding oil	0.1

Lot 22. The yellow corn basal diet with vitamin D at 10 A.O.A.C.
chick units per 100 grams of feed. Vitamin A was added in

the form of a supposedly D free vitamin A concentrate.

Lot 23. A diet calculated to have at least 4 times the required quantities of each of the vitamins involved in growth and of manganese.

Yellow corn basal diet	79.5 percent
Dried skim milk	5.0
Dried cereal grass	5.0
Fish meal	5.0
Bacterial-yeast fermentation residue	3.0
Dried yeast cells	1.0
Wheat germ oil	0.5
Vitamin B, 160 I.U. per 100 grams	
Manganese added to make 250 parts per million	
Vitamin A and D feeding oil	1.0

Lot 24. The yellow corn basal diet with its manganese content reduced to 10 parts per million.

Lot 25. The yellow corn basal diet 99.9, A and D oil 0.1

Lot 26. The white corn basal diet with vitamin A added to a level of 100 I.U. per 100 grams of feed and activated animal provitamin D used as a source of vitamin D. After 4 weeks on this diet the chicks showed symptoms of severe vitamin A deficiency and were changed to the same diet as fed Lot 25 for the two remaining weeks.

Lot 27. The organic ingredients of the yellow corn basal diet were heated for 6 days at 100° C to destroy their panothenic acid content. The inorganic ingredients and the vitamin A and D feeding oil were then added. 95 parts of this mixture and 5

parts of the same diet as fed Lot 25 were then mixed to form the final diet.

Lot 28. The yellow corn basal diet 99.9 percent and vitamin A and D feeding oil 0.1 percent.

Lots 29 and 30 were also fed the same diet as lot 28.

During the first three weeks of the experiment the chicks of lots 29 and 30 mingled as one lot of 50 chicks. At the end of the third week they were divided into two lots on the basis of previous rate of growth. All chicks that exceeded 118 grams were placed in Lot 29, and those that weighed less than 118 grams were placed in Lot 30. The chicks in Lot 25 were used as a source of material for the comparisons of glands and organs in fast and slow growing chicks as has been mentioned earlier in this paper.

The pertinent data of this experiment are tabulated in Table V. Partial deficiencies of riboflavin, manganese, and vitamin D increased variability. Panothenic acid deficiency decreased variability by two means, resulting mortality among the slower growing chicks and exceedingly slow rate of growth for all chicks. Of greater interest was the fact that variability was also high on the diet that contained an excess of all of these factors. The most important result of this experiment was the discovery that the fast growing chicks in Lot 29 were more than twice as efficient on a live weight basis in their utilization of feed as the slow growing chicks in Lot 30. Also of interest is the fact that the slow growing half of the population as represented by Lot 30, was nearly twice as variable as the fast growing half, as represented by Lot 29.

The fourth experiment was conducted for the purpose of verifying

some of the results of the previous experiments and investigating the

effect of forced feeding of equal quantities of feed to each chick in

a lot on variability of growth. As in the third experiment, the diets

were ground to pass through the 1/16 inch screen of a hammer mill and

vitamin A and D feeding oil was used instead of straight cod-liver oil.

The 10 lots of 25 chicks each were fed as follows:

Lot 31. The white corn basal diet colored red 10 percent, colored

blue 10 percent, colored orange 10 percent, and colored green

10 percent, and the yellow corn basal diet 60 percent fed as

a mixture with 0.1 percent of fortified vitamin A and D feed-

ing oil.

Lot 32. The yellow corn basal diet 99.9 percent and vitamin A and D

feeding oil 0.1 percent. The chicks in this lot were fed

individually a uniform dosage at each feeding. They were fed

twice daily at intervals of at least 10 hours. The dry feed

was mixed with 1.5 times its weight of water and the re-

sulting wet mash fed by pipette directly into the crop.

During the first 2 weeks of the experiment the size of the

dose was regulated by the limit of the crop capacity of the

smallest chick. When these chicks were 12 days old it was

noted that 5 of them were unable to empty their crops be-

tween feedings. It was found necessary to reduce the dosage

for 3 feedings until these chicks could empty their crops.

Thereafter, the daily dose was fixed at 10.91 grams of dry

feed for each chick each day.

Lot 33. The same diet as fed to Lot 22, the yellow corn basal diet

with 10 A.O.A.C. chick units of vitamin D per 100 grams of feed.

Lot 34. A diet similar to that fed to Lot 27, the yellow corn basal diet heated at 100° C for 6 days 90 percent, the yellow corn basal diet 9.9 percent, and vitamin A and D feeding oil 0.1 percent.

Lot 35. The yellow corn basal diet, with no additional source of vitamin A., and activated animal provitamin D to supply 40 A.O.A.C. chick units per 100 grams of feed.

Lot 36. The yellow corn basal diet 79.9 percent, ground paper (prepared in the same manner as described under the second experiment) 20 percent, and vitamin A and D feeding oil 0.1 percent.

Lot 37. The yellow corn basal diet 79.9 percent, dextrinized starch (brought to a boil in several volumes of water, dried, and ground) 20 percent, and vitamin A and D feeding oil 0.1 percent.

Lot 38. The yellow corn basal diet 79.9 percent, paper flour (prepared by pulverizing the ground paper in a ball mill) 20 percent, and vitamin A and D feeding oil 0.1 percent.

Lot 39. A diet known to have at least 4 times the optimum quantities of the vitamins known to affect growth and of manganese. It was composed of the following ingredients:

Ground yellow corn	40.0 parts
Ground whole wheat	9.0
Ground whole oats	10.0
Wheat Bran	8.0
Dried skim milk	10.0
Casein	8.0
Soybean meal	5.0

Dried cereal grass   5.0

Bacterial-yeast fermentation residue   2.0

Steamed bone meal   1.3

Salt (manganized 250 p.p.m.)   0.7

3000 A-400 D feeding oil   1.0

Thyamine hydrochloride 1.25 mg. per kilo.

Riboflavin 100 micrograms per kilo.

Lot 40. The yellow corn basal diet 99.9 percent and vitamin A and D

feeding oil 0.1 percent. This diet is the same as that fed

to Lots 25, 28, 29, and 30 in the preceeding experiment.

A summary of the more important data collected in this experiment
is tabulated in Table V. As in preceding experiments, a partial
deficiency of vitamin A greatly increased variability as did large
quantities of indigestible material, in this case, ground paper and
paper flour. The dextrinized starch had a more adverse affect on
growth than paper flour but did not affect variability. Variability
remained constant and low for the chicks fed individually and for the
chicks fed a diet low in panthenic acid. As in the previous experiment,
variability was not decreased by feeding a diet that far exceeded the
vitamin requirements for growth. It is of interest that the chicks
that were fed individually were about a fourth more variable 4 hours
after feeding than just prior to feeding in spite of the fact that each
chick had received an equal weight of feed. During the first two weeks
of feeding some of the fast growing individual were nearly twice as
efficient as the slowest growing chicks. Between the ages of 6 and 7
weeks not one chick in Lot 32 gained in live weight. These chicks were
weighed daily at the same hour and just prior to the night feeding.

Daily fluctuations in live weight were exceedingly small. Thus it was possible to calculate the feed required to maintain 100 grams of live weight for 24 hours for each chick. The live weights at 2 weeks and at 7 weeks, the efficiency of feed utilization to 2 weeks, and the feed required to maintain 100 grams of live weight for each chick that survived in Lot 32 are tabulated in Table VII.

As live weight was found to have a direct relationship to the quantity of feed that could be ingested at any one feeding, it seemed desirable to find the coefficients of correlation for live weights at intervals of one week. Five lots of chicks, totaling 130 individuals, that had been fed the yellow corn basal diet were used in this study. Coefficients of correlation, between the live weights at each age and all other ages from 1 day to 6 weeks, were determined, and, with corresponding coefficients of determination, are tabulated in Table VIII. The coefficients were found to be significant between all ages except day old and 6 weeks. At each age live weight was found to be more closely correlated with the following live weight than with the preceding live weight. In general, correlation decreased as time between points correlated increased.

The actual live weight of three chicks that were typical of the most rapidly growing, the average, and the slowest growing in a normal lot of chicks grown in confinement in a battery brooder are plotted on their calculated efficiency of feed utilization lines in Figure 2. This material shows that, although relatively the difference in efficiency between the chicks is always the same at any given live weight, absolutely it becomes less at each increase in live weight. Furthermore, it shows that, as the spread in live weight between

Table VII.   Individual live weights at ages of 2 and 7 weeks, efficiency
of feed utilization to 2 weeks and the feed required to maintain 100
grams of live weight 24 hours for each chick that survived in Lot 32.

| Chick No. | Average live weight | | Efficiency of feed utilization to 2 weeks | Feed required 100 grams of live weight for 24 hours |
	At 2 weeks	At 7 weeks		
	Grams	Grams		Grams
1	96	180	.4740	6.06
2	71	118	.2528	9.25
3	93	161	.4003	6.78
5	91	145	.4739	7.52
6	88	147	.3687	7.42
8	84	150	.3476	7.27
9	96	156	.4319	6.99
11	93	173	.3897	6.31
12	91	139	.4424	7.85
13	90	153	.4950	7.13
14	75	131	.3371	8.33
18	80	152	.4213	7.18
20	90	148	.4213	7.37
21	94	174	.4424	6.27
22	82	143	.3792	7.63
24	86	146	.4108	7.47
26	90	152	.3897	7.18
27	96	172	.4635	6.34
Average	88.1	152.2	.4079	7.17

Table VIII. Coefficients of correlation between live weights of 130 Barred Plymouth Rock chicks at 1 day, 1, 2, 3, 4, 5 and 6 weeks of age and the corresponding coefficients of determination.

| Ages at which live weights were correlated	:	Coefficients of Correlation	:	Coefficients of determination
1 day and 1 week	:	.3166**	:	.100
1 day and 2 weeks	:	.3175**	:	.101
1 day and 3 weeks	:	.4791**	:	.230
1 day and 4 weeks	:	.2403**	:	.058
1 day and 5 weeks	:	.2175*	:	.047
1 day and 6 weeks	:	.1679-	:	.028
1 week and 2 weeks	:	.7747**	:	.600
1 week and 3 weeks	:	.3096**	:	.096
1 week and 4 weeks	:	.3650**	:	.133
1 week and 5 weeks	:	.5088**	:	.259
1 week and 6 weeks	:	.4713**	:	.222
2 and 3 weeks	:	.9176**	:	.842
2 and 4 weeks	:	.8254**	:	.681
2 and 5 weeks	:	.9218**	:	.850
2 and 6 weeks	:	.7051**	:	.497
3 and 4 weeks	:	.9496**	:	.902
3 and 5 weeks	:	.6510**	:	.424
3 and 6 weeks	:	.8088**	:	.654
4 and 5 weeks	:	.9487**	:	.900
4 and 6 weeks	:	.9573**	:	.916
5 and 6 weeks	:	.9645**	:	.930

  - Indicates odds less than 20 to 1.
  * Indicates odds exceed 20 to 1.
 ** Indicates odds exceed 100 to 1.

Figure 2.

Decrease in the difference in efficiency of feed utilization
between efficient and inefficient chicks
due to change in live weight
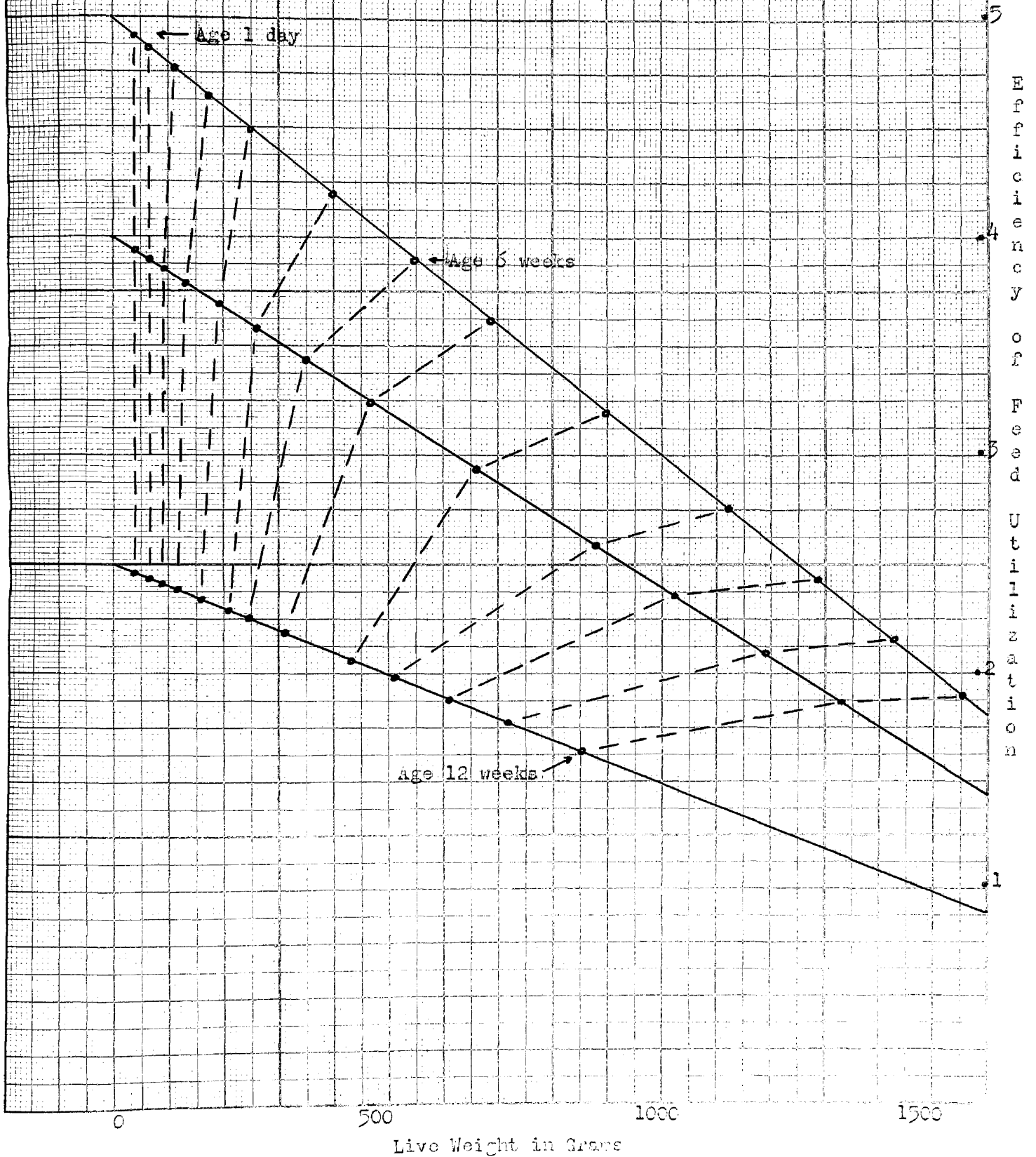
efficient and inefficient chicks increases, the difference in absolute
efficiency between them greatly decreases to the point where it is
practically nonexistent.

DISCUSSION.

Although the thymus and bursa Fabricius of rapidly growing chicks were found to be approximately 5 times as large in proportion as those of their slow growing pen mates it seems highly probable that this disproportion is a result rather than a cause of rate of growth. In support of this contention are the results of Riddle and Krizenecky (1931) who removed both the thymus and bursa from pigeons without delaying maturity and the writer's results following removal of the thymus from day old chicks. Then, if it is assumed that the precocious growth secured in successive generations of inbred mice by Rowntree and associates (1935) was due to thymus feeding rather than selective breeding, Mitchell (1938) appears to have suggested the correct interpretation of thymus function. He suggested that the thymus acted as a storage depot for special nutrients not immediately needed but which might be needed later.

Mitchell, Card, and Hamilton (1931) found that the relative weight of the digestive tract decreased as the chicks increased in size. This observation explains, in part, the fact that the proventriculuses, and the digestive tracts in general, of the slowly growing chicks were disproportionately large. Only a small part of the disproportion can be accounted for in this manner and no adequate explanation is available for the remainder. However, as slowly growing chicks, generally, were found to use their feed inefficiently, it seems probable that a compensation mechanism is involved.

This study has emphasized the fact that there is a basic pattern in the variability of the growth of chickens which cannot be altered except by treatments which prevent the most rapid development that is

genetically possible for each individual in the lot. As measured by the coefficient of variability under ideal conditions, variability increases rapidly from the first day to the fourth week, decreases less rapidly to the eighth week and slowly from then to the fourteenth week after which it remains practically constant. This fundamental variability appears to be the result of 3 primary factors (a) the efficiency of feed utilization, (b) adult body weight, and (c) appetite. The increase in variability during the first 4 weeks can be explained almost entirely on the basis of differences in efficiency of feed utilization. It is easy to calculate that if a chick gets only half as much good out of a given unit of feed as another chick it will be smaller than the second chick after digesting the feed. With each succeeding unit of feed eaten the second chick will become proportionately larger which in turn will enable it to ingest more units of feed per day than the inefficient chick. Thus the spread in live weight between an inefficient and an efficient chick increases with increasing rapidity. Here appetite enters the problem. The inefficient chick has approximately the same energy requirement per gram of live weight as the efficient chick. However, the inefficient chick, simply because it is less efficient, must eat more feed to supply the energy required per gram as was shown in Table VII. The demands of its energy requirement apparently stimulate the less efficient chick to utilize its digestive tract more nearly to capacity as illustrated by the higher feed consumption per unit of body weight by the inefficient chicks in Lot 30 as compared with the efficient chicks in Lot 29. As it was pointed out before in connection with Figure 2, because of the spread in live weight between efficient and inefficient chicks, the absolute efficiency

of efficient chicks rapidly approaches that of inefficient chicks after the sixth week. Thus the inefficient chick, now eating relatively more feed per unit weight with practically the same efficiency at this later age is able to prevent difference in live weight from becoming greater. It follows that, with a fixed difference in live weight and an increasing size of mean live weight, the coefficients of variability have to decrease in size. If all chicks reached the same adult weight, the final coefficient of variability would be zero, of necessity. However, this is not the case and differences in adult live weight begin to influence the coefficients of variability about the sixteenth week and after the thirty-second week account for all of the variability under ideal conditions.

Unfortunately, ideal conditions cannot exist when it is possible to demonstrate differences in growth response due to diets. Therefore, whenever differences in growth due to diet are found, it is safe to assume that the basic pattern in variability of growth has been altered to some extent. These alterations usually account for far less variability than the basic pattern unless the treatment is quite drastic. Drastic treatments encountered in this study, that greatly altered the basic pattern, were severe vitamin D and vitamin A deficiencies, which greatly increased and prolonged high variability, individual rationing, and panothemic acid deficiency, which prevented the development of the maximum variability of the basic pattern. The individual rationing reduced variability by eliminating response to appetite and regulating the daily intake regardless of capacity.

It is of interest that all treatments that would render the diet

of itself less digestible or place the nutrients of the diet in extreme imbalance increased variability. This adds support to the argument that differences in the efficiency of feed utilization are the greatest source of variability in growth. When a diet is comparatively less digestible, the inefficient chick is at a greater disadvantage than the efficient chick because it must ingest proportionately more feed in order to utilize equal quantities of nutrients. There is a marked general tendency, as seen in Table V, for any diet that is used efficiently to produce low variability. Treatments which greatly de-layed growth did not follow this rule. The diets that were colored were outstanding contradictions of this theory. It may be that their uniform color had an adverse effect on appetite, for the diet fed Lot 15 which was a mixture of these same colors was used with equal efficiency but supported excellent growth with normal variability.

It was rather disappointing that the diets containing large quantities of vitamins did not decrease variability. This is es-pecially true in view of the fact that sunlight alone or, more effectively, sunlight and grass range hastened the decrease in variability. It seems evident from this study that, judged by variability, sunlight supplies something, other than activity to vitamin D precursers that is needed by chickens, to make conditions ideal.

The correlation studies yielded coefficients of correlation that were in close agreement with those found by other workers. The fact that significant correlations were found between day old weight and later weights in this study but not in previous investigations was due entirely to the numbers of individuals involved. In spite of the fact

that the correlation between day old and 1 week live weights is highly significant, the coefficient of determination shows that the correlation accounts for less than 10 percent of the variability involved at 1 week. On the other hand, the 1 week live weights account for over half of the variability at 2 weeks and the live weights at 5 weeks account for 93 percent of the variability at 6 weeks. It should be kept in mind that these coefficients of correlation were determined only for chicks on a normal diet that followed the basic pattern of variability in live weights. Coefficients of correlation between live weights of chicks fed diets that caused high variability would of necessity be lower.

The distribution of variability in chick live weights should be considered when chick nutrition investigations are planned. There is little point in starting an experiment where 10 percent differences between means are expected if only enough chicks are used to show significance when the differences between means are 20 percent. Careful consideration should also be given to the age of chicks that will be used for comparison. Under usual conditions it takes twice as many chicks at 6 weeks of age to demonstrate the significance of a 20 percent difference between means as it does at 14 weeks of age or older. After 4 weeks of age more chicks are required to demonstrate significance if the males and females are considered together than if they are considered separately.

It should be of some comfort to the broiler producer to know that if he has fed a well balanced diet the variability of his flock is less when he sells them than at any time since the first week after hatching.

Few new suggestions to the industry will result from this study but important and frequently unheeded suggestions will be reemphasized. A well balanced diet is necessary for minimum variability. Partial vitamin A deficiency, so mild that no external symptoms can be detected, greatly increases variability. Over-crowding increases variability. Feeds of low digestibility increase variability. Chicks that grow much more slowly than the average should be culled when they are young rather than at selling time. It would seem that it should be possible to eliminate considerable variability by a breeding program in which both the rate of growth and efficiency of feed utilization of progenies were considered. While the studies of inheritance of rate of growth indicate that such a project would be difficult and complex, a successful culmination would be of great value to both the poultryman and the research worker.

SUMMARY AND CONCLUSIONS.

A series of experiments were conducted in a study of variability in growth of the chick. The endocrine glands and sections of digestive tract of newly hatched chicks were weighed. Those of chicks from matings producing efficient progenies were not found to be different from those of chicks from matings producing relatively inefficient progenies. Great individual variation in thymus size was noted. Endocrine glands and sections of digestive tract from several pairs of chicks, one of which grew rapidly and the other slowly, were compared on the basis of percent body weight. The thymus glands and bursas of Fabricius of rapidly growing chicks were found to be several times as large in proportion to body weight as those of slowly growing chicks. Removal of the thymus glands of day old chicks did not hinder their rate of growth or development of normal variability. Support is given to the theory that the thymus is not an endocrine gland. It was observed that the proventriculuses and in general the entire digestive tract of rapidly growing chicks were smaller in proportion than those of slowly growing chicks.

The second part of this series of experiments was devoted to a study of the effect of diet on variability in the growth of chickens. It had been reported that variability in chicks was not affected by early handicaps and that variability increased during the first six weeks of age and decreased thereafter. An analysis of data compiled at the Beltsville Research Center, which had been summarized in publications cited, revealed that there was a basic pattern in the variability of growth of chickens. Under ideal conditions variability

increased rapidly from hatching to 4 weeks of age after which it decreased at the same rate to 10 weeks of age then more slowly until it reached a low constant value at maturity. When chicks were deprived of an excellent diet, maximum variability did not occur until the sixth or seventh week.

Several lots of chicks were fed the same diet under different systems of management. Variation was least when chicks had access to both direct sunlight and grass range. The period of high variability was slightly prolonged when chicks had access to direct sunlight but not to grass range. The period of high variability was both delayed and prolonged when vitamin D was supplied but both direct sunlight and grass range were denied. Under the latter conditions when vitamin D was not supplied variability increased greatly and continuously.

Variability was both delayed and increased at extremely low levels of either feed or protein intake. Variability was markedly affected by different cereal grains in simple diets. At 6 weeks the variability of chicks fed a diet containing oats was very low. It was followed in order by those fed diets containing barley, wheat, corn. The variability of the chicks fed the diet containing corn alone was exceedingly high.

Three other problems concerning the effect of diet on variability were investigated. They were the effect of selection of feed ingredient by chicks, the effect of texture of diet, and the effect partial deficiencies of several vitamins known to affect growth in chickens. Four experiments were conducted in which 41 lots of chicks totaling 1010 individuals were used. When the same diet was fed but ground to different degrees of fineness variability increased with particle size.

Chicks fed pellets or diets dyed to uniform color, both of which treatments prevented selection, were highly variable. Partial deficiency of vitamin A greatly increased variability. Partial deficiencies of riboflavin and manganese also increased variability but an excess of vitamins and manganese failed to decrease variability.

Rapidly growing chicks were found to eat less feed per unit of live weight per day and to use their feed far more efficiently than slowly growing chicks. It was found to be quite possible to explain the basic variability pattern in terms of efficiency of feed utiliza - tion, appetite due to energy requirement, and inherited adult body size. One gram of feed maintained from 11 to 16 grams of chick for 1 day. The average was approximately 14 grams. Thus, chicks were less variable in their utilization of feed for maintenance than in their utilization of feed for growth.

Correlation studies were made of the live weights of 130 chicks at ages of 1 day, 1, 2, 3, 4, 5 and 6 weeks. Significant correlations were found between the live weights at all ages except between 1 day and 6 weeks. Correlation between live weights increased at each successive age. At any age live weight was more closely correlated with the following live weights than with the preceeding live weight. In general, correlation increased with proximity of ages correlated.

It is concluded that:

The basic pattern of variability in growth of chickens is due to the results of efficiency of feed utilization, appetite, and adult body size; the variability may be increased and prolonged by any defect in diet which prevents normal development, and variability may be decreased by individual rationing of feed or partial starvation.

The probable effect of diet upon variability should be considered before an experiment is begun so that sufficient numbers of individuals will be used to allow expected differences to be significant.

Correlation between live weight at different ages increases with age and with proximity between ages.

Size of thymus and bursa Fabricius is a result rather than a cause of rapid growth.

LITERATURE CITED

Ackert, J. E., 1924. Effect of parasitism on fowl thymi. Anat.
Rec. 29 (2):120.

Asmundson, V. S. and I. M. Lerner, 1933. Inheritance of rate of growth
in domestic fowl. II Genetic variation in growth of Leghorns.
Poul. Sci. 12(4):250-255

Barrie, M. M. O., 1937. The relation of vitamin E to the anterior
lobe of the pituitary gland. 233:251-254

Copping, A. M. and V. Korenchevsky, 1940. The effect of vitamin E
deficient diet on the weights of organs of male and female rats.
Vitamin E. Chemical Rubber Pub. Co. New York City:44-46.

Dam, H., J. Glavind, O. Bernth, and E. Hagens, 1938. Anti - en-
cephalomalacia activity of dl-alpha-tocopherol. Nature 142:
1157-58.

Drummond, J. C., 1940. Physiological action of vitamin E. Vitamin
E. Chem. Pub. Co. New York City:41-43.

Federal Security Agency, 1940. Coal - tar color regulations. Service
and Regulatory Announcements. F.D.C. 3:1-53.

Funk, E. M., H. C. Knandal, E. W. Calenbach, 1930 Statictical studies
of the variations in the growth of single comb White Leghorns
and their significance. Poul. Sci. 9:157-163.

Hale, R. W., 1931. Experimental errors in chicken-rearing experiments.
Jour. Agr. Sci. 21:716-725.

Hammond, J. C., 1934. The effect of diet on the growth, fattening,
and egg production of poultry. U. S. Egg and Poul. Mag.
40(11):17-and 40,(12):30(23 pages)

Hammond, J. C., W. A. Hendricks, and H. W. Titus, 1938. Effect of
percentage of protein in the diet on growth and feed utilization
of male chickens. Jour. Agr. Res. 56:791-810

Hays, F. A. and R. Sanborn, 1929. Rate of growth in Rhode Island Reds.
Mass. Agr. Expt. Sta. Bull. 259:303-321.

Hess, C. W., T. C. Byerly, and M. A. Jull, 1941. The efficiency of
feed utilization by Barred Plymouth Rock and cross-bred broilers.
Poul. Sci. 20:210-216.

Jull, M. A., 1923. Differential sex growth curves in Barred Plymouth
Rock chicks. Sci. Agr. 4:58-65.

Jull, M. A., 1932. Poultry Breeding. John Wiley & Sons, Inc.,
New York. pp 376.

Jull, M. A., and J. P. Quinn, 1924. Shape and weight of eggs in re-
lation to sex of chicks. Jour. Agr. Res. 29:195-201.

Jull, M. A., and J. P. Quinn, 1931. The inheritance of body weight
in the domestic fowl. Jour. Hered. 22:283-288.

Jull, M. A., and H. W. Titus, 1928. Growth of chickens in relation
to feed consumption. Jour. Agr. Res. 36:541-550.

Keller, C., 1933. Comparative cells and nuclear measurement of large
and small breeds of chickens through the test of genetic re-
stricted growth differences. Zeitschrift für Zellforschung und
mikroskopische Anatomie 19:510-536.

Latimer, H. B., 1924. The variability in weight of Leghorn chickens
at hatching, thirty-five days, and maturity. Am. Naturalist
58:278-82.

Mitchell, P. H., 1938. General Physiology, McGraw - Hill Book Co.
Inc., New York. p.p. 851.

Mitchell, H. H., L. E. Card, and T. S. Hamilton, 1931. A technical
study of the growth of white Leghorn chickens. Univ. of Ill.
Agr. Expt. Sta. Bull. 367:83-139.

Nelson, W. O., 1933. Studies on the anterior hypophysis III. The
anterior hypophysis in vitamin E-deficient rats. Anat. Rec.
56:241-253.

Parker, S. L., 1929. Effects of early handicaps on chickens as
measured by yolk absorption and body weight to twenty weeks
of age. Hilgardia 4(1):1-56.

Phillips, P. H. and R. W. Engel, 1938. The histopathology of
neuromalacia and 'curled toe' paralysis in the chick fed
low riboflavin diets. Jour. Nutr. 16:451-463.

Plagge, J. C., 1941. The thymus gland in relation to sex hormones and
reproductive processes in the albino rat. J. Morph. 68:519-545.

Riddle, O. and J. Krizenecky, 1931. Studies on the physiology of
reproduction in birds XXVIII. Extripation of thymus and
bursa in pigeons with a consideration of the failure of
thymectomy to reveal thymus function. Amer. Jour. Physiol.
97:343-352.

Rowlands, I. W. and E. Singer, 1936. Gonadotropic activity of the
pituitaries of vitamin E deficient rats. Jour. Physiol.
86:323-326.

Rowntree, L. G., J. H. Clark, A. Steinberg, A. M. Hanson, N. H.
Einhorn, and W. A. Shannon, 1935. Further studies on thymus
and pineal glands. Ann. Int. Med. 9:359-375.

Schneider, M. and L. C. Dunn, 1924. On the length and variability of
the bones of the white Leghorn fowl. Anat. Rec. 27:229-39.

Schnetzler, E. E., 1936. Inheritance of rate of growth in Barred
Plymouth Rocks. Poul. Sci. 15:369-76.

Schroeder, C. H. and H. B. Lawrence, 1932. The number of chicks re-
quired to demonstrate the significance of growth differences.
Poul. Sci. 11:208-218.

Smith, C. and L. M. Ireland, 1941. Studies on the thymus in the
mammal I. The distribution of argyrophil fibers from birth
through old age in the thymus of the mouse. Anat. Rec.
79:133-153.

Souba, A. G., 1923. Variation and correlations of the organs of
single comb white Leghorn cockerels. Anat. Rec. 26:291-297.

Titus, H. W., 1939. Practical nutritive requirements of poultry.
Yearbook of Agriculture, 1939, U. S. Dept. of Agr., Wash. D. C.
:787-818.

Titus, H. W., W. A. Hendricks, and M. A. Jull, 1934. Growth of
chickens as a function of feed consumption. Jour. Agr. Res.
48:817-835.

Titus, H. W., and M. A. Jull, 1928. 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.

Upp, C. W., 1928. Egg weight, day old chick weight and rate of
growth in single comb Rhode Island Red chicks. Poul. Sci.
7:151-155.

Verzár, F. and E. v. Kokas, 1931. Die Wirkung des Mangels an
E-Vitamin auf das Haarkleid der Ratten. (Inkretion und
Avitaminose) XIII. Pfluger's Arch. Ges. Physiol. 227:511-516.

Vogt-Möller, P., 1940. The therapeutic employment of vitamin E in
human and veterinary clinical medicine. Vitamin E. Chem.
Rubber Pub. Co. New York:57-66.