

GENETICAL AND ENVIRONMENTAL RELATIONSHIPS
BETWEEN GROWTH AND EGG PRODUCTION IN THE LEGHORN FOWL

by

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INTRODUCTION

Low egg production in meat strains of chickens is a major problem to the broiler industry. Chick cost becomes a larger share of the total cost of producing broilers as feed efficiency improves, turnover becomes faster, and margins become narrower.

The high price of eggs from these strains possibly contributes to instability in the broiler market. Hatching eggs from meat strains cannot be sold as market eggs except at great loss. Consequently they are frequently hatched regardless of the demand for chicks. If these eggs could be more economically produced, not only would the cost of producing broilers be reduced, but cycles of over and under production would tend to disappear.

A popular approach to the problem is the use of single or multiple strain crosses to produce broiler chicks (5, pp.4-10). The male side of the cross is often selected for maximum growth rate and conformation, while the female side is selected with emphasis on egg production.

While this is a partial solution to the problem, hens that will produce chicks of satisfactory growth rate do not approach the egg laying ability of the production bred strains. Possibly the egg production of a strain now used in these crosses could be improved while maintaining or continuing to improve its broiler qualities.

Possibly the broiler qualities of an egg production strain could be improved while maintaining or continuing to improve its egg laying ability.

In the past, surplus cockerels from egg laying strains were a major source of broilers. However, growth rate, and the resulting feed efficiency, have been so improved in the meat strains that it is now uneconomical to produce Leghorn or Rhode Island Red broilers. Consequently the price of the pullets must cover all of the costs of producing chicks, plus the sexing costs.

If growth rate of laying strains could be improved, the sale of cockerels would allow pullets to be priced lower. The broiler weight of an egg laying strain would not need to equal that of the meat strains. The fifteen to twenty-five percent heavier weights of males (11, pp.240, 246) would make a brood of all cockerels comparable with a brood of mixed sexes, even though the latter were of heavier average weight. Since cockerels from egg laying strains are a by-product, their price can be set at whatever level is necessary to make them competitive with meat strains.

As physiological limits are approached in growth rate and feed efficiency, progress becomes more difficult. In the future, breeders of meat strains must certainly give attention to egg production.

The better egg laying strains have already been developed to a level where further progress in egg production is slow (6, p.1105). If growth rate can be improved without seriously interfering with economical egg production, breeders of egg laying strains might well

consider growth rate in their program.

The concern of breeders over the poor egg production in meat strains, has led to investigation of the inter-relationships between meat and egg production characteristics. Little is known, however, of these inter-relationships in the egg laying strains.

Lerner has discussed the possibility that continued selection for two traits results in negative genetic correlations between them (14, p.239). These inter-relationships, then, would not necessarily be the same in strains bred for egg production as in those bred for meat production.

The present study has been undertaken to determine the possible effects that breeding for improved rate of growth would have on egg production and other characteristics in a strain of White Leghorns.

CONDUCT OF EXPERIMENT

Data for this work is from the records for 574 Single Comb White Leghorn pullets originating from 8 sires and 97 dams. These birds were hatched in the spring of 1954, at the Oregon Agricultural Experiment Station, Corvallis, Oregon. The strain was produced in 1946 from a cross between two Oregon commercial strains. Since 1948 the production line has been selected on the basis of family hen housed records to February first and maintained with eight breeding pens. Since the mating of sibs and half-sibs has been avoided, it is assumed that no important amount of inbreeding has occurred by this time.

The pullets used in this study were from three hatches with hatching dates at seven day intervals starting on April 22. They were brooded under electric hovers on litter in unheated rooms. The first two hatches were allowed 2.2 square feet per bird, including space on a concrete porch opened at six weeks. The third hatch was allowed 0.55 square feet per bird and was not given access to an outside porch. All birds were fed commercial broiler mash until ten weeks old.

The chicks were immunized for coccidiosis at one week of age. The first two hatches each experienced a mild attack of bronchitis at three weeks, but the third hatch was immunized against bronchitis and no symptoms were observed. No other outbreak of disease occurred. The birds were weighed at ten weeks to the nearest gram. After being

weighed, they were divided at random with 50 percent put on an irrigated grass range, 30 percent put on a non-irrigated grass range, and 20 percent confined on litter with four square feet of floor space per pullet. From ten weeks through the rest of the rearing period, all birds received free choice a 15 percent protein breeder mash. About two percent of mixed grain was hand fed.

The pullets were housed over a period of five days starting on October 4 when they were from 22 to 24 weeks of age. Weighing at housing was to the nearest tenth of a pound.

Birds were trapnested two days each week. Pullets that started laying before they were housed, were trapped on the range. After production was fifty percent, artificial light was used to stimulate late maturing birds. Egg records used in this work were converted to a seven day basis and are from the birds' first eggs until January 31, 1955.

Eggs were weighed three consecutive days in December.

REVIEW OF LITERATURE

To determine the best breeding program, the breeder must know the following information about each characteristic under consideration: (1) the genetic variance, (2) the heritability, (3) the genetic and environmental correlations between each of the characteristics, and (4) their relative economic values (7, p.487).

Genetic variance is the variance due to the average effects of genes (19, p.85).

Heritability is the percentage of the total variance that is genetic (19, p.85). Heritability determines how accurately it is possible to recognize the genetic merit of an individual. If a breeder is working with traits of low heritability, he will necessarily make many errors in selecting the best breeding stock, and progress will be slow.

Genetic correlations indicate the change that may be expected in one trait when selection is practiced on another. For example, selection to improve weight at broiler age may change adult weight, age at first egg, and total egg production. Pleiotropy, or multiple effects of genes, is probably a major cause of genetic correlations (2, pp.33-35). Most genes affecting production quite likely do have pleiotropic effects. A gene affecting the thyroid gland or the digestive system, for example, would probably affect many production characteristics. Linkage, if close, could cause genetic correlation.

Environmental correlations are the result of certain conditions

of the birds' environment affecting two or more characteristics. For example, a chronic disease condition could reduce growth rate and also egg production. If an environmental condition affects one trait favorably and another unfavorably, then discriminating against a bird for her record in the first trait would tend to be compensated for by favoring her for her record in the second. However, if environmental conditions affect both characteristics in the same direction, a bird will be either doubly favored or doubly discriminated against. Environmental correlations of the first type, then, are a help to good selection, while those of the second are a hindrance.

Knowledge of genetic and environmental correlations is of great value to the breeder. Phenotypic correlations have little meaning, however, being a mixture of genetic and environmental correlations in unknown proportions.

To give the proper weighting to each characteristic in a breeding program, one must determine the relative economic importance of each characteristic. A breeder must, for example, estimate the value of an extra ounce of weight at broiler age as compared to the value of an extra egg.

This paper is concerned with the genetic variance, the heritability, and the genetic and environmental correlations between body weight at ten weeks and the following factors affecting economical egg production: (1) body weight at housing, (2) egg production for the first three months of lay, (3) age at first egg and (4) egg weight.

It has been well established that weight at a given age in chickens is largely inherited. A sample of some of the later work on the inheritance of body weight is shown in Table 1. Heritability estimates made at broiler age cluster near 0.45 and those made at housing age average between 0.35 and 0.40. The low figure obtained by dividing the sires' component of variance by the dams' component indicates that maternal effects or sire-dam interaction may seriously bias these estimates upward. Dillard's flock shows evidence of sex linkage.

Lerner (14, pp.12-32) has included in his book an extensive review of the earlier work on the inheritance of egg production. King and Henderson (12, p.160) have summarized the findings of many workers on the heritability of egg production. Most research shows the total first year production of survivors to be about 0.20 heritable, and production on a hen housed basis to be about 0.05 heritable.

Egg production can be broken down into many periods, but breeders are becoming more concerned with production for the first three months of lay. While greater accuracy of measurement can be gained from the use of more complete records, the breeding of pullets allows the breeder only three months of lay on which to base his selections. Lerner and Cruden, working with several lines of White Leghorns, reported the gain in total egg production to be two-thirds as great each generation if selection was based on partial egg production records as compared to complete records (19, p.73). The

Table 1
Inheritance of Body Weight

Investigator	Variety	Age in weeks	h^2 (S + D)	$\frac{\sigma_S^2}{\sigma_D^2}$	Mean	Standard deviation	Reference
Krueger	4 varieties	10	0.46	0.45	845 gms.	98.0 gms.	13, pp.86, 92
Dillard	NH	8-12	0.32	1.61	1260 "	121.2 "	3, pp. 22, 48, 53
Lerner et al	NH	12	0.51	0.70	1353 "	202.6 "	16, pp.516-518
Peeler	RIR	10	0.38	0.63			23, p.23
Martin	RIR	9	0.27			143.0 "	21, p.32
Garber and Godbey	SCWL	12	0.63	0.20			4, p.950
Krueger	NH	22	0.45	0.73	3.9 lbs.	0.43 lbs.	13, pp.86, 92
Hazel and Lamoreux	SCWL	22	0.34	0.87		0.43 "	9, pp.511-512
Wyatt	9 varieties	23½	0.31		3.7 "	0.55 "	25, pp.1269, 1221

Table 2

Inheritance of Early Egg Production

Investigator	Variety	h^2 (S + D)	$\frac{\sigma_S^2}{\sigma_D^2}$	Mean (eggs)	Standard deviation	Reference
Lerner and Cruden	SCWL	0.30	0.72	71.9	21.9	17, pp.69-73
Dillard	NH	0.12	1.04	42.8	18.4	3, pp.22, 48, 53
King and Henderson	SCWL	0.31	0.48	73.0	20.8	12, pp.159-162

Table 3

Inheritance of Age at First Egg

Investigator	Variety	h^2 (S + D)	$\frac{\sigma_S^2}{\sigma_D^2}$	Mean (weeks)	Standard deviation	Reference
Krueger	4 varieties	0.20	2.24	24.5	3.75	13, pp.86, 92
Dillard	NH	0.16	1.05	22.9	3.12	3, pp.22, 48, 53
Hazel and Lamoreux	NH	0.27	1.00		3.15	9, pp.511, 512
Peeler	RIR	0.39	0.38			23, p.23
King and Henderson	SCWL	0.46	0.70	28.2		12, pp.159-160
Lerner	SCWL			23.8	2.67	15, p.205

Table 4
Inheritance of Egg Weight

Investigator	Variety	h^2 (S+D)	$\frac{\sigma_s^2}{\sigma_D^2}$	Mean (oz./doz.)	Standard Deviation	Reference
Lerner and Cruden	SCWL	0.36	2.00	20.6		18, p.37
Osborne	SCBL		2.99			22, p.61
King and Henderson	SCWL	0.33	0.94	21.6		12, p.159
Wyatt	9 varieties	0.52	1.26	23.8	1.13	25, pp.1269, 1270

time between generations is a minimum of two years when only hens with complete records are bred, but this can be reduced to one year by breeding pullets. From this information then, the expected genetic gain in any unit of time is 50 percent greater if pullets with partial records are used for breeders than if only yearling hens with complete records are used. Data that the above authors took from a line bred only for egg production, favored pullet breeders even more.

King and Henderson found by analyzing the records of a large commercial breeding farm that the offspring of pullets consistently produced better than the offspring of older hens (12, p.158).

Table 2 summarizes work done on early egg production.

The age at which pullets begin to lay is of importance to commercial poultrymen and to breeders. Table 3 shows studies on age at first egg. Of the five reports, three show evidence of sex-linkage. It is quite possible for sex-linked variance to be present in some flocks and not in others. In small flocks, or where selection pressure has been against a sex-linked character, sex-linked variance could be easily eliminated. If much sex-linked variance is present, maternal effects and sire-dam interaction are hidden.

Egg size is of particular importance to producers of hatching eggs. Buyers prefer large chicks, which are produced by large eggs. Table 4 shows that this character has an average heritability of about 0.40, but seems to be largely sex-linked.

Phenotypic correlations between these traits are easily found

in the literature, but only recently have techniques been available to compute genetic and environmental correlations. Consequently little work has been done to separate correlations into genetic and environmental components.

Krueger calculated the phenotypic correlation between 10-week weight and housing weight to be 0.65. Basing his figures on both sire and dam variance, he calculated the genetic and the environmental correlations to be 0.85 and 0.51 respectively (13, pp.109-110). Wyatt calculated the genetic correlation between housing weight and 8-week weight to be 1.09 (25, p.1270). While this is an impossible estimate, it is evidence that the genetic correlation between housing weight and broiler weight is high and positive. There seems to be a strong tendency for heavier broilers to also be heavier at housing time, with genetic factors having an especially strong influence.

Krueger compared weight at ten weeks with age at first egg and reported -0.15, -0.39, and -0.05 respectively for phenotypic, genetic and environmental correlations (13, pp.109-110), while Peeler found -0.18, -0.01, and -0.28 (23, p.24). Dillard reported -0.18, -0.07 and -0.21 for the respective correlations between weight at eight or twelve weeks and age at first egg (3, pp.69, 74). When Peeler based his estimate on the dams' component of variance and covariance he found -0.14 and -0.21 respectively for genetic and environmental correlations. Based on the sires' component, he found 0.26 and -0.32 (23, p.24). Except for Peeler's positive genetic estimate based on sires, all of the above evidence shows that heavier broiler

weights are associated with earlier age at first egg, and that this is a result of both genetic and environmental causes.

The phenotypic correlation between weight at ten weeks and total first year egg production was calculated by Krueger to be 0.05. He found the genetic correlation to be 0.13 and the environmental correlation to be zero (13, pp.109-110). Dillard compared weight at eight and twelve weeks with three month production and found phenotypic, genetic, and environmental correlations of -0.01, -0.17 and 0.03 respectively (3, pp.69, 74). While the findings of these two men disagree in the direction of the genetic correlation, they agree that whether positive or negative all of the correlations are small.

To the writer's knowledge, no previous work has been done to find the relationship between broiler weight and egg weight. Between housing weight and egg weight, Lerner found a phenotypic correlation of 0.37 (15, p.207), and Wyatt found a genetic correlation of 0.31 (25, p.1270).

STATISTICAL MODEL

The procedure used in estimating genetic variance, heritability, and the genetic and environmental correlations in this study is the method of variance component analysis (1, pp.254-266) (8, pp.119-125). The phenotypic expression "X" of a character may be considered the sum of two sources of variation: (1) a genetic source "G" composed of the average effect of all genes affecting that character, and (2) a residual source "E" composed of the effects of gene interactions and the effects of environment peculiar to certain individuals or groups. The expression of a character can be defined by the equation

$$X = G + E$$

where each variable is expressed as a deviation from the mean.

In a population of individuals, the total variance " σ_X^2 " of a character in that population may be considered the sum of two sources of variance: (1) a genetic source " σ_G^2 ", and (2) a residual source " σ_E^2 ". The total variance of a character can be defined by the equation

$$\sigma_X^2 = \sigma_G^2 + \sigma_E^2 .$$

Each level of the family structure of a population contains variance from the two sources in different amounts. By analysis of variance it is possible to estimate the variance from each source.

In this problem three levels of the family structure of the general population are considered. Each level contains all of the

variance from each smaller subdivision plus a component of variance of its own, and each component contains genetic and environmental variance in proportions based on Mendelian theory. Table 5 shows the components of variance at each level of the population (1, p.256).

Mendelian theory explains that at meiosis, half of the genes of each parent are passed to the offspring. In a population breeding at random¹ a gene occurring at average frequency (50 percent) would be expected to occur in a heterozygous condition in half of the individuals. The remaining half of the individuals would be homozygous either for one gene or its allele. The gene coming to an individual from a homozygous parent would be predetermined, but the gene coming from a heterozygous parent would be decided by chance at meiosis. On the average, half of an individual's genes would be predetermined by the dam or the sire. Because full sibs have the same sire and the same dam, they can be expected to differ in only half as many genes as do unrelated individuals. Half-sibs could be expected to differ in three-fourths as many genes as unrelated birds (14, pp.81-85). The difference between the variance of half-sibs and the larger variance of unrelated individuals should equal one-fourth of the genetic variance of the whole population. Also the difference between the variance of full-sibs and that of half-sibs

¹ The population studied in this problem is considered a random breeding one. Except that the mating of sibs and half-sibs has been avoided, there has been no plan to decide which of the birds selected as breeders go into each pen.

should equal one-fourth of the genetic variance of the whole population (10, p.100). Expressed mathematically,

$$\sigma_G^2 = 4(\sigma_s^2 - \sigma_d^2) = 4(\sigma_d^2 - \sigma_1^2),$$

where σ_G^2 is the total genetic variance, σ_s^2 is the variance among unrelated individuals or the progeny of different sires, σ_d^2 is the variance among half-sibs, or progeny of different dams but the same sire, and σ_1^2 is the variance among full sibs or the progeny of the same sire and the same dam.

Two estimates of genetic variance are then possible, but neither is perfect. The sires' component of variance ($\sigma_s^2 - \sigma_d^2$) contains, not one-fourth, but all of the sex linked genetic variance. Consequently use of the formula, $\sigma_G^2 = 4(\sigma_s^2 - \sigma_d^2)$, overestimates the genetic variance by an amount equal to three times the sex-linked genetic variance (14, p.121). A second weakness is that the sires' component of variance may often be based on so few degrees of freedom, that the figure can be accepted only within a wide confidence interval. An estimate from the dams' component of variance is usually based on many degrees of freedom. It contains no sex-linked genetic variance, but does contain all of the maternal effects and about one-fourth of the sire-dam interaction. The formula, $\sigma_G^2 = 4(\sigma_d^2 - \sigma_1^2)$, therefore underestimates the genetic variance by the amount of the sex linked variance, but overestimates it by the amount of the sire-dam interaction and four times the maternal effects.

Table 5
Distribution of Variance and Covariance
in a Random Breeding Population

Source of variance	Expectation of mean square or mean cross product
Sires	$\sigma_1^2 + k\sigma_d^2 + n\sigma_s^2$
Dams in sires	$\sigma_1^2 + k\sigma_d^2$
Individuals in dams	σ_1^2

Key to Table 5

σ_1^2 is the variance within full sibs.

σ_d^2 is the variance due to dam effects.

σ_s^2 is the variance due to sire effects.

k is the average number of individuals per dam.

n is the average number of individuals per sire.

More frequently used is an estimate based on both the sires' and the dams' components of variance, $\sigma_G^2 = 2(\sigma_S^2 - \sigma_I^2)$. Genetic variance as found by this formula is too high by an amount equal to the sex linked variance, plus twice the maternal effects, plus one-half of the sire-dam interaction.

Heritability " h^2 " can be defined by the formula

$$h^2 = \frac{\sigma_G^2}{\sigma_G^2 + \sigma_E^2} \quad (10, \text{ p.111}).$$

An estimate of heritability suffers from the faults of the estimate of genetic variance used in its computation.

The covariance in each level of the population is distributed the same as is the variance. The phenotypic correlation between characters "a" and "b" can be found by the formula

$$r_{ab} = \frac{\text{cov}_{ab}}{\sqrt{(\sigma_a^2)(\sigma_b^2)}} \quad (8, \text{ p.121})$$

where " r_{ab} " equals the phenotypic correlation between characters "a" and "b", and " cov_{ab} " equals the phenotypic covariance of "a" and "b".

Since genetic covariance is distributed the same as is genetic variance, its estimates are subject to the same errors. Genetic correlations, being computed from genetic variances and covariances which themselves are subject to error, can be accepted only with the assumption of some inaccuracy. Genetic correlations can be found by the formula

$$r_{G_a G_b} = \frac{\text{cov } G_a G_b}{\sqrt{(\sigma_{G_a}^2)(\sigma_{G_b}^2)}} \quad (8, \text{ p.121}).$$

Environmental correlations are based on the residual source of covariance, and are subject to errors complementary to those of genetic correlations. Environmental correlations can be found by the formula

$$r_{E_a E_b} = \frac{\text{cov } E_a E_b}{\sqrt{(\sigma_{E_a}^2) (\sigma_{E_b}^2)}} \quad (8, \text{ p.121}).$$

If character "a" is subjected to selection so that its genetic mean will change by " G_a ", then the change in the genetic mean of character "b" can be found by the formula

$$\Delta G_b = \Delta G_a \sqrt{\frac{(r_{G_a G_b}) (\sigma_{G_b}^2)}{\sigma_{G_a}^2}} \quad (25, \text{ p.1272}).$$

RESULTS AND DISCUSSION

The flock studied appears to be quite similar both genetically and environmentally to others reported in the literature. A comparison of tables 1, 2, 3, and 4 with tables 7, 8, and 12 shows that means, variances and heritabilities in most cases are close to those reported even in the heavier strains of chickens.

The mean body weights are low, of course, because Leghorns are a small, slow growing variety. Heritability of body weight is in agreement with other reports. The much greater variance between dams than that between sires is evidence of strong maternal effects, or of sire-dam interaction. This throws serious doubt on the accuracy of heritability estimates based on sires and dams in this and in other reports.

The relatively high heritability and low total variance in age at first egg shows that there is less than the usual amount of environmental variance in this flock. Age at first egg is apparently sex-linked. This is in agreement with what has been found in most other flocks.

Mean early egg production cannot be compared with that of other flocks because each researcher has selected his own arbitrary period of measurement. However the heritability is high, and the total variance is high compared to the mean. Again, the dams' component of variance is substantially greater than the sires', but heritability based only on the sires' component shows that there is still

improvement possible in this population.

The inheritance of egg weight in these birds does not agree with most reports in the literature. Except for King and Henderson others have found sex-linked variance in this character, while maternal effects or sire-dam interaction seem important here. Possibly all flocks originally had both sex-linked variance and variance caused by maternal effects and sire-dam interaction, but this flock has lost the sex-linked variance, permitting the other terms to appear in the analysis.

The phenotypic correlations between characters in this flock are in close agreement with those in other flocks. If one considers the comparatively large error inherent in estimating the genetic and environmental correlations, they too are in agreement.

The phenotypic, genetic and environmental correlations found between 10-week weight and housing weight are close to those found by Wyatt in Single Comb White Leghorns and those found by Krueger in several varieties. Chickens with the ability to grow fast to broiler age, seem to possess the ability to continue to grow fast.

The low, negative phenotypic correlation between 10-week weight and age at first egg is close to that observed by Krueger, Dillard, and Peeler. The genetic and environmental correlations, however, are not consistent with those in the literature or with themselves. Since the characters are not closely correlated phenotypically, sampling error in separating their variance into genetic and environmental components could be comparatively large. The inconsistencies,

then, are likely to be due to sampling error.

The phenotypic correlation between 10-week weight and early egg production was found to be small. Krueger and Dillard also found small phenotypic correlations. Again because of this small phenotypic correlation one can have little faith in the relative size of its components.

The positive genetic and phenotypic correlations observed between housing weight and egg weight are not far from the figures reported by Lerner and by Wyatt. Since 10-week weight and housing weight are closely correlated, it is to be expected that egg weight and broiler weight would be related in a manner similar to housing weight and egg weight.

Table 15 shows the estimated consequences of selection to improve weight at ten weeks by one hundred grams when the flock is subject to no other selection. Estimates of the effects on early egg production and on age at first egg differ widely depending on the source of the estimate. As in the calculation of genetic and environmental correlations, the low phenotypic correlations between these traits and 10-week weight make estimates subject to much sampling error. Figures based on the sires' components of variance and covariance are especially liable to sampling error because only eight sires were used in this study. Sex-linkage could also be important. Maternal effects and sire-dam interaction could cause inaccuracy in estimates based on the dams' components of variance and covariance.

Table 6
Number of Birds Used in Each Analysis

	Sires	Dams	Individuals
10-week weight	8	97	574
Housing weight	8	97	574
Age at first egg	8	97	563
Early egg production	8	97	563
Egg weight	8	96	494

Table 7
Mean Performance and Standard Deviation
of Characters Studied

		Mean	Standard deviation
10-week weight	(gms.)	750.35	81.82
Housing weight	(lbs.)	3.20	0.40
Age at first egg	(weeks)	25.72	2.54
Early egg production	(eggs)	75.64	25.90
Egg weight	(oz./doz.)	22.28	1.57

Table 8

Components of Variance

Variance Attributed to	10-week weight (gms.)	Housing weight (lbs.)	Age at first egg (weeks)	Early egg production (eggs)	Egg weight (oz./doz.)
Sires	285.1	0.00552	0.9303	48.53	.1381
Dams	1108.6	0.01948	0.5772	80.30	.5038
Individuals	5300.0	0.13775	4.9406	541.86	1.8171
Total	6693.7	0.16275	6.4481	670.69	2.4590
<u>Sires</u> Dams	0.248	0.283	1.61	0.604	0.275

Table 9
Estimated Genetic and Environmental Variances

		Sires		Dams		Sires and Dams	
		G	E	G	E	G	E
10-week weight (HW)	gms.	1140.5	5553.2	4434.3	2259.4	2787.5	3906.3
10-week weight (AFE and EEP)	gms.	1196	5486	4296	2386	2746	3936
10-week weight (egg wt.)	gms.	612	5863	4692	1783	2652	3823
Housing weight	lbs.	.02209	.14069	.07792	.08982	.05000	.11274
Age at first egg	weeks	3.7212	2.7269	2.3068	4.1393	3.0150	3.4331
Early egg production	eggs	194.12	476.57	321.19	349.49	257.66	413.00
Egg weight	oz./doz.	0.5524	1.9066	2.0152	0.4438	1.2838	1.1152

Table 10
Components of Covariance

	10-week weight (gms.)	Housing weight (lbs.)	Age at first egg (weeks)	Early egg production (eggs)
Housing weight				
S	0.983			
D	3.878			
I	16.590			
Total	21.451			
Age at first egg				
S	17.09	0.03560		
D	-12.06	-0.05312		
I	-37.29	-0.32839		
Total	-32.26	-0.34591		
Early egg production				
S	-115.22	0.1620	-6.679	
D	114.49	0.2478	-4.495	
I	252.63	2.2003	-28.063	
Total	251.90	2.6101	-39.237	
Egg weight				
S	3.790	0.00103	0.3227	-2.6544
D	15.291	0.06966	-0.1880	1.5425
I	20.150	0.09722	-0.1333	2.4199
Total	39.231	0.16791	0.0014	1.3080

Table 11
Estimated Genetic and Environmental Covariance

	10-week weight (gms.)	Housing weight (lbs.)	Age at first egg (week)	Early egg production (eggs)	Egg weight (oz./doz.)
10-week weight (gms.)			<u>Environmental</u>		
S		17.519	-100.62	712.81	24.065
D		5.939	15.98	-206.01	-21.933
S and D		9.722	-42.32	253.38	1.121
Housing weight (lbs.)					
S	3.932		-0.48832	1.9621	0.16379
D	15.512		-0.13345	1.6189	-0.11073
S and D	9.722		-0.31088	1.7905	0.02653
Age at first egg (week)					
S	68.36	.14240	<u>Genetic</u>	-12.520	-1.2896
D	-48.24	-.21246		-21.256	0.7530
S and D	10.06	-.03503		-16.888	-0.2680
Early egg production (eggs)					
S	-460.92	0.6480	-26.718		11.926
D	457.94	0.9912	-17.982		-4.844
S and D	-1.47	0.8196	-22.350		3.532
Egg weight (oz./doz.)					
S	15.160	0.00412	1.2908	-10.618	
D	61.164	0.27864	-0.7520	6.170	
S and D	38.150	0.14138	0.2694	-2.224	

Table 12

Estimated Heritability

	Source of Estimate		
	Sires	Dams	Sires and Dams
10-week weight	0.17	0.66	0.42
Housing weight	0.14	0.48	0.31
Age at first egg	0.58	0.36	0.47
Early egg production	0.29	0.48	0.38
Egg weight	0.22	0.82	0.52

Table 13

Phenotypic Correlations

	10-week weight	Housing weight	Age at first egg	Early egg production
Housing weight	0.65			
Age at first egg	-0.16	-0.34		
Early egg pro- duction	0.12	0.25	-0.60	
Egg weight	0.31	0.27	0.00	0.04

Table 14
Estimated Genetic and Environmental Correlations

	10-week weight	Housing weight	Age at first egg	Early egg production	Egg weight
				<u>Environmental</u>	
10-week weight					
S		0.63	-0.82	0.45	0.23
D		0.43	0.16	-0.23	-0.78
S + D		0.56	-0.36	0.20	0.02
Housing weight					
S	0.78		-0.80	0.24	0.32
D	0.84		-0.20	0.26	0.45
S + D	0.82		-0.50	0.26	0.33
Age at first egg					
S	1.02	0.49		-0.35	-0.60
D	0.48	-0.50		-0.56	0.63
S + D	0.11	-0.09		-0.45	-0.14
Early egg production					
S	-0.96	0.31	-0.99		0.51
D	0.39	0.20	-0.66		-0.44
S + D	0.00	0.23	-0.80		0.27
Egg weight					
S	0.83	0.36	0.89	1.07	
D	0.63	0.73	-0.31	0.32	
S + D	0.65	0.57	0.13	-0.14	

Genetic

Table 15
 Estimated Consequences of Selection to Improve
 10-week Weight by 100 Grams

		Estimated change		
		S	D	S and D
Housing weight	(lbs.)	0.4	0.4	0.4
Age at first egg	(weeks)	5.6	-1.6	1.1
Early egg production	(eggs)	-39	17	--
Egg weight	(oz./doz.)	2.7	1.7	1.8

CONCLUSIONS

The similarity of the correlations and heritabilities found in White Leghorns and those found in the meat strains shows that annual breeding progress would be about the same for any of the characteristics studied in either egg laying strains or meat strains.

Because of the low genetic correlations between egg production qualities and weights at ten weeks, growth rate and egg production could be improved simultaneously. However, progress in broiler weight would be faster if selection were only for broiler weight, and progress in egg production would be faster if selection were only for that character. The question of whether it would be economically feasible to select for both simultaneously, involves economic considerations beyond the scope of this thesis.

The large maternal effects or the large amount of sire-dam interaction present in this flock and others prevents accurate estimates of heritability or of genetic and environmental correlations. Further work needs to be done to measure the influence of these sources of variance.

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