July 31, 1970

To the Graduate Council:

I am submitting herewith a dissertation written by Robert James Mackin, Jr., entitled "Environmental Effects and Genotype-Environment Interactions in Laying Stocks of Chickens." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

H. V. Shirley
Major Professor

We have read this dissertation
and recommend its acceptance:

Robert R. Shrode

L. M. Josephson

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Accepted for the Council:

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ENVIRONMENTAL EFFECTS AND GENOTYPE-ENVIRONMENT INTERACTIONS IN LAYING STOCKS OF CHICKENS

A Dissertation

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

by

Robert James Mackin, Jr.

August 1970

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ABSTRACT

Data collected during the Eighth, Ninth, Tenth, Eleventh and Twelfth Tennessee Random Sample Laying Tests (1964 to 1969) were analyzed statistically using analysis of variance. Egg production, egg size distribution, egg quality and feed efficiency variables were calculated on a yearly and quarterly basis. The effects: strains (20 strains), years (3 years), density level (1 per cage and 2 per cage), protein level (13 and 17 percent), insulation value (4R and 13R), quarters (four quarters) and their interactions were tested for statistical significance.

Strains were found to differ significantly with respect to nearly all traits studied. Strain-density and strain-protein interactions were found for many variables. Differences between quarters were significant as would be expected for the traits studied. The other main effects, years, insulation value, protein level and density level were not consistently significant.

Many of the strain-environment interactions were found to be significant. More strain-environment interactions were detectable as statistically significant when quarterly records, instead of year records, were used as a basis for analysis. Several of the second-order interactions also were found to be significant.

These data indicate that strain-environment interactions are real, are difficult to detect and require experimental procedures which allow for detection of small differences if statistical significance is to be shown. Sub-samples of egg production strains entered in the

Eighth, Ninth, Tenth, Eleventh and Twelfth Random Sample Laying Test did not perform equally within a strain when subjected to different environments.

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I. INTRODUCTION

There has been a change in the poultry breeding industry from many small breeding establishments producing stocks for local use, to a small number of large breeding firms producing birds for world wide distribution. This has increased interest in genotype-environment interactions in egg laying stocks.

The types of housing, housing management systems and feed management employed vary greatly from location to location. Houses in which birds from a primary breeder must perform vary greatly as to the amount of insulation from one production unit to another. In recent years considerable research has been conducted to determine the optimal protein level of the diets used for egg production stocks. Protein levels in commercial feed formulas may range from a low of 15 percent to a high of 20 percent protein. There is also much variation in the hen density used by producers in their laying houses. Floor space per hen in use by the poultry industry ranges from a high of about 3 square feet per hen to a low of about .5 square feet per hen.

With the trend in the industry toward fewer primary breeders of layer stocks in use over a widening range of environments, genotype-environment interactions, where present, should be a factor in the types of management and breeding procedures employed. It may be that the primary breeders will have to offer two strains to the producer, one for high densities and one for low densities, if there is a significant strain-density interaction. The producer may have to fit either his management to the strain available or the strain to his particular management system.

The objective of this study was to determine if genotype-environment interactions exist in laying stocks of chickens available to Tennessee poultrymen.

II. REVIEW OF LITERATURE

The subject of genotype-environment interactions and their general implications in poultry breeding and husbandry has been discussed by many authors during the past 20 to 30 years. No attempt will be made to present an exhaustive review of these discussions as there are several good reviews available, Falconer (1960), Lerner (1950 and 1958) and McBride (1958). There are also good reviews regarding genotype-environment interactions in egg production stocks, in particular those of Tindell *et al*. (1967), Cook *et al*. (1963), Van Vleck (1963), Dickerson (1962), Hale (1961), and Nordskog (1966).

Locations and Years

Gutteridge and O'Neil (1942) found no significant strain by location interaction in a study of 3 strains at 3 locations. The traits analyzed were annual production, egg weight, days to first eggs, body weight at first egg, final body weight and percent mortality. Nordskog and Arvidson (1948) reported 43 percent of the total variance in egg production, in their study of 19 hybrid combinations at 4 locations, to be attributable to cross by location interaction in data from daughters of 38 White Leghorn sires at 4 locations. Again, using daughters of 38 sires at 5 locations, Gowe and Wakely (1954) found no significant genotype-environment interaction for hen-housed, survivor egg production or laying house mortality.

Johnson and Gowe (1956) found significant strain by location interactions for egg weight and blood spot incidence in a test involving

8 commercial strains of White Leghorns at 3 locations.

Hill and Nordskog (1956) tested 10 varieties at 4 locations for 3 years for hen-day egg production and hen-housed mortality. Variety by location and variety by year interactions were significant for hen-housed mortality. The variety by year and location by year interactions were significant for hen-day egg production.

Hull and Gowe (1962), using 2 strains, 3 locations and 2 rearing treatments tested for genotype-environment interactions using sire groups from the 2 strains. For 3 traits; body weight at 21 weeks, egg weight and body weight at maturity, the interaction between sire genotype and location was not significant in any strain. For one strain the only significant interaction was for body weight at 21 weeks. Significant interactions for genotype by rearing treatment were found for days to sexual maturity and body weight at 21 weeks. In no case was the second order interaction significant.

Testing 45 breeding entries in 2 consecutive California Random Sample egg laying tests at 10 and 9 commercial test locations, Abplanalp _et al_. (1962) found variety by location interactions important for egg production and viability of hens. The variety by location interaction was not present for the traits of egg size and body size. An analysis of a portion of the data for the 2 years showed relatively large variety by location by year interactions for egg production and viability.

Bowman and Powell (1963) employing data from several varieties at 16 multi-location tests observed significant interaction for rearing and laying mortality, hen-month and hen-housed egg production and 32-week egg weight. They found significant interactions in approximately one-third of the traits measured but in only 2 cases did the interaction account for more than 20% of the total variance.

Van Vleck _et al_. (1963) found genotype-environment interaction to be of small importance in the Cornell Controls tested at 2 locations. Beck and Baker (1964) tested 19 potential commercial varieties of laying chickens in one year and 22 varieties in the following year at several locations, with the parent flocks being held at 2 locations (source). They found no significant source by location interactions but found significant variety by location interactions. Krause _et al_. (1965), employing reciprocal recurrent selection on two strains of White Leghorns and testing at 3 locations, reported significant sire by location interactions for sexual maturity and survivor's egg production. The interactions were found to comprise 10% and 8% of the total variation for sexual maturity and survivor's egg production, respectively.

Tindell _et al_. (1967) found in data from 10 stocks at 9 locations in 2 years significant stock by location interaction for 8-, 18- and 58-week body weight, sexual maturity, specific gravity and Haugh units. Stock by year interactions were significant for 8-week body weight, sexual maturity, most of the egg quality traits measured at 200 days of age and egg weight at 350 days of age. Marks _et al_. (1969) reported stock by location interactions to be of minor importance in an experiment involving 10 production stocks on 2 protein levels at

9 locations in 2 years. The stock by location interactions accounted for only 0 to 6 percent of the explained variation. The stock by year interactions also were of small importance. The location by year interaction was found to account for a large percentage of the explainable variation in most traits.

Marks (1969) used a design which incorporated 4 parent-flock stocks each maintained at 4 locations from which pullets were distributed to 10 growing locations in each of 2 years. The parent-flock location by parent-stock interaction was found to be significant for 8- and 18-weeks body weight, sexual maturity, eggs per bird, percent hen-day egg production, egg weight, specific gravity, albumen height, Haugh units and laying mortality. Although responsible for only a small percentage of the explained variation, parent-stock by growing locations interactions were significant for body weight, egg production and mortality. The parent-flock location by growing location interactions were of small importance.

Housing Management

One means by which significant location-strain interactions could possibly result would be by having differences in the methods of housing management at the locations; such as floor, cages, slatted floors or differences in housing densities.

Lowry *et al.* (1956) observed no significant sire or dam group by management system (floor and cage) interaction for egg weight, sexual maturity and egg production. Bailey *et al.* (1959), using 4 commercial strains housed on the floor and in cages during the birds' production period found a significant strain by management interaction for egg production. No significant strain by management interaction was reported by Yao (1959) in a study of 9 strains and 2 management systems, floor and slatted floors. Nordskog and Kempthorne (1960) reported a significant interaction between strains and cage or floor for survivor's egg production. Proudfoot and Gowe (1961) found no interaction using 6 strains reared in confinement or on range. Hale (1961) reported observing no interaction between strain and cage or floor (small houses with grass runs) using light Sussex and Brown Leghorn stocks. Cook and Dembnicki (1966) using 7 stocks housed 1 bird per cage, 2 per cage and 5 per 2 cages found significant interaction between strain and density for hen-housed egg production and laying mortality.

Feed Management

Another factor or factors which could greatly influence differences between locations and a genotype's performance would be the feeding management (level of protein, restricted feeding, etc.). Fox *et al*. (1960) observed a significant genotype-diet interaction for egg production. In his experiment there were 2 strains and two levels of protein (16.4 and 18 percent). Thornton and Whittet (1960) reported no strain by diet interaction using 4 strains and diets of 11, 13, 15 and 17 percent protein.

Employing 2 rearing treatments (feed restriction and full feed) and 2 strains, Hull and Gowe (1962) observed a significant interaction for days to sexual maturity and body weight at 21 weeks. Strain by protein level interactions were reported also by Harms and Waldroup (1962) for body weight, egg production and egg weight. They included 2 strains and 11, 13 and 17 percent protein levels in their experiment. Moreng et al. (1964) found significant strain by diet interactions for Haugh units and egg weight in an experiment using 4 strains and three protein levels, i.e., 13, 15 and 17 percent. Deaton and Quisenberry (1965), using 4 commercial stocks and 14, 15, 16 and 17 percent protein diets reported significant stock by protein level interactions for body weight, egg production, egg weight, feed efficiency, Haugh units score and shell thickness. Harms et al. (1966) found significant interactions for body weight and egg production in data from 6 strains fed protein levels of 11, 13, 15 and 17 percent. Marks et al. (1969), using 10 stocks fed 2 protein levels (13 and 17%) found the interaction of strain by location to be nonsignificant for all traits and accounted for only 0 to 7 percent of the explained variation.

The present information regarding genotype-environment interactions is inconclusive. Some authors are of the opinion that although these interactions do exist they contribute only a very small amount to the total explained variation thus making the interactions of small importance. Others have shown that the interactions with genotype (genotype-year and genotype-location) are statistically significant and could result in mistakes in selection based on certain traits. Many of the data presented from records of commercial breeders show a definite genotype-location interaction large enough to be important. It is desirable to learn which environmental factors under the control of the researcher are responsible for these strain-location interactions in order that testing environments can be designed which would not produce interactions capable of causing serious errors in selection. If certain kinds of interaction are inevitable, precise knowledge of their nature would permit intelligent selection of stocks specifically suited to certain environmental situations.

III. PROCEDURE

Management

Data used in this study are from the Eighth, Ninth, Tenth, Eleventh and Twelfth Tennessee Random Sample Laying Tests.

Each of the tests was initiated by securing hatching eggs of each of the stocks (strains) to be entered. Stocks in each of the tests were subjected to uniform management practices during the incubation, growing and rearing periods. When the chicks were one day of age, they were sexed and wing banded. For the first ten weeks in the brooder house infrared heat lamps served as the heat source. At ten weeks of age the pullets were moved to a growing shelter. The birds were vaccinated for Newcastle disease and infectious bronchitis at one day, 70 days and 140 days of age and for fowl pox at approximately 12 weeks of age. A coccidiostat was used from one day of age until housing at 20 weeks of age. Pullets were fed a 22 percent protein starter diet to ten weeks and 17 percent protein grower diet from ten weeks to twenty weeks (Table I). These diets were formulated to meet or exceed all nutritive requirements for each class of pullets as given by the National Research Council.

A cage laying house was employed throughout these tests. The pullets were all housed in cages, 8" x 16", at 140 days of age, where they remained for 360 days of production. In the Eighth, Ninth, and Tenth Tests, one-half of the mature pullets of each entry were housed one bird per cage with a ceiling insulation value of 4R, while the other half of each entry was housed one bird per cage with a ceiling

TABLE I

STARTER AND GROWER DIETS

Feedstuff	Starter BR1* Lbs.	Grower GR6* Lbs.
Yellow corn	638.00	718.75
Alfalfa meal, 17%	25.00	50.00
Fish meal	25.00	25.00
Vitamin mix*	6.00	6.00
Defluorinated rock phosphate	15.00	15.00
Ground limestone	6.00	10.00
Salt	4.80	5.00
Manganese sulfate	0.20	0.25
Soybean oil meal, 50%	255.00	145.00
Coccidiostat premix	25.00	25.00
	1000.00	1000.00
Calculated to contain:		
Crude protein, %	22.04	17.68
Productive energy, C/lb.	957	966
C/P (Calorie:protein ratio)	43.40	54.65
Metabolizable energy C/lb.	1346	1356
Metabolizable energy C/P ratio	61.08	76.69
Methionine, %	.361	.3061
Cystine, %	.334	.2746
Lysine, %	1.260	.9396
Calcium, %	.894	1.057
Phosphorus, %	.711	.636
Available phosphorus, %	.414	.4217
Manganese, mg./lb.	31.27	36.84
Vitamin A, I.U./lb.	5349	7970
Vitamin D, I.C.U./lb.	340	340
Riboflavin, mg./lb.	3.05	3.10
Niacin, mg./lb.	28.44	28.43
Pantothenic acid, mg./lb.	6.71	6.57
Choline, mg./lb.	735.3	625.45

*Minerals and vitamin content calculated to equal or exceed requirements as given by National Research Council.

insulation value of 13R. Each entry was divided into 4 lots of 15 birds each, two lots under each insulation treatment.

In the Eleventh Test entries were divided into 4 lots; 2 lots consisting of 15 birds each, 1 bird per cage, and 2 lots consisting of 30 birds each, 2 birds per cage. Entries in the Twelfth Test were divided into 8 lots at housing, 4 lots of 15 pullets each, 1 bird per cage, and 4 lots of 30 pullets each, 2 birds per cage. At housing all pullets received a laying diet containing 17 percent protein (Table II). When the house production reached 50 percent, 2 lots of each of the 1 bird and 2 birds/cage groups were placed on a diet of 13 percent protein (EL38, Table II) with the other lots remaining on the 17 percent diet. All tests were terminated when the birds were approximately 500 days of age, in every test this being during the first 12 days of August of the respective years.

Data Collection and Calculations

Traits considered in this study were measured on a per lot basis. Eggs-per-bird-housed was calculated as the total number of eggs produced divided by the total number of birds housed. Percent egg production was determined by multiplying by 100 the ratio of total number of eggs laid per lot to the total number of eggs possible if every bird housed had produced an egg each day of the laying period. Percent hen-day production was calculated by multiplying by 100 the ratio of average number of eggs laid per hen to the average number of days each hen spent in the laying house.

Feed consumed was determined each month for each pen. The total weight of eggs, in grams, laid on one day each week were recorded for

TABLE II

LAYER DIETS

Feedstuff	Hi-Protein Layer LR3*	Low-Protein Layer EL38*
	Lbs.	Lbs.
Yellow corn	669.75	762.25
Alfalfa meal, 17%	50.00	50.00
Fish meal	25.00	25.00
Vitamin mix*	5.00	5.00
Defluorinated rock phosphate	15.00	15.00
Ground limestone	60.00	60.00
Salt	5.00	5.00
Manganese sulfate	0.25	0.25
Soybean oil meal, 50%	170.00	77.50
Coccidiostat premix	-	-
	1000.00	1000.00
Calculated to contain:		
Crude protein, %	17.19	13.29
Productive energy, C/lb.	911	940
C/P (Calorie:protein ratio)	53.02	70.20
Metabolizable energy C/lb.	1280	1315
Metabolizable energy C/P ratio	74.45	98.20
Methionine, %	.297	.250
Cystine, %	.266	.203
Lysine, %	.923	.643
Calcium, %	2.957	2.939
Phosphorus, %	.621	.584
Available phosphorus, %	.417	.406
Manganese, mg./lb.	36.70	35.66
Vitamin A, I.U./lb.	7123	7262
Vitamin D, I.C.U./lb.	1342	1342
Riboflavin, mg./lb.	2.931	2.87
Niacin, mg./lb.	20.68	20.63
Pantothenic acid, mg./lb.	5.44	5.09
Choline, mg./lb.	631.45	529.70

*Minerals and vitamin content calculated to equal or exceed requirements as given by National Research Council.

each lot, enabling the amount of feed required to produce a unit weight of eggs to be calculated. The eggs used to obtain the above weights were then sized into classes of: peewee, medium, large, and extra-large and over in order to obtain the size distribution, the weight in ounces per dozen per egg each being: under 17, 17-19, 20-22, 23-25, 26 and over, respectively.

The following egg quality characteristics: shell thickness, albumen height, Haugh units and incidence and size of blood and meat spots for all eggs laid by each pen on one day of each three-month period were recorded. The specific gravity of the shell eggs was used as a measure of shell thickness. Ten salt solutions, ranging in specific gravity from 1.068 to 1.100 by increments of .004, were employed. The albumen heights of broken out eggs were measured with a tripod micrometer and at the same time the eggs were examined for the presence of meat and blood spots. The Haugh unit score was calculated using the average albumen height and average egg weight for each lot.

The income over chick and feed cost was calculated. The prices of feed, eggs, market hens and chicks used to calculate costs and income were local prices and assumed to be representative of the local situation at that particular time. The chick price was obtained from each breeder as the price per chick in lots of 1000 day-old pullet chicks. All hens were sold at the termination of each test for the market price per pound at the time. Feed consumption during the growing period was calculated by determining the average weight of pullets at housing and multiplying this weight by six, the estimated pounds of feed required to produce a pound of egg-type pullet at 140 days of age. The cost of the feed consumed during the laying period plus the value of feed consumed during the growing period and cost of the day-old chicks was the chick and feed cost for each of the five tests.

The income from eggs laid was determined by using the market price for small, medium and large size eggs quoted on the Chicago market, as secured from the Market News Report issued at Atlanta, Georgia. Prices quoted were those paid to first receiver, 80 percent Grade A. The total eggs, in dozens, of each size produced was multiplied by the average price per dozen for the year, giving the income from eggs. As the market reports gave no quotation for peewee size eggs, this price was determined by subtracting the average difference in price between small and medium sizes from the price paid for small eggs. The income from eggs produced for each stock was determined as the gross income from eggs for that stock minus the percentage of income lost due to all sizes of blood and meat spots.

Analysis of Data

Analyses of variance were based on a factorial arrangement of stocks, insulation values, years, quarters, protein levels and cage densities, all considered as fixed effects. The following mathematical models describe the variables studied in each of the respective tests:

Eighth, Ninth and Tenth Tests:

$$X_{ijklm} = u + S_i + Q_j + (SQ)_{ij} + Y_k + (SY)_{ik} + (QY)_{jk} + (SQY)_{ijk} + (SI)_{il} + (QI)_{jl} + (SQI)_{ijl} + (YI)_{kl} + (SYI)_{ikl} + (QYL)_{jkl} + (SQY)_{ijkl} + e_{ijklm}$$

Where: $i = 1, 2, \ldots 10$ stocks
$j = 1, 2, 3, 4$ quarters
$k = 1, 2, 3$ years
$l = 1, 2$ insulation values
$m = 1, 2$ lots per stock in each quarter in each year under each insulation value.

X_{ijklm} is the observation on the m^{th} lot under the l^{th} insulation value in the k^{th} year in the j^{th} quarter for the i^{th} stock. The mean of the population is represented by u and e_{ijklm} represents random variation among lots.

The same model with the exception of the quarter effect and its interactions being excluded also was used.

The Twelfth Test:

$$X_{ijklm} = u + S_i + P_j + SP_{ij} + D_k + SD_{ik} + PD_{jk} + SPD_{ijk} + Q_e + SQ_{il} + PQ_{jl} + PQ_{ijl} + DQ_{kl} + SDQ_{jkl} + PDQ_{ijkl} + SPDQ_{ijkl} + e_{ijklm}$$

Where: $i = 1, 2 \ldots 14$ stocks
$j = 1, 2$ protein levels
$k = 1, 2$ densities
$l = 1, 2, 3, 4$ quarters
$m = 1, 2$ lots per stock in each quarter in each density fed each protein level.

X_{ijklm} is the observation on the m^{th} lot in the l^{th} quarter in the k^{th} density fed the j^{th} protein level for the i^{th} stock. The mean of the population is represented by u and e_{ijklm} represent random variation among lots.

The same model with the exception of the quarter effect and its interactions being excluded also was used.

The Eleventh Test:

$$X_{ijkl} = u + S_i + D_j + SD_{ij} + Q_k + SQ_{ik} + DQ_{jk} + SDQ_{ijk} + e_{ijkl}$$

Where: $i = 1, 2 \ldots 16$ stocks
$j = 1, 2$ densities
$k = 1, 2, 3, 4$ quarters
$l = 1, 2$ lots per stock in each quarter in each density.

X_{ijkl} is the observation on the l^{th} lot in the k^{th} quarter in the j^{th} density for the i^{th} stock. The mean of the population is represented by u and e_{ijkl} represents random variation among lots.

The same model with the exception of the quarter effect and its interactions being excluded also was used.

IV. RESULTS AND DISCUSSION

Egg Quality Characteristics

Mean squares for percent large and small blood and meat spots, Haugh units and specific gravity are presented in Table III, for the Eighth, Ninth and Tenth Tests; in Table IV, for the Eleventh Tests and in Table V, for the Twelfth Test. Those mean squares which were found to be significant are denoted in the conventional manner.

Strains were found to differ from each other in regard to the quality of the eggs produced. Egg quality was found to differ also from year to year. The magnitude of the mean square for the year effect was generally twice that for strains for the egg quality characteristics studied. The methods of measuring factors which make up egg quality are, to some extent, under the influence of a number of uncontrolled environmental variables. It is understandable how measurements might differ from year to year. One of the characteristics, Haugh units, was found to differ from year to year and there was apparently a steady improvement since the successive year means were 72.2, 74.9 and 80.0. This may be an indication that genetic improvement was being made in the strains represented in these tests. Protein level had no significant effect on egg quality as measured in these tests.

Ceiling insulation value was found to have a significant effect on the percentage of large and small meat spots detected. The percentage of large meat spots was .80 and the percentage of small meat spots was 1.04 for the insulation value of 4R, and .36 and .35 percent

TABLE III

ANALYSIS OF VARIANCE OF EGG QUALITY CHARACTERISTICS
AND INCOME OVER CHICK AND FEED COST
(EIGHTH, NINTH AND TENTH TESTS)

		Mean Square						
Source	Degrees of Freedom	Haugh Units	% Large Blood Spots	% Small Blood Spots	% Large Meat Spots	% Small Meat Spots	Specific Gravity	Income Over Chick and Feed Cost
Strains (S)	9	28.34**	10.87	13.87	2.38	2.88	1.03**	2.09**
Years (Y)	2	578.53**	4.39	57.69**	4.02	5.99	7.94**	16.34**
SY	18	6.62	8.67	13.38	1.28	3.04	0.18	0.29
Insulation (I)	1	0.26	0.60	3.71	5.90**	14.28**	0.26	0.04
SI	9	2.53	5.73	15.95	1.92	1.93	0.08	0.25
YI	2	9.74	12.83	5.02	1.74	2.28	0.21	0.18
SYI	18	2.48	5.30	13.40	1.31	1.63	0.15	0.24
Error	60	6.21	5.70	6.95	2.12	2.75	0.16	0.20
Total	119	---	---	---	---	---	---	---

** Significant ($P \leq 0.01$).

TABLE IV

ANALYSIS OF VARIANCE OF EGG QUALITY CHARACTERISTICS AND INCOME OVER CHICK AND FEED COST (ELEVENTH TEST)

		Mean Square						
Source	Degrees of Freedom	Haugh Units	% Large Blood Spots	% Small Blood Spots	% Large Meat Spots	% Small Meat Spots	Specific Gravity	Income Over Chick and Feed Cost
Strain (S)	15	43.49**	15.57	14.74	20.62**	2.44**	0.38*	0.80**
Density (D)	1	0.81	9.15	3.80	1.76	0.66	0.01	0.79**
SD	15	5.38	11.97	8.43	0.96	0.66	0.08	0.12
Error	32	5.78	11.66	7.48	3.74	0.33	0.15	0.09
Total	63	---	---	---	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

TABLE V

ANALYSIS OF VARIANCE OF EGG QUALITY CHARACTERISTICS
AND INCOME OVER CHICK AND FEED COST
(TWELFTH TEST)

Source	Degrees of Freedom	Mean Square						
		Haugh Units	% Large Blood Spots	% Small Blood Spots	% Large Meat Spots	% Small Meat Spots	Specific Gravity	Income Over Chick and Feed Cost
Strain (S)	13	49.88**	7.73	9.34*	12.32**	40.42**	0.70**	3.19**
Protein (P)	1	0.24	1.93	9.26	2.96	2.83	0.01	1.00*
SP	13	4.95	11.04*	4.36	3.35**	3.32	0.09	0.16
Density (D)	1	82.97**	7.66	0.82	3.57**	9.37	2.48**	0.10
SD	13	6.39	7.15	6.37	5.07**	4.36	0.10	0.31
PD	1	7.93	5.62	7.61	0.52	0.32	0.03	0.00
SPD	13	1.83	11.18*	7.75	0.56	1.63	0.11	0.37**
Error	56	5.04	5.21	4.30	1.28	2.79	0.13	0.17
Total	111	---	---	---	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

large and small meat spots, respectively, for the insulation value of 13R. However, insulation level is confounded with ends of the laying house and this difference may not be purely an effect of difference in insulation value.

In the two tests (Eleventh and Twelfth) birds were housed one per cage and two per cage. The birds in the higher density produced eggs with a significantly lower Haugh unit score, lower specific gravity and a higher percentage of small meat spots. There was a significant strain by protein level interaction for percentage of large blood spots and the percentage of small meat spots in the Twelfth Test. One strain, while producing only .62 percent of eggs with large blood spots on the 17 percent protein diet, produced 2.85 percent on the 13 percent protein diet. Another strain produced 1.28 percent of eggs with large blood spots on the lower protein level and 5.00 percent on the higher level protein diet. The strain by density interaction for percent small meat spots also was found to be significant in the Twelfth Test. The three-way interaction, strain-protein-density, was significant for the percentage of large blood spots produced. Some strains produced more large blood spot eggs under one treatment combination than did other strains, but the differences were not consistent from treatment to treatment.

Egg quality characteristics were recorded for approximately 160 eggs per strain per test, and even with this number of observations, it is possible that some of the differences were due to sampling error.

These results are sufficient to indicate that in further research on the effects of protein levels and cage density the conclusions reached may depend upon the strain or strains of chickens tested.

Income Over Chick and Feed Cost

Mean squares for income over chick and feed cost are given in Table III (Eighth, Ninth and Tenth Tests, p. 19), Table IV (Eleventh Test, p. 20) and Table V (Twelfth Test, p. 21).

There were significant differences between strains in all tests for the performance index, income over chick and feed cost. In the Eighth, Ninth and Tenth Tests, where year effect was included in the analysis, differences between years were significant. The second-order interaction, strain-protein-density, also was significant for this performance index. One strain had an income over chick and feed cost per hen housed of \$4.55 on the 17 percent diet housed at the rate of one bird per cage, the second best treatment combination for this same strain was two birds per cage on the 13 percent diet, earning \$4.15. For another strain the best treatment combination was 17 percent protein at two birds per cage, being \$.53 better than the second best, 13 percent protein at a density of one bird per cage. This significant interaction, if real, has broad implications for the poultry industry. The producer, in order to determine which strain is best for his environment, must test several strains under his management system. Breeders of commercial strains may find it necessary to produce strains that perform well on lower protein levels and at higher densities.

Egg-Size Distribution

In Tables VI (Eighth, Ninth and Tenth Tests), VII (Eleventh Test), and VIII (Twelfth Test) are shown mean squares for percent peewee, small, medium, large and extra large and larger laid during the production year. Data on egg-size distribution calculated on a quarterly basis are given in Tables IX (Eighth, Ninth and Tenth Tests), X (Eleventh Test), and XI (Twelfth Test).

Significant main effects and interactions were numerous for the percentage of peewee, small, medium, large and extra large and larger, calculated both for the yearly and quarterly production. For at least one of the size classifications there was significant difference found for each of the main effects; strain, year, insulation, protein, density and quarter. The quarter effect is expected since egg size normally increases during the production year. The year differences could be due to differences in the growing-period environment from year to year which could cause differences in body size and number of days to sexual maturity or a difference in age at housing.

Protein level of the diet in the Twelfth Test (Table VIII and XI) was found to have a significant effect on several egg size classifications, both for yearly and quarterly production. The birds fed the 17 percent protein diet laid significantly more eggs which were classified as extra large and larger and significantly fewer eggs of the medium size. An important point to consider is the lack of any significant difference between the percentage of large eggs produced by hens fed the 13 percent and 17 percent diets. The protein level fed may

TABLE VI

ANALYSIS OF VARIANCE OF YEARLY EGG SIZE DISTRIBUTION
(EIGHTH, NINTH AND TENTH TESTS)

Source	Degrees of Freedom	Mean Square				
		% Peewee	% Small	% Medium	% Large	% Extra Large and Over
Strain (S)	9	0.25	25.90**	153.74**	167.94**	770.80**
Insulation (I)	1	0.00	0.94	68.40*	24.75	198.40
SI	9	0.02	1.60	12.09	28.24	47.80
Years (Y)	2	1.47**	16.76**	75.67**	382.12**	108.92
SY	18	0.34	6.73*	26.67*	35.02	83.32
IY	2	0.10	2.34	24.84	73.42	183.56*
SYI	18	0.03	1.65	20.05	47.59	83.50
Error	60	0.19	3.08	14.16	28.54	50.92
Total	119	---	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

TABLE VII

ANALYSIS OF VARIANCE OF YEARLY EGG SIZE DISTRIBUTION
(ELEVENTH TEST)

Source	Degrees of Freedom	Mean Square				
		% Peewee	% Small	% Medium	% Large	% Extra Large and Over
Strain (S)	15	1.34	10.89**	109.61**	46.99**	269.92**
Density (D)	1	2.60	0.18	0.15	0.04	2.21
SD	15	0.51	2.19	8.87	13.95	26.88
Error	32	0.70	1.34	16.97	15.16	46.35
Total	63	---	---	---	---	---

** Significant ($P \leq 0.01$).

TABLE VIII

ANALYSIS OF VARIANCE OF YEARLY EGG SIZE DISTRIBUTION
(TWELFTH TEST)

Source	Degrees of Freedom	Mean Square				
		% Peewee	% Small	% Medium	% Large	% Extra Large and Over
Strain (S)	13	7.99**	90.66**	201.90**	74.62*	562.74**
Protein (P)	1	0.27	26.23*	222.89**	2.46	492.24**
SP	13	0.66	7.52*	19.47*	39.98**	66.82**
Density (D)	1	3.98**	4.80	10.44	8.80	14.86
SD	13	0.75*	6.98	9.38	37.46*	51.61*
PD	1	0.06	3.86	0.09	0.79	1.08
SPD	13	0.18	3.54	9.48	34.94*	42.08
Error	56	0.37	4.00	9.49	15.20	25.40
Total	111	---	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

TABLE IX

ANALYSIS OF VARIANCE OF QUARTERLY EGG SIZE DISTRIBUTION
(EIGHTH, NINTH AND TENTH TESTS)

Source	Degrees of Freedom	Mean Square				
		% Peewee	% Small	% Medium	% Large	% Extra Large and Over
Strain (S)	9	0.74	75.46**	507.38**	831.54**	3,269.92**
Insulation (I)	1	0.03	0.04	158.58*	80.36	662.23*
SI	9	0.06	4.63	61.66*	137.41	199.26
Years (Y)	2	5.02**	38.01*	149.02**	1,416.74**	334.98*
SY	18	1.07*	19.29**	106.47**	162.90*	388.22**
IY	2	0.21	4.24	92.07*	338.74*	911.23**
SIY	18	0.08	4.08	69.25**	185.21**	207.62**
Quarters (Q)	3	10.97**	3909.42**	37,524.89**	11,948.75**	93,422.33**
SQ	27	0.86	60.09**	88.34**	638.00**	275.18**
IQ	3	0.06	3.08	42.08	224.44*	379.69*
SIQ	27	0.15	5.01	25.14	67.23	38.18
YQ	6	4.10**	49.20**	259.21**	519.60**	1,352.66**
SYQ	54	1.09	15.00**	33.22	103.53	77.08
IYQ	6	0.22	2.55	53.24	170.61	304.10*
SIYQ	54	0.10	4.56	19.51	61.10	56.01
Error	240	0.59	8.15	26.62	83.90	108.95
Total	479	---	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

TABLE X

ANALYSIS OF VARIANCE OF QUARTERLY EGG SIZE DISTRIBUTION
(ELEVENTH TEST)

Source	Degrees of Freedom	Mean Square				
		% Peewee	% Small	% Medium	% Large	% Extra Large and Over
Strain (S)	15	2.97	25.66**	364.05**	245.54**	1,088.14**
Density (D)	1	4.30	0.30	19.30	7.22	0.10
SD	15	1.57	5.97*	27.74	76.24	138.95
Quarters (Q)	3	873.22**	1796.09**	23,400.08**	7776.58**	44,479.92**
SQ	45	2.88*	18.50**	30.62	205.01**	113.93
DQ	3	3.98	0.01	5.50	39.86	30.71
SDQ	45	1.42	3.98	18.39	56.86	32.35
Error	128	1.76	3.04	27.39	62.47	80.00
Total	255	---	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

TABLE XI

ANALYSIS OF VARIANCE OF QUARTERLY EGG SIZE DISTRIBUTION
(TWELFTH TEST)

Source	Degrees of Freedom	Mean Square				
		% Peewee	% Small	% Medium	% Large	% Extra Large and Over
Strain (S)	13	24.95**	261.71**	710.64**	297.50**	2,314.75**
Protein (P)	1	0.74	95.64**	835.22**	31.93	2,048.15**
SP	13	1.98*	19.71**	73.05**	200.27**	289.31**
Density (D)	1	17.92**	80.75**	5.04	8.75	340.03*
SD	13	1.78*	14.92*	40.69	141.36**	221.76**
PD	1	0.27	11.57	1.25	0.08	6.43
SPD	13	0.62	6.48	45.69	157.01**	187.99**
Quarters (Q)	3	526.67**	22,555.08**	38,575.42**	33,873.92**	40,339.96**
SQ	39	20.60**	145.10**	415.25**	482.88**	263.41**
PQ	3	0.62	36.97**	113.72*	342.50**	282.28**
SPQ	39	1.96	14.52**	56.51**	115.93**	57.29
DQ	3	21.92**	87.18**	111.75*	186.48*	131.47
SDQ	39	1.27	7.80	30.66	63.38	41.92
PDQ	3	0.20	7.80	55.60	35.17	1.59
SPDQ	39	0.61	7.08	22.83	70.55	40.34
Error	224	1.01	8.28	32.92	57.74	52.93
Total	447	---	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

be a means to control the percentage of large eggs laid. To emphasize this point further, the protein-quarter interaction was significant. Birds on the 13 percent protein diet laid approximately three percent and two percent fewer large eggs during quarters one and two, respectively, but six and two percent more large eggs during quarters three and four, respectively. Egg size during the first two quarters might have been due to the relationship of body size as related to the percent protein fed.

The main effect density also was found to have an effect on the quarterly production of eggs extra large and larger. The density-quarter interaction was significant for the percent large eggs produced by quarters. The birds housed two per cage produced fewer large eggs during the first quarter than did birds housed one per cage, producing approximately equal numbers during the second and third quarter, but producing a higher percentage during the final quarter.

The significant strain-protein interaction is of interest. Some strains of birds, for example, produced a higher percentage of large eggs on the 13 percent protein diet while others produced more large eggs on the 17 percent diet. It may be possible to select strains that would produce an acceptable number of large eggs on what would now be considered very low protein diets. Two other first-order interactions, strain-density and strain-quarter, were found to be significant in regard to certain egg size classifications. The strain-quarter interaction points out that all strains do not produce, for example, the same percentage of large eggs in any given quarter. This may be due to differences in sexual maturity, or body size. Strains differed in their ability to lay large eggs whether housed one bird per cage or two birds per cage. One strain laid seven percent more large eggs when housed at the higher density than it did at the low density, while this relationship was reversed for another strain. The strain-protein-density interaction also was significant for the percent large eggs produced. This significant three-way interaction indicates that, if one were trying to produce a strain which would produce the maximum number of large eggs, one should consider both protein level of the diet and cage density.

Egg Production and Egg Weight

Tables XII (Eighth, Ninth and Tenth Tests), XIII (Eleventh Test) and XIV (Twelfth Test) present the data calculated for the laying year on average egg weight, number of eggs produced per bird housed and percent hen-housed and hen-day egg production. Data on the same four variables calculated on a quarterly basis are given in Tables XV (Eighth, Ninth and Tenth Tests), XVI (Eleventh Test) and XVII (Twelfth Test).

Strains were found to differ significantly for all four of the production traits. Where year effect was included in the model (Tables XII and XV), the yearly and quarterly percent hen-housed and hen-day egg production and the number of eggs per bird housed differed among strains. Protein level, density and the interactions which were significant for egg weight were previously discussed in relation to egg size distribution.

Density was found to have a significant effect on number of eggs produced per hen housed, percent hen-housed and percent hen-day egg

TABLE XII

ANALYSIS OF VARIANCE OF YEARLY EGG PRODUCTION AND EGG WEIGHT
(EIGHTH, NINTH AND TENTH TESTS)

Source	Degrees of Freedom	Mean Square			
		Eggs Per Hen-Housed	% Hen-Housed Egg Production	% Hen-Day Egg Production	Average Egg Weight
Strain (S)	9	2051.68**	165.38**	127.51**	22.92**
Insulation (I)	1	3.10	0.22	2.46	1.32
SI	9	342.20	27.39	23.09	2.33
Years (Y)	2	765.21	177.39**	215.75**	1.25
SY	18	307.71	24.70	16.79	3.17**
IY	2	415.33	34.05	28.15	0.88
SIY	18	259.11	20.86	16.93	1.66
Error	60	278.77	22.32	17.43	1.31
Total	119	---	---	---	---

** Significant ($P \leq 0.01$).

TABLE XIII

ANALYSIS OF VARIANCE OF YEARLY EGG PRODUCTION AND EGG WEIGHT
(ELEVENTH TEST)

Source	Degrees of Freedom	Mean Square			
		Eggs Per Hen-Housed	% Hen-Housed Egg Production	% Hen-Day Egg Production	Average Egg Weight
Strain (S)	15	1703.36**	136.48**	116.45**	7.93**
Density (D)	1	53.47	5.12	2.60	2.14
SD	15	300.40	24.44	7.16	0.51
Error	32	300.63	24.51	10.11	1.33
Total	63	---	---	---	---

**Significant ($P \leq 0.01$).

TABLE XIV

ANALYSIS OF VARIANCE OF YEARLY EGG PRODUCTION AND EGG WEIGHT
(TWELFTH TEST)

Source	Degrees of Freedom	Mean Square			
		Eggs Per Hen-Housed	% Hen-Housed Egg Production	% Hen-Day Egg Production	Average Egg Weight
Strain (S)	13	2298.64**	195.19**	147.60**	20.94**
Protein (P)	1	71.68	6.32	1.42	5.58*
SP	13	215.72	18.35	6.93	3.71**
Density (D)	1	627.96	53.76	34.10	3.94
SD	13	403.64*	34.34*	17.93*	1.98
PD	1	7.93	0.72	9.96	4.16
SPD	13	519.73**	44.49**	12.44	1.68
Error	56	187.94	15.98	8.86	1.28
Total	111	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

TABLE XV

ANALYSIS OF VARIANCE OF QUARTERLY EGG PRODUCTION AND EGG WEIGHT (EIGHTH, NINTH AND TENTH TESTS)

Source	Degrees of Freedom	Mean Square			
		Eggs Per Hen-Housed	% Hen-Housed Egg Production	% Hen-Day Egg Production	Average Egg Weight
Strain (S)	9	512.39**	617.70**	587.01**	93.83**
Insulation (I)	1	0.88	4.76	6.19	2.90
SI	9	85.54**	97.94*	202.50**	12.22**
Years (Y)	2	191.09**	664.11**	704.38**	3.12
SY	18	77.00**	86.91*	85.04**	13.36**
IY	2	105.34*	97.50	212.88**	3.01
SIY	18	64.81**	75.52	124.42**	6.37**
Quarters (Q)	3	14,840.74**	4323.22**	3107.52**	2606.87**
SQ	27	63.43**	77.77*	87.48**	2.50
IQ	3	9.88	13.44	7.76	1.39
SIQ	27	16.54	23.74	26.40	2.28
YQ	6	257.44**	545.77**	528.68**	36.21**
SYQ	54	23.34	34.50	40.73	1.86
IYQ	6	38.45	80.42	69.56	6.30*
SIYQ	54	12.88	25.40	30.50	1.82
Error	240	28.86	48.55	41.39	2.37
Total	479	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

TABLE XVI

ANALYSIS OF VARIANCE OF QUARTERLY EGG PRODUCTION AND EGG WEIGHT
(ELEVENTH TEST)

Source	Degrees of Freedom	Mean Square			
		Eggs Per Hen-Housed	% Hen-Housed Egg Production	% Hen-Day Egg Production	Average Egg Weight
Strain (S)	15	426.18**	552.87**	495.40**	29.04**
Density (D)	1	13.60	33.13	0.57	15.60**
SD	15	75.21**	97.26**	36.62	1.96
Quarter (Q)	3	8791.64**	3955.71**	3056.03**	1148.01**
SQ	45	35.64	41.85	57.85**	1.11
DQ	3	34.91	49.95	90.34**	0.86
SDQ	45	11.55	14.56	25.87	1.22
Error	128	26.71	35.50	21.89	2.25
Total	255	---	---	---	---

** Significant ($P \leq 0.01$).

TABLE XVII

ANALYSIS OF VARIANCE OF QUARTERLY EGG PRODUCTION AND EGG WEIGHT
(TWELFTH TEST)

Source	Degrees of Freedom	Mean Square			
		Eggs Per Hen-Housed	% Hen-Housed Egg Production	% Hen-Day Egg Production	Average Egg Weight
Strain (S)	13	574.71**	786.21**	589.21**	79.80**
Protein (P)	1	17.96	20.61	6.41	22.72*
SP	13	53.72**	76.77**	31.02	16.47**
Density (D)	1	156.87**	187.59**	102.80*	29.67*
SD	13	100.97**	137.66**	72.72**	10.93**
PD	1	1.97	1.11	33.99	15.79
SPD	13	129.88**	182.42**	51.26**	7.69
Quarter (Q)	3	22,176.18**	7401.07**	4824.91**	2468.38**
SQ	39	41.19**	52.23**	57.01**	4.65
PQ	3	38.92	47.61	28.77	0.34
SPQ	39	19.36	26.25	17.62	5.03
DQ	3	68.72	73.35*	77.09*	4.08
SDQ	39	11.94	16.20	21.48	4.01
PDQ	3	65.82*	84.70*	96.02**	2.48
SPDQ	39	9.75	15.24	15.73	4.31
Error	224	19.22	27.23	19.92	4.85
Total	447	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

production, calculated on a quarterly basis in the Twelfth Test (Table XIV). One strain produced 223 eggs per bird when housed two per cage and 202 eggs per bird housed at the lower density of one per cage. Another strain showed a 15 egg-per-bird-housed advantage at the lower density. Strains can apparently differ by a significant amount in their ability to perform at the higher density. The strain-protein-density interaction also was significant for number of eggs produced per bird housed, both per quarter and per year.

The many significant strain by environment interactions (Tables XV, XVI and XVII) for these production traits calculated on a quarterly basis may be of major importance. This increase in the number of significant interactions found using quarterly versus yearly records is in keeping with the generally recognized difficulty of detection of the interactions. The fact that larger numbers of observations are required to detect small effects is well born out by these data.

Feed Efficiency and Hen-Days

Mean squares for the yearly record number of hen days, pounds of feed per hen housed, per pound of eggs and per average number of hens are presented in Tables XVIII (Eighth, Ninth and Tenth Tests), XIX (Eleventh Test) and XX (Twelfth Test). Data on these same variables, calculated on a quarterly basis, are given in Tables XXI (Eighth, Ninth and Tenth Tests), XXII (Eleventh Test) and XXIII (Twelfth Test).

Strains differed significantly in amount of feed consumed per bird housed, per pound of eggs and per average number of hens. Density level also had a significant effect on feed efficiency as measured in

TABLE XVIII

ANALYSIS OF VARIANCE OF YEARLY FEED EFFICIENCY AND HEN-DAYS
(EIGHTH, NINTH AND TENTH TESTS)

Source	Degrees of Freedom	Mean Square			
		Pounds of Feed			Hen-Days Per Hen Housed
		Per Hen Housed	Per Pound of Eggs	Per Average Number of Hens	
Strain (S)	9	109.84**	31.07**	108.56**	1075.4
Insulation (I)	1	10.15	4.03	11.66	1470.0
SI	9	24.41	10.90	18.97	727.8
Year (Y)	2	48.20	14.28	127.73*	3168.7**
SY	18	21.40	7.28	30.37	1182.0
IY	2	38.87	6.11	28.20	1154.8
SIY	18	33.09	7.58	32.76	687.0
Error	60	33.09	7.23	37.47	952.0
Total	119	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

TABLE XIX

ANALYSIS OF VARIANCE OF YEARLY FEED EFFICIENCY AND HEN-DAYS
(ELEVENTH TEST)

Source	Degrees of Freedom	Mean Square			
		Pounds of Feed			Hen Days Per Hen Housed
		Per Hen Housed	Per Pound of Eggs	Per Average Number of Hens	
Strain (S)	15	168.13**	23.10**	93.30**	2259.36*
Density (D)	1	319.96**	50.23**	689.06	221.26
SD	15	36.51	2.17	12.59	551.46
Error	32	27.12	2.31	11.21	475.42
Total	63	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

TABLE XX

ANALYSIS OF VARIANCE OF YEARLY FEED EFFICIENCY AND HEN-DAYS
(TWELFTH TEST)

		Mean Square			
		Pounds of Feed			
Source	Degrees of Freedom	Per Hen Housed	Per Pound of Eggs	Per Average Number of Hens	Hen Days Per Hen Housed
Strain (S)	13	163.76**	42.97**	82.62**	1301.97
Protein (P)	1	49.96	6.70	8.36	1002.01
SP	13	27.19	2.27	11.93	362.26
Density (D)	1	329.14**	9.03*	314.23**	31.08
SD	13	27.21	2.51	5.11	311.83
PD	1	6.90	0.41	25.46	18.08
SPD	13	40.38*	4.52*	10.68	707.60
Error	56	17.91	2.09	9.79	370.06
Total	111	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

TABLE XXI

ANALYSIS OF VARIANCE OF QUARTERLY FEED EFFICIENCY AND HEN-DAYS
(EIGHTH, NINTH AND TENTH TESTS)

Source	Degress of Freedom	Mean Square			
		Pounds of Feed			Hen Days Per Hen Housed
		Per Hen Housed	Per Pound of Eggs	Per Average Number of Hens	
Strain (S)	9	27.63**	127.62**	26.49**	273.4**
Insulation (I)	1	2.52	16.72	3.18	364.0*
SI	9	6.16*	49.29**	5.26	186.8*
Years (Y)	2	12.03*	77.27**	35.90**	816.8**
SY	18	5.42**	30.75**	8.04**	302.7**
IY	2	9.37*	22.89	6.11	290.2*
SIY	18	8.33**	30.88**	8.01**	172.5**
Quarter (Q)	3	1359.45**	182.79**	1205.76**	21,171.9**
SQ	27	1.03	9.56	0.95	12.8
IQ	3	1.19	1.64	1.25	4.0
SIQ	27	0.94	3.62	0.92	5.6
YQ	6	8.93**	56.60**	9.01*	129.8
SYQ	54	1.18	6.86	1.00	4.6
IYQ	6	1.51	2.25	1.90	0.8
SIYQ	54	1.21	3.83	1.27	4.1
Error	240	2.69	12.25	3.14	65.7
Total	479	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

TABLE XXII

ANALYSIS OF VARIANCE OF QUARTERLY FEED EFFICIENCY AND HEN-DAYS
(ELEVENTH TEST)

		Mean Square			
		Pounds of Feed			
Source	Degrees of Freedom	Per Hen Housed	Per Pounds of Eggs	Per Average Number of Hens	Hen Days Per Hen Housed
Strain (S)	15	42.07**	102.74**	23.78**	569.76**
Density (D)	1	79.66**	215.91**	160.97**	46.41
SD	15	9.11**	9.82*	3.14*	138.26**
Quarter (Q)	3	883.18**	326.98**	556.63**	17,628.41**
SQ	45	2.05	13.92**	2.31	32.56
DQ	3	19.96**	10.50	21.20**	7.42
SDQ	45	1.60	7.10	1.70	13.05
Error	128	2.49	5.52	1.69	38.72
Total	225	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

TABLE XXIII

ANALYSIS OF VARIANCE OF QUARTERLY FEED EFFICIENCY AND HEN-DAYS
(TWELFTH TEST)

Source	Degrees of Freedom	Mean Square			
		Pounds of Feed			Hen Days Per Hen Housed
		Per Hen Housed	Per Pounds of Eggs	Per Average Number of Hens	
Strain (S)	13	40.99**	191.29**	20.83**	328.56**
Protein (P)	1	12.12*	22.23	1.51	243.08**
SP	13	6.78**	11.86	2.96*	96.47**
Density (D)	1	82.89**	62.25**	75.08**	3.94
SD	13	6.91**	11.52	1.28	83.66**
PD	1	1.66	1.46	6.41*	7.51
SPD	13	10.17**	23.98**	2.82*	178.13**
Quarters (Q)	3	1761.67**	302.98**	1567.24**	31,267.94**
SQ	39	3.22*	16.71**	2.32*	25.78
PQ	3	2.24	7.84	2.06	13.87
SPQ	39	1.20	6.75	0.96	11.30
DQ	3	7.36**	18.56	8.45**	7.96
SDQ	39	1.49	6.36	1.22	7.49
PDQ	3	2.77	6.54	3.41	0.75
SPDQ	39	1.31	8.39	1.61*	8.99
Error	224	1.84	7.10	1.40	29.41
Total	447	---	---	---	---

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

these tests. In the Twelfth Test two birds per cage required 4.4, .18 and 6.6 fewer pounds of feed per bird housed, per pound of eggs and per average number of hens, respectively, than the birds housed one bird per cage. The three-way interaction, strain-protein-density, was significant in the Twelfth Test for pounds of feed per hen-housed and per pound of eggs produced.

There were many strain-environment interactions indicated for these feed efficiency traits when calculated quarterly (Tables XXI, XXII and XXIII). This indicates the need when testing for strain-environment interactions to employ an experimental design with the power to test for small differences.

A significant strain-density interaction was found for the number of hen days, an indication of mortality, calculated quarterly in tests Eleven and Twelve (Tables XXII and XXIII). The average number of hen days per quarter for some strains showed very little difference when housed at the different density levels, but some strains seemed at a great disadvantage when housed two per cage. Several strains had 20 to 30 fewer hen days per quarter when housed two per cage than when housed one per cage. This interaction was suspected but not detected by statistical analysis when the yearly record was used as the basis of analysis.

The possibility of not detecting differences between strains due to genotype-environment interactions when they do exist has been discussed by Hill and Nordskog (1956), Nordskog and Kempthorne (1960) and Dickerson (1962).

Hill and Nordskog (1962) found that detection of a significant difference ($P \leq 0.05$) between varieties in the number of eggs the varieties produced at a single location, would require a 60 egg difference. Retesting at the same location for three years required only a 31 egg difference between varieties to find differences at the same level of significance. Nordskog and Kempthorne (1960) pointed out that the number of test locations and pen replications differ in their ability to test accurately for significant differences between strains. Dickerson (1962) showed that more individuals must be tested in order to make a given amount of genetic improvement in traits exhibiting genetic-environment interaction as compared with traits of the same heritability with no genotype-environment interaction.

Genotype-environment interactions can be important but produce such small constant effects for traits of low heritability that statistical significance is frequently not detected. Because of their small magnitude, they are often not demonstrated by experimental procedures which are adequate to demonstrate main effects.

V. SUMMARY

Data collected during the Eighth, Ninth, Tenth, Eleventh and Twelfth Tennessee Random Sample Laying Tests (1964-1969) were analyzed statistically using analysis of variance. Egg production, egg size distribution, egg quality and feed efficiency variables were calculated on a yearly and quarterly basis. The effects; strains (20 strains), years (3 years), density level (1 per cage and 2 per cage), protein level (13 and 17 percent), insulation value (4R and 13R), quarters (four quarters) and their interactions were tested for statistical significance.

Strains were found to differ significantly with respect to nearly all traits studied. Strain-density and strain-protein interactions were found for many variables. Differences between quarters were significant as would be expected for the traits studied. The other main effects, years, insulation value, protein level and density level were not consistently significant.

Many of the strain-environment interactions were found to be significant. More strain-environment interactions were detectable as statistically significant when quarterly records, instead of yearly records, were used as a basis for analysis. Several of the second-order interactions also were found to be significant.

These data indicate that strain-environment interactions are real, are difficult to detect, and require experimental procedures which allow for detection of small differences if statistical significance is to be shown. Sub-samples of egg production strains entered in the Eighth, Ninth, Tenth, Eleventh and Twelfth Random Sample Laying Tests did not perform equally within a strain when subjected to different environments.

The significant strain by environment interactions found in this study demonstrates that not only are there strains presently available to poultrymen which perform differently in different environments, but that through selection strains with improved ability to perform well under new or stressed inducing environments could be developed by breeders.

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VITA

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