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Title: ACCELERATED SELECTION FOR HEN-HOUSED EGG PRODUCTION AND CORRELATED RESPONSES IN WHITE LEGHORNS (*GALLUS DOMESTICUS*)

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(Signature)
Paul E. Bernier

The records of a population of White Leghorns at the Oregon State Agricultural Experiment Station, submitted to accelerated selection for hen-housed egg production on an individual and a family basis at 40 weeks of age for 18 years, were studied. An analysis was made to determine the relative efficiency of accelerated selection compared to direct selection for egg production based on annual records. When annual means of the production line were compared with control populations, accelerated selection proved to be effective in obtaining genetic gains in hen-housed annual production by increasing the part-year or egg production to February 1 while the residual production remained unchanged.

Reliable estimates of genetic parameters obtained from the pooled analysis of the data demonstrated that accelerated selection

on the basis of egg production to February 1 is justified and could provide 1.8 times as much genetic gain per year as would direct selection based on annual records.

The half-sib heritability estimates for hen-housed egg production were 14 percent for production to February 1 and 11 percent for annual production. Sexual maturity had an heritability of 27 percent and body weight one of 53 percent. The estimates of heritability for egg weight and egg specific gravity averaged 32 percent and 30 percent, respectively.

The full-sib estimates of heritability were generally larger than those based on half-sib estimates, indicating the presence not only of additive genetic variance in the population, but also other sources of variation such as non-additive genetic variance and maternal variance. For this reason, half-sib estimates of heritability are more reliable.

The high estimate of genetic correlation, 0.86, between annual hen-housed egg production and that to February 1 justifies the use of accelerated selection. The positive correlation between residual egg production and that to February 1 indicates that there was no decline in residual production as a result of accelerated selection.

Annual egg production seems to have plateaud in the last six generations, possibly due to a reduction in the additive genetic variance as indicated by the negative time trend of the heritability of hen-housed egg production to February 1. The progressive reduction in mortality indicates that the effect of inbreeding caused by restrictions in population number has not been important.

Selection indices for annual and production to February 1 were derived from the estimates of genetic parameters. The results of this study demonstrate that accelerated selection for hen-housed egg production at 40 weeks of age or to February 1 has been more effective than direct selection on annual records would have been.

Accelerated Selection for Hen-Housed Egg Production and Correlated Responses in White Leghorns (*Gallus domesticus*)

by

Oscar Cáceres

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Professor of Poultry Genetics
In Charge of Major

Redacted for privacy

Chairman of Genetics Board

Redacted for privacy

Dean of Graduate School

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INTRODUCTION

In 1947, a long-term investigation to determine the efficiency of accelerated selection for improvement of economic characters in chickens was initiated at the Oregon Agricultural Experiment Station within a Single Comb White Leghorn population. Accelerated selection is selection early in life and on the basis of limited information. This practice permits economy not only in gathering information on the various characters usually taken into account in an improvement program, but also an acceleration of the selection process since the birds selected for breeding can be only one year old as compared to two or more years when selected on the basis of full-year and progeny performance. Soon after this project was initiated, studies by Lerner and Cruden (1948) established the theoretical soundness of the hypothesis of accelerated selection.

If accelerated selection is successful, it should result in an increase in egg production not only in the partial period, but also in the total yearly production, even if the residual period remains unchanged, assuming that the genetic correlation between the partial record and full record is high.

Since the Oregon experiment was initiated, other experiments have been conducted and reported upon to study the effect of accelerated selection and they have shown conflicting results. Some of these experiments have indicated that a considerable genetic gain had been made in both components of production, part and full record, under direct and indirect selection, while in other studies it was observed that gain in the partial record was accompanied by a consistent loss in the residual component. The latter result is considered to be one of the major causes of the plateau condition obtained in many of the selection experiments for genetic improvement of egg production in poultry.

In the present study, which included 17 generations of accelerated selection, the mean-hen-housed egg production to 64 weeks has improved steadily, but in more recent years it has shown a state of equilibrium or a plateau has been reached (Bernier, Oregon State Agricultural Experiment Station, Annual Progress Reports).

The large scale computer analysis reported here has permitted the determination of the extent of genetic progress realized in selection for hen-housed egg production since the inception of the experiment in 1947. The large number of generations included and the control populations maintained throughout the experiment to evaluate the effect of the environment on the means of the selected population have permitted a general analysis of the effectiveness of accelerated selection based on genetic parameters estimated with desirable precision.

The purpose of this study was to determine the relative efficiency of accelerated selection compared to direct selection for egg production based on 64-week records. In addition, selection indices were derived from the estimates of genetic parameters.

REVIEW OF LITERATURE

The results of investigations conducted to study the effect of accelerated selection in annual egg production have demonstrated that it is possible to obtain gains in the annual record from selection based on early records of production, but this improvement in the selected trait could possibly be at the expense of residual production or difference between the early and total records.

Clayton (1927) reported that pullets that laid 60 or more eggs during four winter months would lay 200 or more eggs in the full year. As a rule, the White Leghorn pullets of the experimental flock at the Mississippi Agricultural Experiment Station laid during the winter months approximately 27. 7 percent of their yearly production and, therefore, the annual production could be estimated from the average winter production.

Dickerson and Hazel (1944) demonstrated the need of reducing the interval between generations by yearly or accelerated selection to improve the effectiveness of selection for important traits of farm animals. The criterion of effectiveness was the average genetic improvement expected yearly from early selection alone as compared with that expected when use is made of the progeny test. The study included economic traits in farm livestock for which the basis of earlier culling is restricted to individual performance, pedigree, or average performance of collateral relatives.

Dempster and Lerner (1947) presented the results obtained in the determination of expected genetic gains in egg production under different age compositions of a breeding poultry flock. Different schemes were investigated where selection of the breeding flock was based entirely on birds that had completed the first year of laying, or the selection done among pullets with part records only or a combination of both. They concluded that schemes involving the use of pullets in breeding pens are more efficient than those in which only hens are used. The scheme found to be optimal consisted of 90 percent pullets--selected on the basis of their part record and that of their sisters--and of 10 percent hens selected from full year individual and sister records as well as part progeny records. The genetic correlation between part and full records was 0.75 and this is the first estimate in the literature for the genetic correlation between these two measurements.

Lerner and Cruden (1948) studied the production records in an experimental flock of White Leghorns that consisted of two lines hatched and raised together. One line constituted the production-bred fraction of the flock selected for egg production while the other line was selected for various purposes such as blood spots, shell thickness, persistency, etc. They considered, instead of egg production in the different periods or months of the year, the accumulative records of survivors from the beginning of production to the end of successive calendar months and their correlations with the total annual production. They found that the amount of genetic gain per generation when selection is practiced on the basis of part records to the end of December was about two-thirds of that expected if selection were based on the full annual record. The heritability of accumulative egg production, estimated from components of variance, was nearly constant throughout the year (33 percent), but in the production flock the heritability of early records was, in general, higher than that for more extended periods of time. The genetic correlations between part and full production were found to be high (0.78). They suggested that the greatest efficiency would be obtained with birds selected on the basis of their part records and mated at one year of age.

Bernier (1949) pointed out that the progeny test is the selection method usually recommended for the genetic improvement of egg production, and when the test is completed, dams three years old or over are used for breeding purposes. Since chickens have a short life span, few dams and sires with the best progeny records are still available when sufficient progeny test data are obtained. Due to this consideration and other objections to the use of old stock for breeding purposes he emphasized the importance of obtaining factual information on the exclusive use of pullets and cockerels in a breeding program to confirm the favorable results of Lerner and co-workers with selection based on part-time records.

Lerner and Cruden (1951) demonstrated that, as in the case of egg number, selection for egg weight based on early observations is also more efficient than that based on late measurements, leading to greater genetic gain. The material used in the study was drawn from the University of California production-bred flock of White Leghorns and estimates of heritability were obtained from variance analysis and daughter-dam regression for three consecutive years.

Krueger et al. (1952) analyzed the data collected for four years on four different breeds, including White Leghorns. Among the characters studied were body weight at 10 weeks of age and at housing time, sexual maturity and egg production to 70 weeks of age. The heritability estimates from full-sib correlation for these four characters were 0.46, 0.43, 0.20 and 0.28, respectively. Corresponding heritability estimates from regression of progeny on dam was 0.33, 0.32, 0.07 and 0.23, respectively. Genetic correlations between total production and 10-week body weight was 0.13, housing weight, 0.07, and sexual maturity, 0.53.

Bernier (1953) summarized the results obtained from five generations of White Leghorn pullet breeding at the Oregon State Agricultural Experiment Station. Selection was based on family hen-housed performance to February 1, at which time the birds were 40 weeks of age or after three to four months of production. The cumulated monthly egg production of the production line showed a marked increase not only in performance at 40 weeks of age, but also at the end of the laying year when compared to special lines selected for characters other than egg production. The author concluded that there is little doubt as to the value of accelerated selection, but whether it will remain effective as the level of production increases remains to be determined.

Maddison (1954) studied the egg production records for three consecutive years in a breeding flock of Rhode Island Red chickens at Wye College, England, one part of the flock being submitted to selection based on partial and the other to whole-year records. The statistics used were calculated from the production records of birds surviving their first laying year. The heritability computed for partial and full-year egg production was slightly higher than that obtained by Lerner and Cruden (1948), while the genetic correlations were lower. He concluded that the genetic gain from accelerated selection was about 50 percent more efficient than selection based on full-year survivors records for egg production and, therefore, the use of part records would lead to increased genetic gains on a per-year basis.

Lerner and Dempster (1956) tried to verify the theoretical expectations of gains in annual egg production from pullet and from hen selection. Differences between the alternative selection schemes could not be established because of adverse environmental circumstances, and the test was terminated after three years. The University of California flock of production-bred White Leghorns was divided in two sub-populations designated as the "Pullet" and "Hen" lines. The egg production performance of the Pullet line exceeded by a slight margin that of the Hen line in both hen-housed and survivors production. Laying house mortality, however, was lower in the hen-bred group. The higher rate of inbreeding and also the higher mortality in the Pullet line were possible explanations for the lower than expected cumulative advantage of the Pullet line.

King and Henderson (1954) analyzed three consecutive years of records in a commercial flock of White Leghorns and estimated the heritability of several traits on the basis of variance components and also by regression of progeny mean on dam. The average heritability estimate for hen-housed and survivors egg production to January 1 was 0.34 and 0.48, respectively, and for annual production the estimates were 0.195 and 0.31. Estimates of heritability by regression of progeny mean on dam were obtained only for survivors egg production and were lower than those obtained by variance components for both traits. There was a decline in heritability for egg production from a high in January 1 to a low for annual production. The authors suggested that the higher heritability of the part record combined with the reduced generation interval made possible by selection at an early age could increase genetic gain provided the genetic correlation between part and annual production is sufficiently high. This study lacked a control flock to measure genetic progress in the selected flock.

Jerome et al. (1956) reported estimates of heritability and correlations for different characters based on measurements obtained for five years in a commercial flock of New Hampshires. Matings were made according to a polyallel arrangement of sires and dams and only progeny which survived to 365 days subsequent to sexual maturity were included in the analysis. Three types of heritability estimates were obtained by pooling the variance components obtained in each of the five years. They were from the sire component, from the dam component, and from the combined sire and dam component. In the case of early and annual egg production, the heritability estimates calculated from the sire component exceeded those obtained from the dam component and the average value was 0.29 and 0.12, respectively. The earlier periods of production, as in the previous reports cited, had higher estimates of heritability than the total record. The average genetic correlation between early and annual egg production based on both the sire and the dam covariance was 0.39.

Morris (1956) provided estimates of genetic parameters of production characters obtained from an experimental flock of White Leghorns pullets hatched at the Poultry Research Centre, Werribee, Australia. Information was extracted from three consecutive years of production records and analyzed on a hen-housed and a survivor basis. All records were adjusted to a common hatching date. Heritability of part record and 72-week production was estimated for both hen-housed and survivors production by variance component analysis and by intra-sire regression of daughters' mean production on dam's production. The joint estimate from the pooled analysis indicated an heritability of 32.4 percent for the part period and 30.8 percent for 72 weeks. Heritability estimates obtained from daughter-dam regressions were lower than those obtained by the variance component analysis. The genetic correlation between these two traits was 0.72 and, therefore, it was concluded that early selection should provide approximately 1.44 times as much genetic gain as would selection on the full record.

Abplanalp (1957) presented heritability and correlation estimates obtained on 2,647 pullets from 40 sires and 137 dams belonging to four generations of a White Leghorn strain in which mostly old progeny-tested parents were used. The following characters were included in the study: March egg weight, egg production to February 1 or winter egg production, egg production from February 1 to 72 weeks of age or residual egg production, and sexual maturity. Heritability estimates and genetic correlations were based on sire and dam components. The heritability estimates for March egg weight, winter production, residual production and sexual maturity were 0.49, 0.26, 0.14 and 0.12, respectively. The genetic correlations among these traits indicated that March egg weight was negatively correlated with egg production, winter and residual production were negatively correlated with sexual maturity, and the correlation between winter egg production and residual egg production was 0.55, indicating that the ability of hens to lay eggs at one period is correlated positively with that in another period. From these results, it is observed that when direct selection is applied on winter egg production, an expected direct response of 2.6 eggs is obtained, and a correlated response of 0.36 on residual egg production. When direct selection is applied on residual egg production, the expected direct response is 1.38 eggs and the correlated response on winter production is 1.72.

Yamada et al. (1958) studied an experimental population of White Leghorns at the Purdue Experiment Station submitted to accelerated selection for egg production during ten years and showing no apparent response after the fifth year of selection. The pullet breeders were chosen on the basis of the superiority of their own record and their sib family percent egg production averages to January 1. Heritability was estimated within years by the variance component method and averaged 0.14, 0.24, and 0.19 from sire, dam and combined component, respectively. The annual estimates fluctuated from year to year and the general trend showed a decrease during the early years of selection but remained fairly constant at a lower level during the last five years. The annual realized gains were not found to be significantly different from those expected on the basis of the annual selection differentials and heritability estimates from the sire component of variance.

Schaaf and Wendt (1959) examined the correlation between initial egg production and total annual production during three years. They found for White Leghorns and Brown Leghorns that genetic correlations surpassed phenotypic correlations. Heritability was higher for winter production than for longer periods. Consequently, it was concluded that using young hens selected on the basis of a short test would lead to greater genetical progress than selection on the basis of the entire year and breeding with two-year-old hens.

Onishi and Kato (1960) evaluated the relative efficiency of selection for annual egg production by using part-time records as a selection criterion. The production records of an experimental flock of White Leghorn at the National Institute of Agricultural Sciences, Japan, were used. The flock was composed of several inbred lines and some crosses among them, therefore, the estimates of heritability were corrected for the inbreeding coefficient.

The estimates of heritability from the dam components were higher than those from the sire components and showed an increase during the first four months of production, but a gradual decrease thereafter. The genetic correlation between the first year total production and the part-time record in three or four consecutive months throughout the first laying year was, in general, high (0.65). It was concluded that a part record of production (40 weeks) is as reliable as the full-year record itself and, therefore, part records may be used more effectively for improvement of egg production than annual records for economical reasons.

Bray et al. (1960), with the same data originally used by King and Henderson (1954), studied the effect of various refinements in handling egg production data on calculation of heritability and correlations. Sexual maturity was demonstrated to have large effects on estimates of heritability for early production when egg numbers from date of first egg is the measure. The use of percent production removed these effects.

James and Foenander (1961) reported the results of an experiment designed to study the effect on egg production of the actually determined social ranks of caged hens. An experimental Australorp flock maintained at the University of Queensland, Australia, was divided into three groups, two under selection for part-record egg production and one mated at random without selection. The results obtained gave clear evidence of a relationship between social rank and production, mainly through age at sexual maturity. The authors suggest, according to the results, that social rank is a component of part-record egg number, but not of full record production. Selection on part record might then be expected to lead to increased aggresiveness, as a correlated response to selection for part-record egg number.

King (1961) reported estimates of genetic parameters from the data collected on pullet flocks at the regional Cornell control population hatched in 1957 and 1958. The traits considered in this study included: Sexual maturity, percent or hen-day egg production to approximately 40 weeks and 72 weeks of age, 32 weeks body weight and egg weight. Heritability estimates, using the dam components of variance, were as large or larger than those from the sire components, and averaged 0.26 for sexual maturity, 0.62 for 32 weeks body weight and egg weight, 0.06 for percent production to 40 weeks of age, and 0.16 for percent production to 72 weeks of age. The higher heritability estimates, as compared to others reported in the literature, were attributed to the broad genetic base of the regional Cornell control population, without the effects of artificial selection, and inbreeding. Genetic correlations were not as consistent between years as heritability estimates and more often exceeded 1.0. These results emphasize the complexity of the inheritance of economic traits and perhaps explain the difficulties which apparently have arisen in maintaining continued progress with selection programs.

Nordskog and Festing (1962) reported the results of a five-year study on a selection experiment, conducted at the Iowa Agricultural Experiment Station, to determine the direct and correlated responses to selection for egg production, body weight and egg weight. Two breeds were used, White Leghorn and Fayoumi, including lines in which selection for the mentioned traits was practiced in both an up and down direction as well as control lines. The results for part-year production and total egg production suggested that selection on a part-year egg rate was not highly effective. Also it appeared that change in body size influenced egg production more adversely than egg size. Body weight lines showed lower egg production than the egg weight lines.

Friars _et al_. (1962) investigated the changes over a period of nine years in heritability and correlation between certain traits as observed in a population of White Rocks, to which multiple objective selection was applied. The characters measured were early body weight and breast conformation score at eight weeks of age, percent production to January 1, egg weight, and mature body weight. No time trend of apparent consequence was evident in the heritability estimates of the traits studied. Estimates from sire components were smaller than those obtained from the dam components in the five characters analyzed, and they averaged 0.63 for early body weight, 0.61 for adult body weight, 0.33 for egg production to January 1, and 0.48 for egg weight. The time trend in the genetic correlations was negative in most of the cases. In the 18 estimates of genetic correlations between pairs of traits, the only two positive time trends were between adult body weight and juvenile body weight, and between egg weight and juvenile body weight. These results indicated that the genetic correlations were apparently declining over the nine years of this study. It was concluded that selection on more than one trait and genetic correlations between selected and unselected traits could be the reason for the negative trends in the correlations.

Erasmus (1962) obtained data over a five-year period from a production flock of White Leghorns at the University of Stellenbosh, South Africa. The part record was considered as the production until the end of June (December in the Northern Hemisphere) and the full-year record until January (July in the Northern Hemisphere). An important feature of the results obtained appears to be the fact that the increase in the average full production record of the flock in the last four years was due to an increase in the part-record production. From 1956 to 1960, an increase of 35 eggs in the part-period production index and an increase of 11 eggs in the total annual production were observed along with a decline of 24 eggs in the residual period. The increase in the part-period production was sufficiently large to compensate for the loss in the residual part.

Waring et al. (1962) studied the effects of selection for egg production in an experimental flock of Light Sussex at Wye College, England. The flock consisted of 1,000 pedigreed pullets replaced annually by mating 12 cockerels each to 12 pullets. Genetic parameters were estimated for the characters: Egg number, egg mass and egg weight up to January 22, May 7, and August 6, 1960; egg number, egg mass and egg weight at 40, 55 and 65 weeks of age; and egg number, egg mass and egg weight at 17 and 32 weeks after first egg. Egg mass was not measured directly but was obtained by multiplying the average weight of eggs by the number of eggs recorded during a four-week period. Sire, dam and combined estimates of heritability and correlations were obtained from the variance-covariance analyses. The results showed consistently higher estimates of heritability from the dam component than from the sire component. As in previous studies, it is not possible to determine exactly whether maternal or interaction effects might be responsible for these results. Another possibility suggested by the authors is that the higher selection practiced on males in this population could account for the disparity between the two estimates. Another interesting finding, contrasting with other results in the literature, was the consistent increase in the heritability estimates as the laying year progressed. Selection based on a calendar date gave higher estimates of heritability than at specific ages or periods of lay. The genetic correlations between early and full records were high, both with respect to egg number and egg weight. The genetic correlations between egg mass and egg number were uniformly high, being of the order of 0.9, indicating that egg number and egg mass are just different measurements of the same trait.

Gowe and Strain (1963) analyzed data collected from two strains of White Leghorns under selection for increased egg production for 10 and 11 generations. Selection for the first seven generations was based on a combination of part-year and full-year records. In the last five generations, only the part year production record was used for selection. A control population based on three sources (commercial strain cross, broody inbred line, and meat and blood spot inbred line) served to measure the genetic progress in the production lines. The results revealed that the part-year production increased about 16 eggs in one strain and about 22 eggs in the other. Egg production on the residual part did not improve for the last eight generations and rapidly decreased in the last four generations in both strains.

Kraszewska-Domanska (1963) calculated genetic correlations between initial rate of production and the remaining part of the annual egg production from breeding population of the breeds Polbar, Greenleg, Rhode Island Red and Leghorn pullets. It was found that with the exception of Leghorns, the relationship of the two measurements was negative in all the other breeds. The author suggests that the negative genetic correlation was caused mostly by poor persistency and the large incidence of broodiness observed in three of the four breeds tested.

Morris (1963) reported the results on 12 years of selection for high egg production in a flock of White Leghorn chickens already described (Morris, 1956). Selection was based on part-record production from date of first egg until May 31 (November 31 in the Northern Hemisphere). Considerable genetic gain was made in the character under selection. This gain was approximately three eggs per generation for the part period, and at the end of the experiment the rate of gain remained about the same. The annual production, however, increased during the first years of selection but a leveling off was reached in subsequent generations. The average heritability, obtained by pooling the records of seven years, for part and residual production for both hen-housed and survivors was approximately 0.23. Estimates seem to have decreased during the first years to rise again during the last years. No evidence was found to suggest that the decline in heritability was due to selection. Genetic correlations between part-period and residual performance decreased in value with the progression of selection. The size of the correlated decline in the residual production suggests, according to the author, not only a reduction in value of the genetic correlation, but also a change of sign. It was concluded that the considerable gain in the part-period production and the consistent loss in the residual part may be the result of a negative genetic correlation between these two traits, and the use of part-period egg production cannot be justified since it is not a satisfactory selection criterion.

Morris (1964) points out the evidence of a decline in egg production in the residual period, when selection is directly exercised only on the part period. He maintains that prolonged selection for part-period egg production may result not only in a plateauing of total annual egg production, but also an economic loss which would come from the altered distribution of the same quantity of eggs. It is suggested as a possible solution to this problem that a breeding program incorporating as many of the advantages of population genetics as practicable and attaining a reasonable compromise with management restrictions be initiated. Such a program should consider: (1) Male selection on an index based on the part-period rate of lay of full and half-sister families; (2) Similar female selection, but the index would be constructed from actual egg production recorded over a considerably extended period (no breeding would take place from pullets), even though one half of the benefit of a shortened generation interval, obtained by the use of part-period records, is lost.

Binet (1965) considered the statistical and mathematical treatment of the construction of an index for indirect selection, based on a linear combination of the characters involved. An expression was deduced from the resulting biometrical formulas which yields the optimal linear combination of two measurable characters for selection aiming at genetic improvement in a third. He concluded that the method of constructing this index is of interest, as a substantial advantage might well be attainable from such an index in breeding projects, with different values of genetic parameters.

Jaffe (1966) estimated the heritability and genetic correlation between part-record production, body weight, egg weight, shell color, specific gravity and albumen quality in one strain each of Light Sussex and Rhode Island Red and in three strains of White Leghorns using variance and covariance components. The heritability values were in general agreement with published figures and significant positive genetic correlations were found between egg weight and body weight in four strains, egg weight and shell color in one strain, and in specific gravity and Haugh units in one strain. A negative correlation was found between body weight and shell color in one strain.

Morris and Binet (1966) analyzed the results obtained with two hybrid lines generated by crossing White Leghorns and

Australorps reciprocally and developing two F_2 populations, one from each cross. The populations were then closed and accelerated selection was exercised on a hen-housed basis for five generations. A randomly mated non-selected line was utilized as a control. The results obtained were similar to those reported when a similar selection scheme was applied to a non-related line (Morris, 1963). The character directly selected for showed a positive response in both lines, indicating that selection was effective in shifting mean performance. As there was no gain in annual production, it would appear that the gain in the part period was achieved at the expense of the residual period of production.

Lowe et al. (1966) determined the response in part, residual, and annual egg production from selection based on early records in the regional Cornell control population. Eight years' data were pooled to obtain estimates of heritability and genetic correlations among egg production traits. The traits studied were: Percent or hen-day egg production and actual number of eggs laid in the part period, production during the residual period and total period, and sexual maturity. The components of variance and covariance for sire and dam were obtained using survivors records and considering only the birds that laid. Positive genetic correlations of 0.4 to 0.6 between part and residual egg production and 0.8 between part and total production indicate that selection on a part-record basis should be effective in improving both residual and total production. Estimates of average expected genetic gain from accelerated selection for five generations as based on hen-day production to 40 weeks of age were 1.6 percent, 2.5 eggs and 6.2 eggs for part, residual and annual record, respectively.

Nordskog *et al*. (1967) presented the results of eight generations of accelerated selection for egg production in two populations of White Leghorns and Fayoumis. Heritability estimates from half-sib correlations were significantly higher for the full record than for the early record (0.25 and 0.09, respectively). The genetic correlation between the early record and the full-year record was 0.88 in Leghorns and 0.79 in Fayoumis. These results failed to demonstrate that accelerated selection for egg production improved either early rate or total rate of egg production. From the parameter estimates it could not be demonstrated that indirect selection on early rate was any more efficient than direct selection on total rate of egg production.

EXPERIMENTAL PROCEDURE

Source and Description of Data

Production Line

A strain of White Leghorns has been under selection for egg production since 1947 at the Oregon State Agricultural Experiment Station. Hen-housed egg production at 40 weeks of age or part-year production, on the basis of both individual and family performance, has been the primary criterion of selection of the dams in this production line. In addition, egg weight received consideration in selection because of its economic importance. The sires used for breeding were selected on the basis of their full sister's records. At the initiation of this investigation, the base population was obtained from a cross between two Oregon commercial strains and remained closed to outside breeding until 1956 when males of six other commercial strains were introduced for a test of combinability.

Control Group

A population of White Leghorns, the control group, was also maintained to measure the relative selection progress, making possible the separation of the environmental and genetic trends. The control group consisted of four different sources:

Special Lines. These lines have been maintained throughout the investigation starting with 1949, and they were selected not for egg production but for traits such as broodiness, shell thickness, incidence of blood and meat spots, etc. With the exception of the blood and meat spot line, isolated by Professor J. A. Harper prior to 1947, all the other lines were extracted from the production line.

Commercial Lines. This sub-group consisted of samples of commercial strains and strain crosses and was incorporated in the investigation in 1955.

Cornell Randombred Control. In 1960, this strain was added to the control group. It was maintained originally at Cornell University and later transferred to the North Central Regional Poultry Laboratory at Purdue University. This source is widely used as a control for random tests and breeding experiments.

Exchange Lines. This source was obtained through hatching eggs from the flocks of the New Mexico and Wyoming Experiment Stations and was maintained in the control group between 1960 and 1963 as part of a study on genotype-environment interaction.

Management

Management practices and facilities have remained fairly constant over the period of the study. Originally five weekly hatches were necessary to produce sufficient number of replacement pullets, but gradually this was reduced to three. The pedigreed chicks were hatched during the spring in the same weeks, 15th, 16th and 17th, beginning with 1950. A double shift of males was used during a period of five years (1950, 1951, 1952, 1955 and 1956) to allow testing of more males.

During the regular hatching season, a record of eggs set for each mating was kept along with information on infertility, embryonic mortality and hatchability. All unhatched eggs were broken out to determine fertility and, in the case of embryonic mortality, the age and cause of death were ascertained. The chicks from each hatch were brooded in one house. Feeding was maintained as uniform as possible throughout the experiment. All chicks were immunized against the five common species of coccidiosis when one week old and vaccinated for fowl pox at ten weeks of age. All dead birds were autopsied by the Poultry Diagnostic Laboratory. No epidemic was ever observed in the laying flock throughout the experiment which is possibly a unique observation. At 10 weeks of age, body weight was measured in male and female chicks. At around 20 weeks of age, all pullets were transferred to the laying house and trap-nested an average of three consecutive days each week.

Characters Measured

Several characters of economic importance were measured on individual birds every year, and the record-keeping system included the identification of ancestors, data on incubation, egg production, body weight, egg quality and mortality.

Incubation Records. The eggs accumulated weekly from each of the breeding pens were identified on the blunt end with the pen number, the temporary mating number, and date. The eggs set were candled on the 18th day and transferred to separate wire pedigree hatching trays to insure proper identification. At hatching, every chick was identified by a wing band and sexed; two males were kept from each family in the second hatch and the third if necessary. The record on fertility and hatchability was included in the family summary.

Production Records. All the females transferred to the laying house at about 20 weeks of age were identified with a Dryden type plastic wing badge. The egg production of each bird was recorded on trapnesting sheets. The average production of the flock and of sire and dam families was expressed as a hen-housed average or production index. This measurement is the ratio of the number of eggs laid by the group considered and the number of pullets housed in that group. Production records were analyzed on part-time trapnesting basis and later converted to seven trapnesting days per week. The adjustment factors were calculated from the data on weekly trapnesting days maintained in the laying records.

Body Weight. Body weight of all birds was recorded in pounds at 10 weeks of age, at about 20 weeks of age when pullets were transferred to the laying house, and at the end of the year or at about 64 weeks of age.

Egg Weight. Egg weight was measured in December and in July. The eggs were identified for a period of usually four consecutive days and weighed the day following lay on different scales over the years. Currently, they are weighed on a Shadograph to the nearest gram. The shell thickness of the eggs was determined on the day of lay indirectly by the specific gravity method; they were immersed in a series of 16 salt solutions of different concentrations ranging from density 1.044 to 1.104 with intervals of 0.004. The various solutions are coded to simplify recording and analysis, and the eggs are called the particular number of that solution in which they last sank. The solution with a specific gravity of 1.104 was called No. 16.

Mortality. All dead birds were autopsied by the Poultry

Diagnostic Laboratory and the week of death and autopsy results were recorded.

Selection Procedure

Selection of the breeding stock was done on the basis of individual and family performance to February 1. During the early part of February, all the available data on egg production, sexual maturity, body weight, egg size and shell thickness were summarized to the end of January and, on the basis of these summaries, the breeding pens were made up. Generally, ten single male breeding pens were used to maintain the production line with approximately 15 dams mated to each sire, avoiding half-sibs and full-sib matings.

Statistical Methods

The variables chosen for analysis were:

SM - Sexual maturity measured in weeks from hatch week to week of first egg.

NFE - Hen-housed egg production to February 1 (about 40 weeks of age) measured as number of eggs.

NYE - Annual hen-housed egg production (about 64 weeks of age) measured as number of eggs.

NRE - Residual hen-housed egg production (between 40 and 64 weeks of age) measured as number of eggs.

PFE - Hen-housed egg production to February 1 measured in percent or number of eggs divided by number of days trapnested.

PYE - Annual hen-housed egg production measured in percent on the same basis as PFE but at 64 weeks of age.

PRE - Residual hen-housed egg production measured in percent on the same basis as PFE but the period PYE-PFE.

BW10 - Body weight at 10 weeks of age measured in pounds.

BWH - Body weight at housing measured in pounds at approximately 20 weeks of age.

BWM - Body weight at maturity measured in pounds at approximately 64 weeks of age.

EWF - February egg weight measured in grams.

EWY - July or year egg weight measured in grams.

SGF - February specific gravity of eggs coded from 1-16.

SGY - July or year specific gravity of eggs coded from 1-16.

The data were analyzed on the Control Data Corporation 3300 computer at the Oregon State University Computer Center. A program furnished by Dr. K. E. Rowe of the Department of Statistics was used to estimate variance and covariance components. The data were transformed to deviations from year means and estimates were obtained for each year and pooled over years. An analysis of variance was carried out to give estimates of sire, dam and full-sib components (σ_S^2, σ_D^2 and σ_W^2, respectively). The estimate of the phenotypic or total variance is given by the sum of the three components: $\sigma_T^2 = \sigma_S^2 + \sigma_D^2 + \sigma_W^2$. According to the structure of the usual poultry breeding flock, the statistical model is that appropriate to the "nested" or "hierarchical" classification with unequal numbers (King and Henderson, 1954; Snedecor, 1956), and we have, therefore:

$$Y_{hijk} - \mu = a_h + s_{hi} + d_{hij} + e_{hijk}$$

where Y_{hijk} is the record of the k^{th} progeny of the j^{th} dam mated to the i^{th} sire within the h^{th} hatch and μ is the overall year mean.

The components of covariance (cov_S, cov_D and cov_W) were obtained by summing the two variables considered on each individual and analyzing these compound observations. The same analysis of variance was made and exactly the same formulas hold for the expectations of mean squares. If we consider variables 1 and 2, the corresponding component of covariance would be:

$$cov_{1,\ 2} = \frac{\sigma^2_{(1\ +\ 2)} - \sigma_1^2 - \sigma_2^2}{2}$$

where σ_1^2 and σ_2^2 are components obtained from the analysis of variance and $\sigma^2_{(1\ +\ 2)}$ is the component obtained from the analysis of the compound observations. The estimate of the phenotypic covariance is given by: $cov_T = cov_S + cov_D + cov_W$. Heritability estimates on an annual and pooled over year basis were obtained on the sire component and combined sire and dam component and the standard errors for these estimates were calculated according to the method of Osborne and Paterson (1952). Estimates of genetic, environmental and phenotypic correlations were calculated from the variance and covariance components obtained in the determination of heritability. The following formulae were used (Lerner, 1950):

Heritability:

From sire component $h^2_S = 4\sigma^2_S / \sigma^2_T$

Combined component $h^2_{(S + D)} = 2(\sigma^2_S + \sigma^2_D) / \sigma^2_T$

Phenotypic correlation:

$$r_{P_{1,2}} = \frac{cov_{T_{1,2}}}{\sqrt{\sigma^2_{S_1} + \sigma^2_{D_1} + \sigma^2_{W_1}}\ \sqrt{\sigma^2_{S_2} + \sigma^2_{D_2} + \sigma^2_{W_2}}}$$

Genetic correlations:

From sire component $r_{G_{1,2}} = \dfrac{cov_{S_{1,2}}}{\sqrt{\sigma^2_{S_1} \cdot \sigma^2_{S_2}}}$

Combined component

$$r_{G_{1,2}} = \frac{cov_{S_{1,2}} + cov_{D_{1,2}}}{\sqrt{\sigma^2_{S_1} + \sigma^2_{D_1}}\ \sqrt{\sigma^2_{S_2} + \sigma^2_{D_2}}}$$

Environmental correlations:

From sire component

$$r_{E_{1,2}} = \frac{\mathrm{cov}_{W_{1,2}} - 2\,\mathrm{cov}_{S_{1,2}}}{\sqrt{\sigma^2_{W_1} - 2\sigma^2_{S_1}}\ \sqrt{\sigma^2_{W_2} - 2\sigma^2_{S_2}}}$$

Combined component

$$r_{E_{1,2}} = \frac{\mathrm{cov}_{W_{1,2}} - \mathrm{cov}_{S_{1,2}} - \mathrm{cov}_{D_{1,2}}}{\sqrt{\sigma^2_{W_1} - \sigma^2_{S_1} - \sigma^2_{D_1}}\ \sqrt{\sigma^2_{W_2} - \sigma^2_{S_2} - \sigma^2_{D_2}}}$$

February production as compared to that expected if the selection were based on year production was calculated by the formula given by Lerner (1950):

$$\frac{\Delta G_{NYE\ (indirect)}}{\Delta G_{NYE\ (direct)}} = \frac{2 r_{G(NFE,\ NYE)}\ h^2_{NFE}}{h^2_{NYE}}$$

The rate of inbreeding per generation in the production line was computed from the formula

$$\Delta F = \frac{1}{8_{N_m}} + \frac{1}{8_{N_f}} \quad \text{(Wright, 1931)}$$

where N_m and N_f are the number of sires and dams, respectively, which left progeny selected as breeders in the following generation.

The effective number of parents N_e was obtained as:

$$N_e = \frac{4N_m \cdot N_f}{N_m + N_f}$$

The inbreeding coefficient in the base population was assumed to be zero. The coefficient of inbreeding in generation t was calculated by:

$$F_t = \Delta F + (1 - \Delta F)\ F_{t-1}$$

The estimates of the genetic parameters available from this study permitted the derivation of a selection index which was directly applicable to this population, taking into account characters involved in an accelerated selection program or a direct selection on year records. In the procedure followed (Hoggset and Nordskog, 1958; Becker, 1964) the selection index is defined as

$$I = b_1\ x_1 + b_2\ x_2 \ldots . + b_n\ x_n$$

where the b_i's are the derived optimum weighting coefficients for the characters x_i.

The genetic-economic value of the index is defined as

$$H = a_1\ g_1 + a_2\ g_2 \ldots . + a_n\ g_n$$

where the a_i's are economic values corresponding to one unit of the x_i. The desired solution of the b_i's is obtained from a set of simultaneous linear equations represented by matrix notation

$$P \cdot B = G \cdot A$$

where P is the phenotypic variance-covariance matrix, B is the column vector of unknown b_i's, G is the genotypic variance-covariance matrix and A the column vector of economic weight. Setting $H = G \cdot A$ and inverting the P matrix leads to the solution of the b's. Thus, $B = P^{-1} \cdot H$. The variance of the index is $\sigma_I^2 = B' \cdot P \cdot B$, where B' is the transpose of the column vector B.

The expected genetic change in each trait associated with one standard deviation of selection in the index was calculated from the formula:

$$\Delta x_i = \frac{b_1 g_{i_1} + \dots + b_n g_{i_n}}{\sigma_I} .$$

RESULTS

The structure of the production line and control group, an indication of the total size of the experimental flock, is presented in Tables 1 and 2. The average number of pullets housed each year was 693 in the production line and 611 in the control group. The special lines within the control group which were maintained throughout the experiment averaged 257 pullets housed each year. The commercial lines, exchange lines and Cornell randombred averaged 421, 238 and 70 pullets, respectively.

Inbreeding

The pedigree records available for all the birds in the production line would permit calculation of the expected inbreeding coefficient, but this although planned has not been carried out as yet. An approximate estimate of the increase in the coefficient of inbreeding per generation was obtained using the effective number of sires and dams in each generation (Wright, 1931).

The effective number of sires and dams, the effective number of parents and the expected increase in inbreeding per generation are given in Table 3.

The average effective number of parents per generation was 26 and the average increase in inbreeding was calculated to be

Table 1. Production line. Number of sires, dams and pullets housed each year.

Year	No. of Sires	No. of Dams	No. of Pullets Housed
1947	19	61	824
48	18	211	899
49	6	92	890
50	12	85	481
51	12	89	641
52	16	111	725
53	8	118	588
54	8	133	617
55	15	109	669
56	20	184	696
57	11	184	835
58	10	197	903
59	10	140	743
60	10	141	680
61	10	128	630
62	10	130	504
63	10	170	527
64	10	151	612
65	10	170	715
Total	225	2,604	13,179
Average	11	137	693

approximately two percent per year. This is very likely an overestimate of the true value since, as already mentioned, full-sib and half-sib matings were avoided during the experiment.

Response to Selection

The phenotypic and genetic changes in the production line were estimated for each of the variables analyzed by the regression of

Table 2. Number of pullets housed each year in the control group.

Year	Control Group: Special Lines	Commercial Lines	Cornell Randombred	Exchange Lines	Total Control
1948	--	--	--	--	--
49	326	--	--	--	326
50	449	--	--	--	449
51	548	--	--	--	548
52	413	--	--	--	413
53	460	--	--	--	460
54	571	--	--	--	571
55	349	27	--	--	376
56	503	247	--	--	750
57	55	358	--	--	413
58	39	492	--	--	531
59	26	664	--	--	690
60	115	377	92	202	786
61	114	454	68	134	770
62	99	520	93	347	1,059
63	105	606	82	269	1,062
64	110	496	62	--	668
65	102	392	20	--	514
Total	4,384	4,633	417	952	10,386
Average	257	421	70	238	611

means on year. The annual means of the 14 variables in the production line, control special lines, and total control group are presented in Figures 1 to 14 (Appendix Tables 3 and 4).

Phenotypic Change

Means, standard deviations and the unweighted regressions on years are included in Table 4 for each trait measured. The mean

Table 3. Production line. Effective number of sires, dams and parents and expected inbreeding coefficient.

Year	Sires N_m 1/	Dams N_f 2/	Parents N_e 3/	ΔF 4/	F 5/
1948	9	41	29.5	0.01694	0.01694
49	5	13	14.4	0.03461	0.05096
50	8	12	19.2	0.02604	0.07567
51	4	19	13.2	0.03783	0.11064
52	13	35	37.9	0.01319	0.12237
53	8	28	24.9	0.02009	0.14000
54	8	29	25.1	0.01994	0.15715
55	13	39	39.0	0.01282	0.16796
56	15	52	46.6	0.01074	0.17690
57	5	46	18.0	0.02772	0.19972
58	7	45	24.2	0.02063	0.21623
59	7	36	23.4	0.02133	0.23295
60	8	31	25.4	0.01966	0.24803
61	7	29	22.6	0.02217	0.26470
62	7	25	21.9	0.02286	0.28151
63	10	37	31.5	0.01588	0.29292
64	8	30	25.3	0.01979	0.30691
65	10	36	31.3	0.01597	0.31798
Average	8.4	32.4	26.3	0.02101	0.01766

1/ Effective number of sires

2/ Effective number of dams

3/ Effective number of parents

4/ Rate of inbreeding

5/ Inbreeding coefficient

Table 4. Production line. Pooled means and estimated phenotypic change for the variables analyzed as measured by regression of the annual means on year.

Variable	Mean	Standard Deviation	Phenotypic Change per Year	F-Value
Egg production to February (no. of eggs)	85.6	35.40	3.44 ± 0.57	36.05**
Annual egg production (no. of eggs)	173.6	48.40	4.95 ± 1.17	17.91**
Residual egg production (no. of eggs)	88.0	26.60	1.24 ± 0.63	3.89
Egg production to February (percent)	66.5	22.40	1.17 ± 0.03	13.70**
Annual egg production (percent)	52.5	22.80	1.21 ± 0.11	11.60**
Residual egg production (percent)	46.2	27.00	0.73 ± 0.12	3.60
Sexual maturity (weeks to first egg)	24.7	2.70	-0.46 ± 0.05	70.30**
Body weight at 10 weeks of age (pounds)	1.7	0.18	0.01 ± 0.01	1.41
Body weight at housing (pounds)	3.2	0.37	-0.04 ± 0.01	6.23*
Body weight at maturity (pounds)	3.8	0.48	-0.01 ± 0.02	0.10
February egg weight (grams)	53.1	3.40	0.09 ± 0.11	0.63
Year egg weight (grams)	58.1	4.00	0.40 ± 0.21	3.51
February egg specific gravity (code 1-16)	10.9	1.20	-0.01 ± 0.02	0.07
Year egg specific gravity (code 1-16)	8.9	1.40	-0.06 ± 0.03	3.34

* Significant at 5% level

**Significant at 1% level

February egg production was 85.6 eggs and 66.5 percent when measured in actual number and on a percent basis, respectively. The direct phenotypic response to accelerated selection on the primary trait, early egg production (Figures 2 and 5), shows an average increase per generation of 3.4 eggs and 1.17 percent, with both figures highly significant statistically.

The basic trait, annual egg production, had a mean of 173.6 eggs and 52.5 percent in both measurements. The phenotypic change in this trait (Figures 3 and 6) was a highly significant increase of 4.95 eggs and 1.21 percent per year. Residual egg production averaged 88 eggs and 46.2 percent and increased at a rate of 1.24 eggs and 0.73 percent every year. These values are not statistically significant, indicating that the gain in annual production was primarily obtained by an increase in early production (Figures 4 and 7).

The average age at first egg was 24.7 weeks and sexual maturity (Figure 1) decreased at a rate of approximately half a week per year which is highly significant. The average body weight at 10 weeks of age, at housing time and maturity was 1.7, 3.2, and 3.8 pounds, respectively (Figures 8, 9 and 10). The only significant trend in body weight was observed in body weight at housing which decreased about 0.04 pounds per year.

The average egg weight in February was 53 grams and the mean egg weight at 64 weeks of age was 58 grams, a difference of

5 grams. Both variables increased positively through the years, but neither was statistically significant (Figures 11 and 12). The average shell strength, measured by specific gravity, was higher in February than at 64 weeks of age with means of 10.9 and 8.9, respectively. In both cases, a decrease throughout the 18 years was observed, but this trend was not statistically significant (Figures 13 and 14).

Genetic Change

The realized genetic change was measured as the unweighted regression of the deviations of the production line from the control population on year (Table 5). The difference between the production and the control lines was calculated from the total control group and also from the special lines, since the latter were derived from the production line and have been maintained throughout the experiment.

The realized direct response or genetic change in production to February indicated an increase in both comparisons, but it was statistically significant only when calculated from the special lines control. The unweighted regression of the deviations of the production line from the special lines on year was 3.5 eggs and 3.01 percent, showing highly significant response to accelerated selection in both cases. When the correction was made from the total control group, the same trend was observed but was not significant.

Table 5. Production line. Estimated genetic change for the variables analyzed measured by the regression of the annual means of the production line as deviation from the control populations on year.

Variables	Prod. Line Deviated from Special Lines (b)	F-Value	Prod. Line Deviated from Control Group (b)	F-Value
Egg production to February (no. of eggs)	3.500 ± 1.06	10.80**	0.878 ± 0.48	3.30
Annual egg production (no. of eggs)	7.020 ± 2.24	9.80**	0.664 ± 0.85	0.61
Residual egg production (no. of eggs)	3.450 ± 1.04	10.80**	-0.233 ± 0.40	0.34
Egg production to February (percent)	3.010 ± 0.44	46.30**	0.245 ± 0.22	1.20
Annual egg production (percent)	3.240 ± 0.39	67.70**	0.206 ± 0.25	0.70
Residual egg production (percent)	3.060 ± 0.36	72.60**	-0.025 ± 0.24	0.01
Sexual maturity (weeks to first egg)	-0.254 ± 0.09	7.20*	-0.131 ± 0.05	4.80*
Body weight at 10 weeks of age (pounds)	0.014 ± 0.01	1.30	-0.003 ± 0.01	0.12
Body weight at housing (pounds)	0.012 ± 0.01	0.60	-0.006 ± 0.01	0.40
Body weight at maturity (pounds)	-0.034 ± 0.04	0.22	0.005 ± 0.02	0.07
February egg weight (grams)	0.386 ± 0.10	14.00**	0.030 ± 0.03	0.63
Year egg weight (grams)	0.408 ± 0.32	1.60	-0.151 ± 0.18	0.69
February egg specific gravity (code 1-16)	0.024 ± 0.01	6.20	-0.005 ± 0.01	0.19
Year egg specific gravity (code 1-16)	0.041 ± 0.07	0.03	-0.029 ± 0.04	0.45

* Significant at 5% level
**Significant at 1% level

The realized correlated genetic response in annual egg production was similar to that observed in the direct genetic response. Annual egg production increased 7 eggs and 3.2 percent when measured from the special lines control. These increases were highly significant. The increase was not statistically significant when measured from the total control group.

Residual production increased 3 eggs and 3.1 percent per year when the means of the production line were corrected from the annual means of the special lines and both figures are statistically highly significant. When the correction was made from the total control group, a decline of 0.23 eggs and 0.025 percent was observed. These values are not significant and, considering the standard errors of both regression coefficients, they may be considered to be essentially zero.

Sexual maturity decreased 0.25 weeks and 0.13 weeks per year when measured as deviation from special lines and total control group, respectively. The realized correlated response in this trait was statistically significant at the five percent level.

The correlated response in the other traits measured (Table 5), body weight, egg weight and shell strength, was not statistically significant and the yearly rates of change were higher when estimated from the special lines than from the total control group, with the exception of mature body weight.

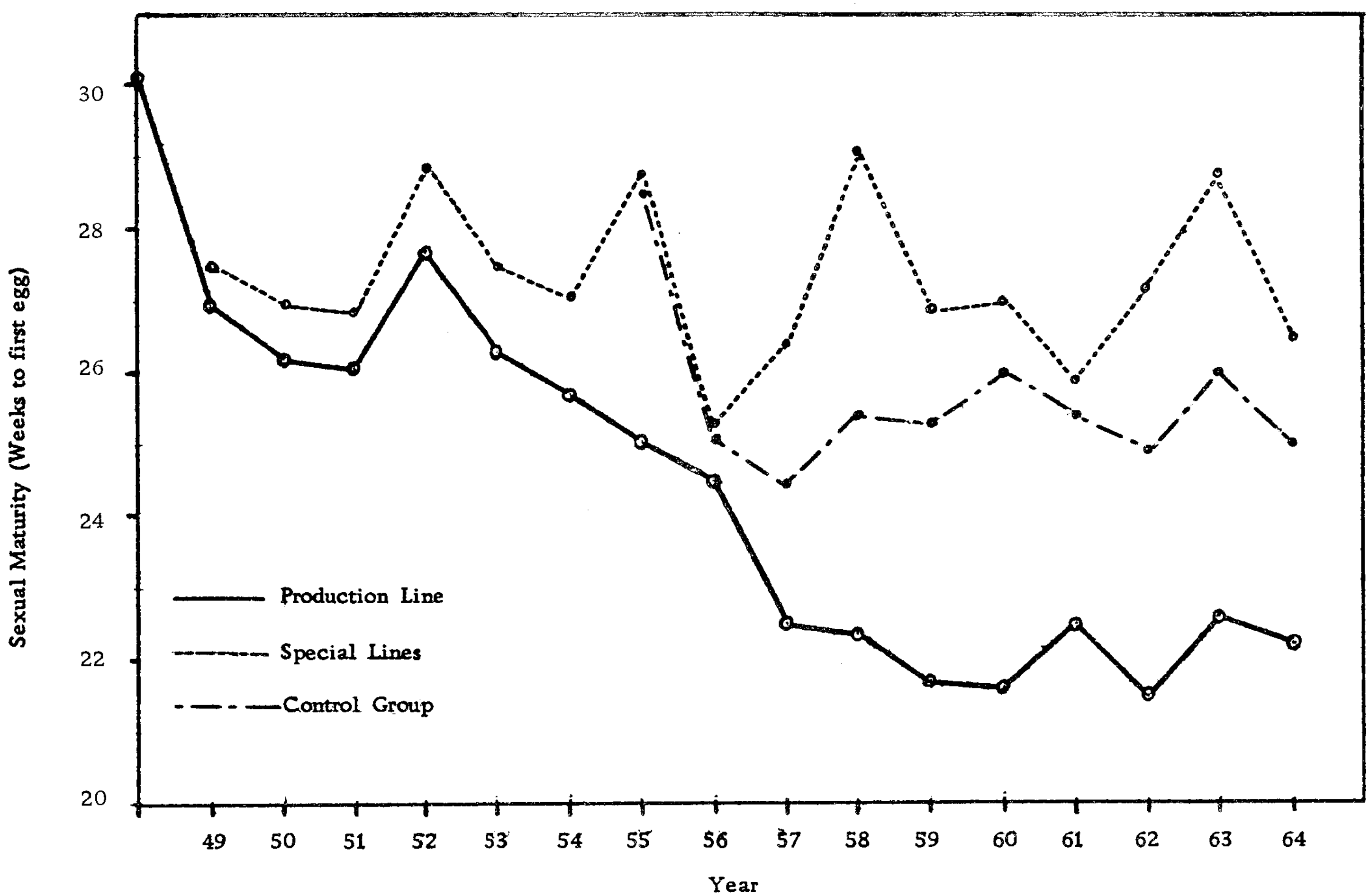


Figure 1. Production line, special lines and control group annual means for sexual maturity measured in weeks to first egg.

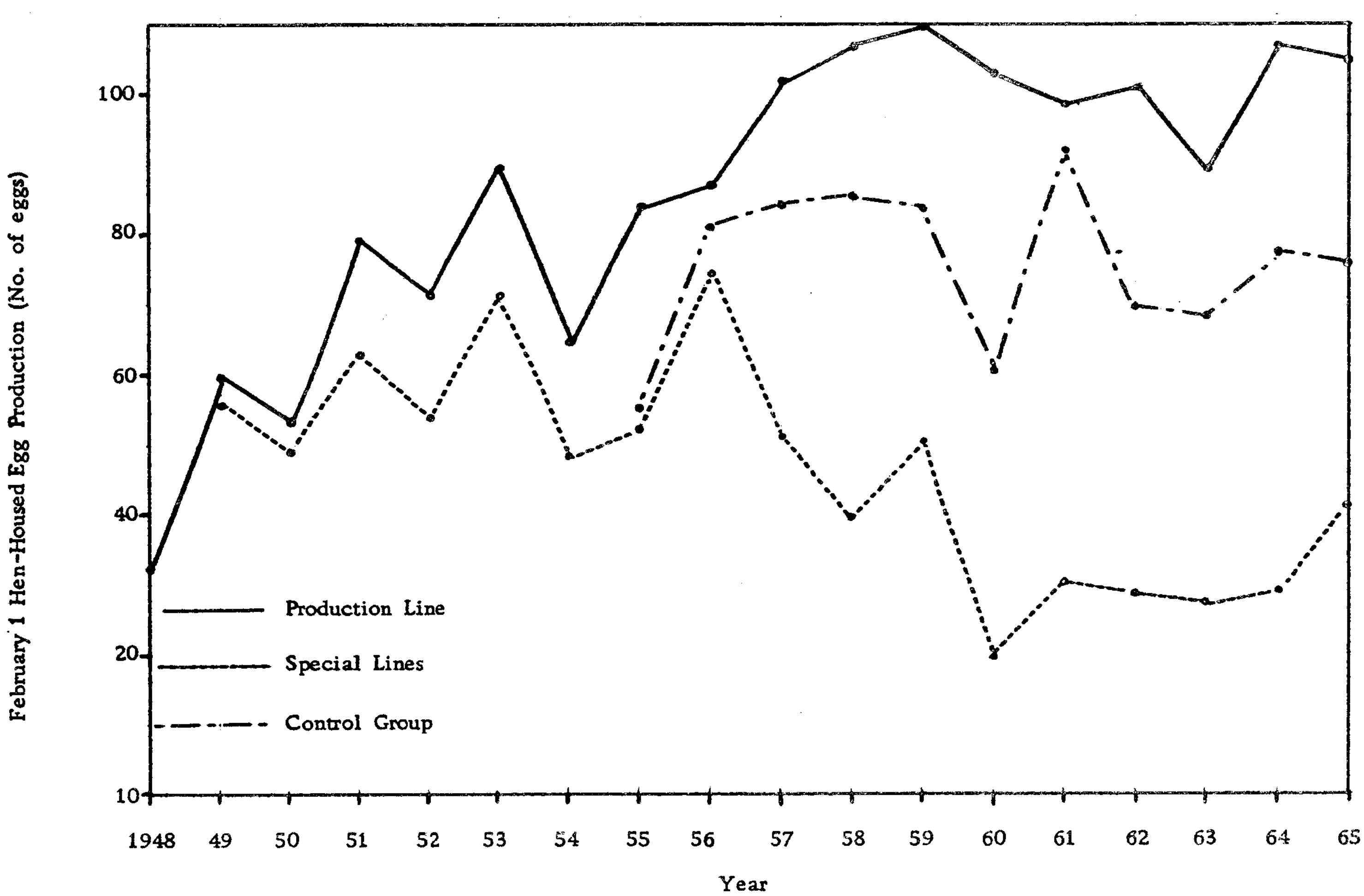


Figure 2. Production line, special lines and control group annual means for February 1 hen-housed egg production measured in number of eggs.

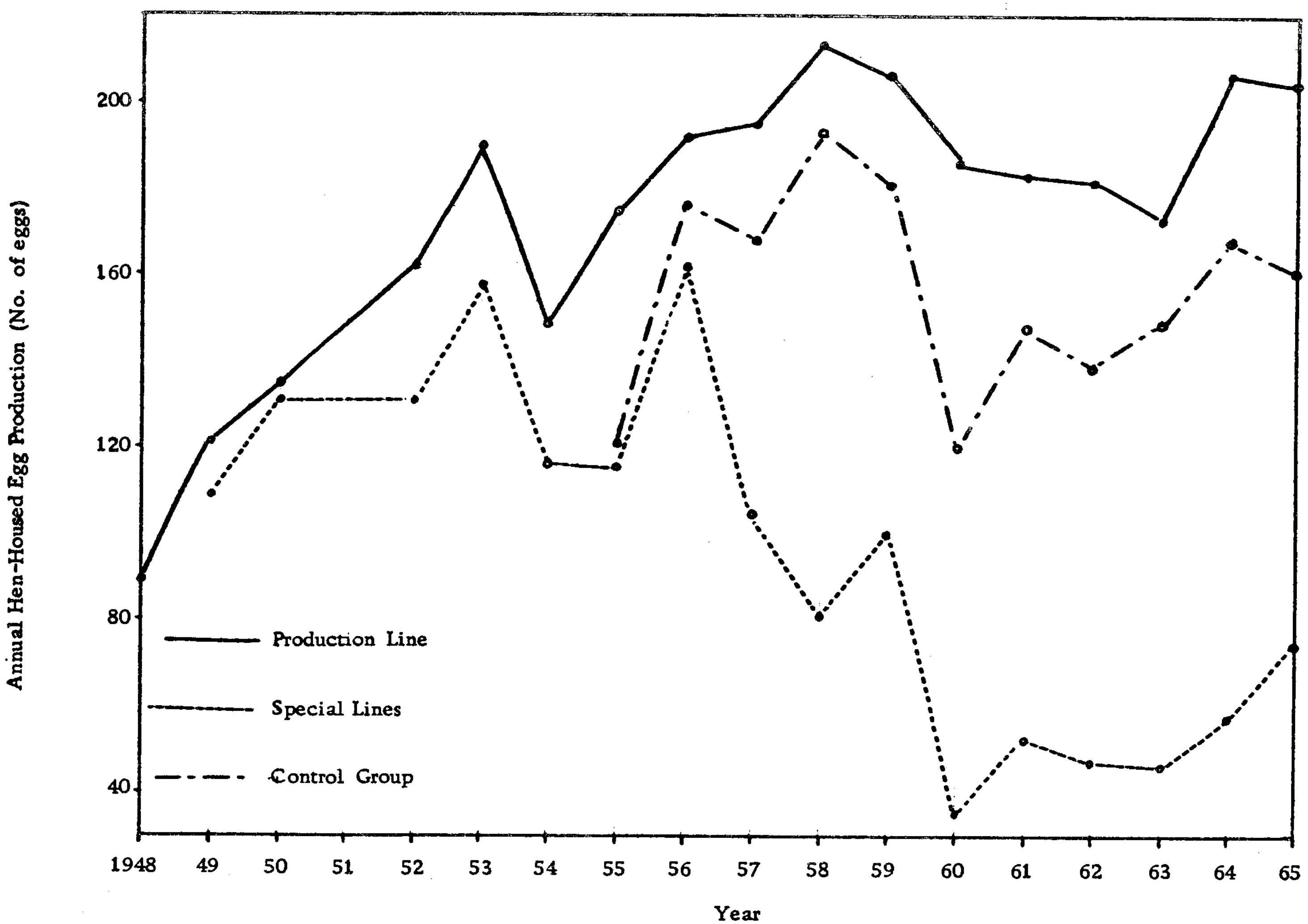


Figure 3. Production line, special lines and control group annual means for annual hen-housed egg production measured in number of eggs.

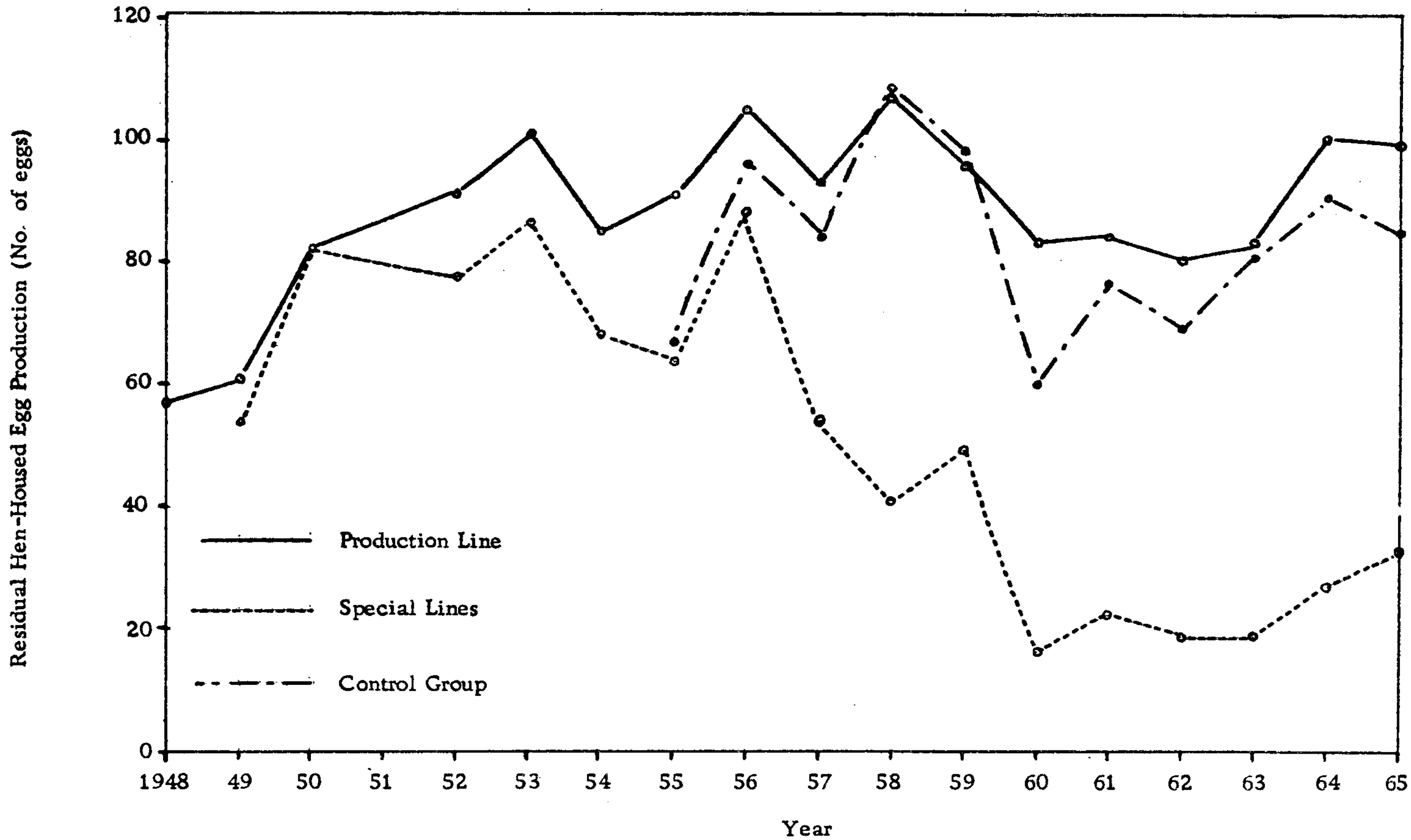


Figure 4. Production line, special lines and control group annual means for residual hen-housed egg production measured in number of eggs.

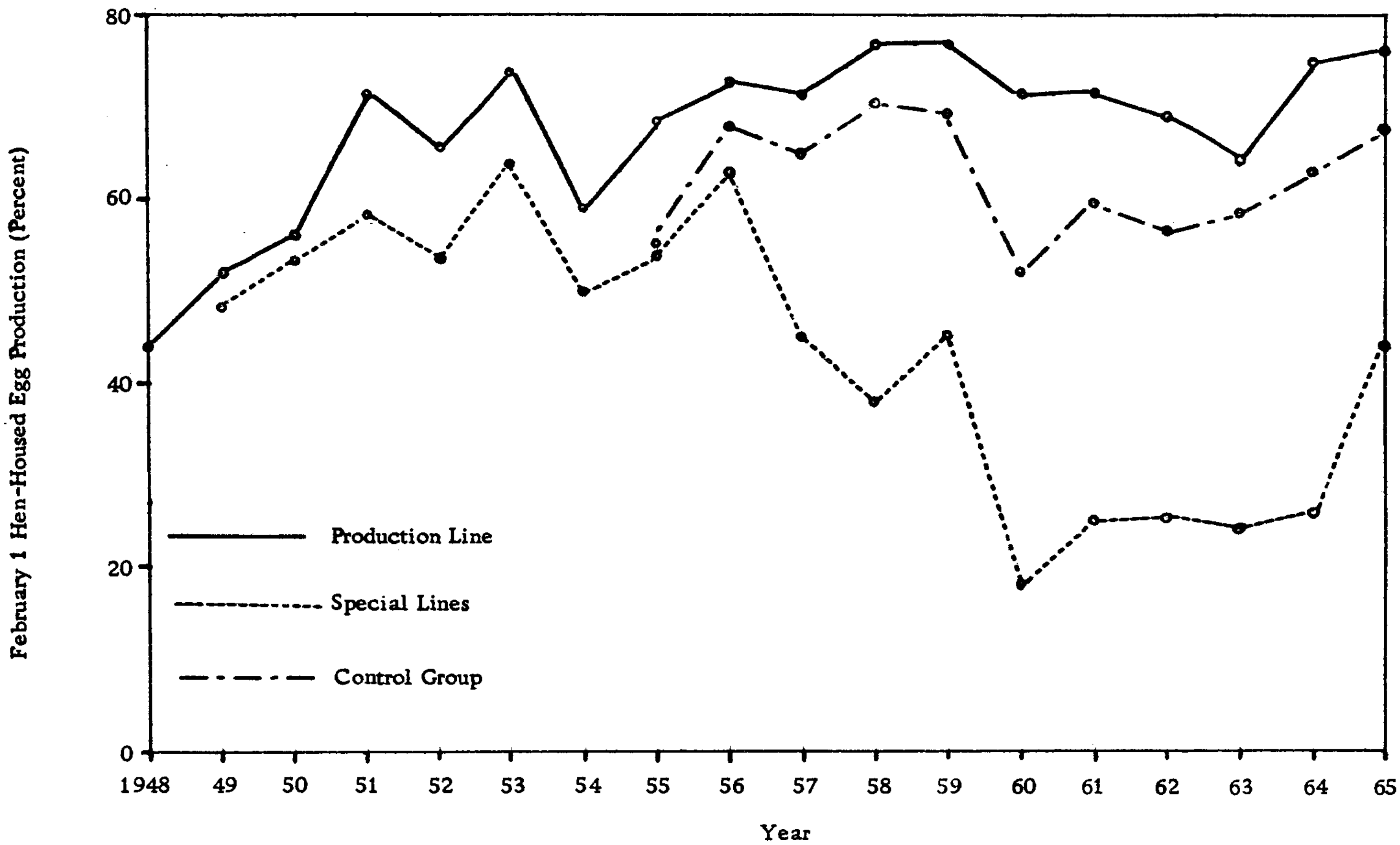


Figure 5. Production line, special lines and control group annual means for February 1 hen-housed egg production measured in percent.

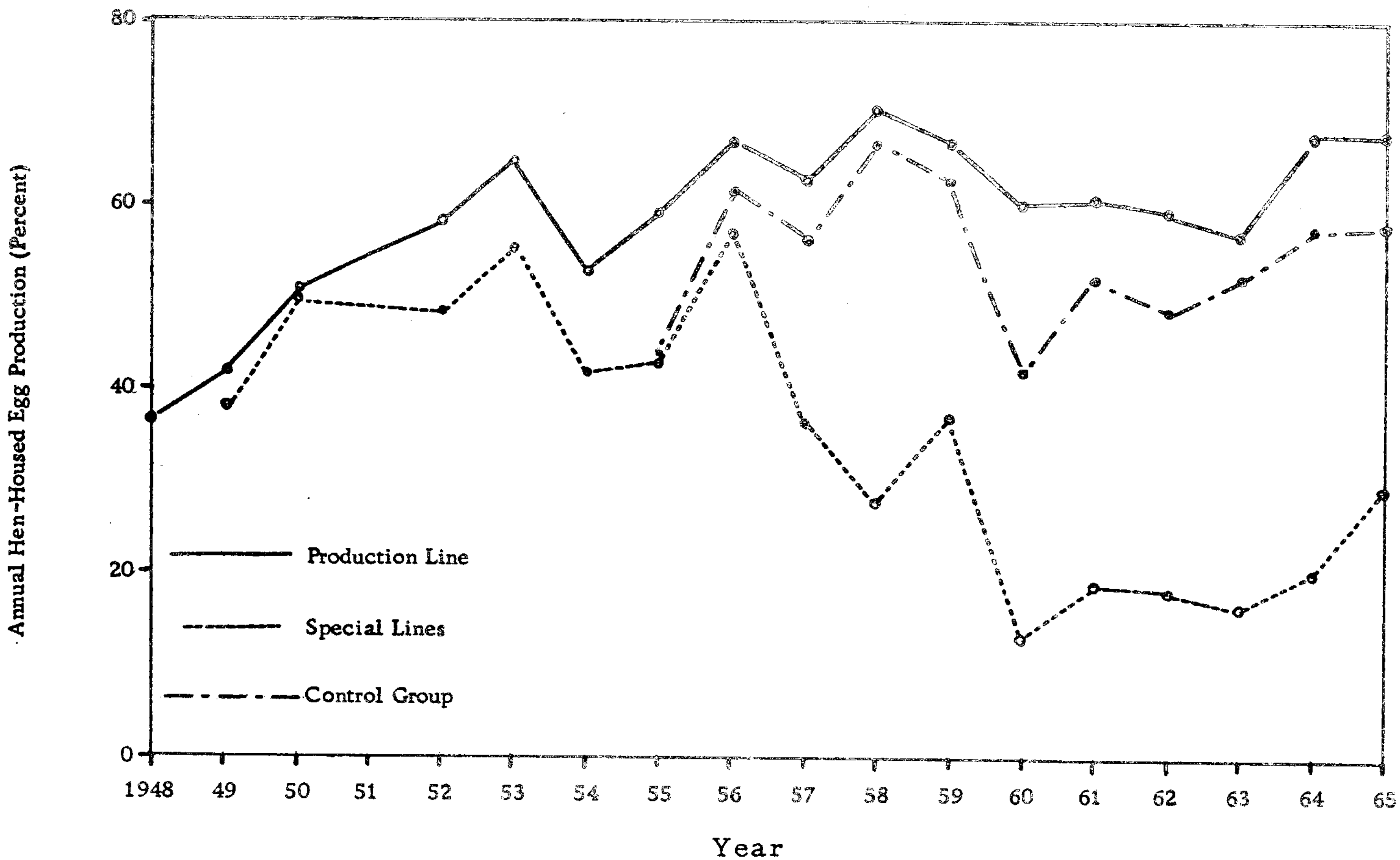


Figure 6. Production line, special lines and control group annual means for annual hen-housed egg production measured in percent.

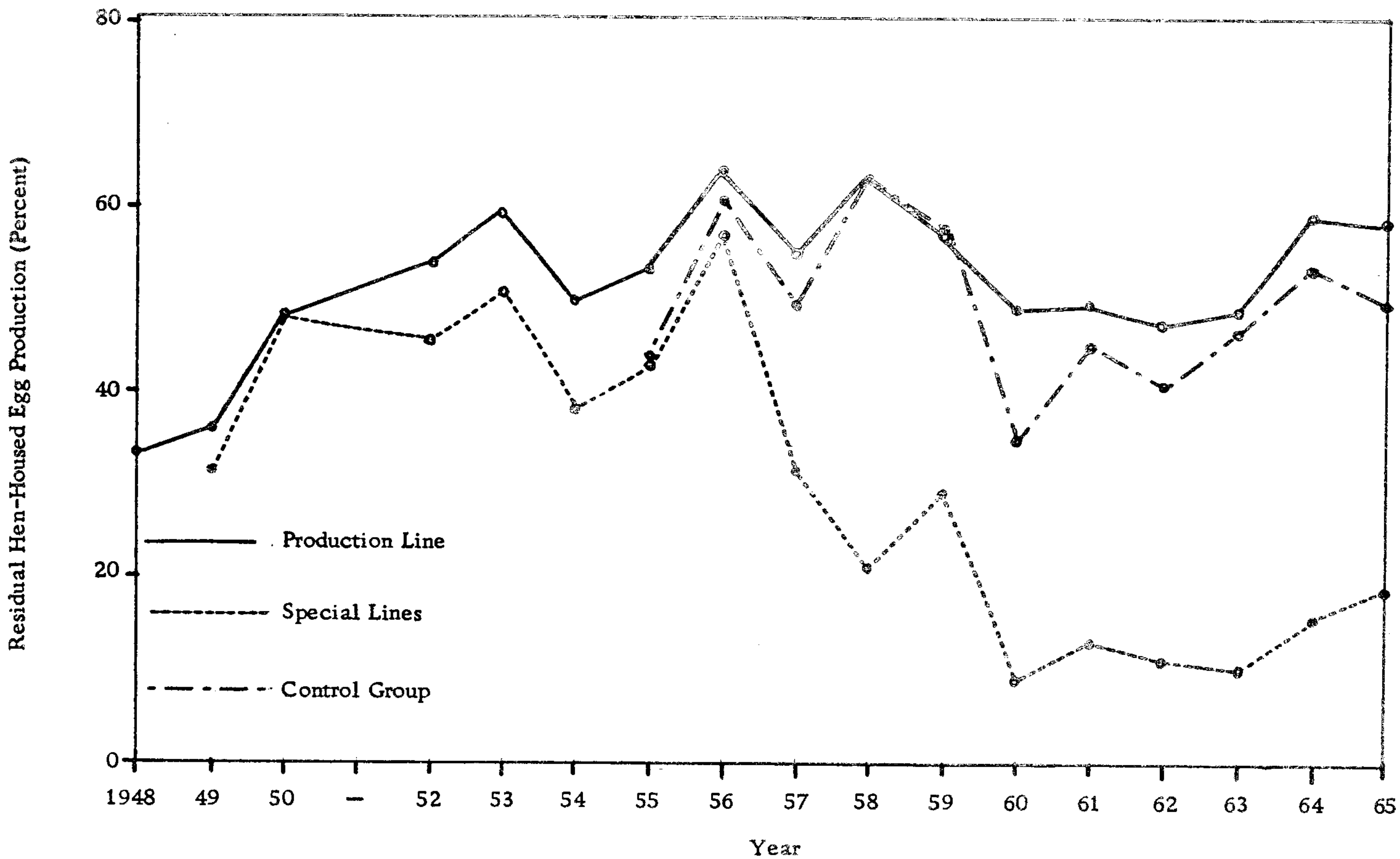


Figure 7. Production line, special lines and control group annual means for residual hen-housed egg production measured in percent.

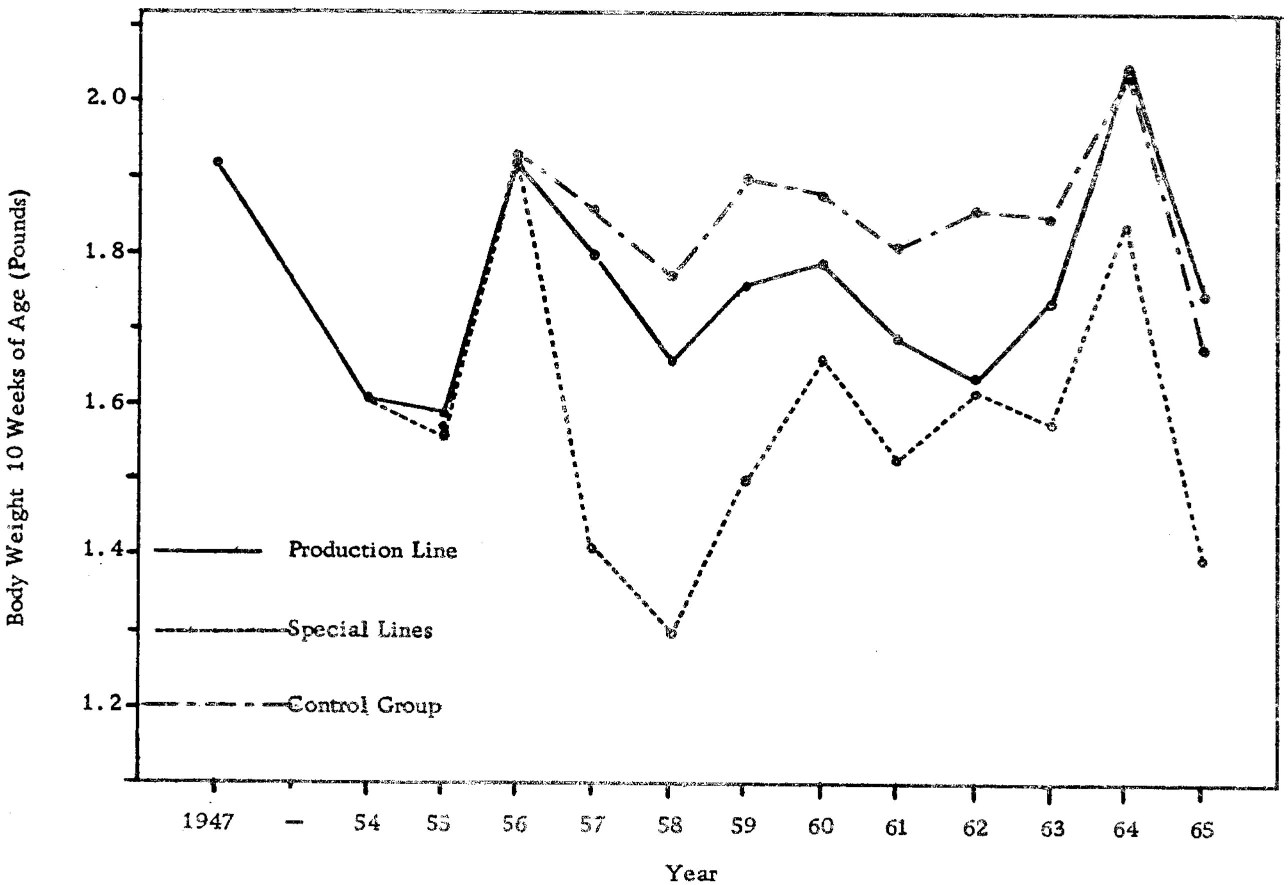


Figure 8. Production line, special lines and control group annual means for body weight at 10 weeks of age measured in pounds.

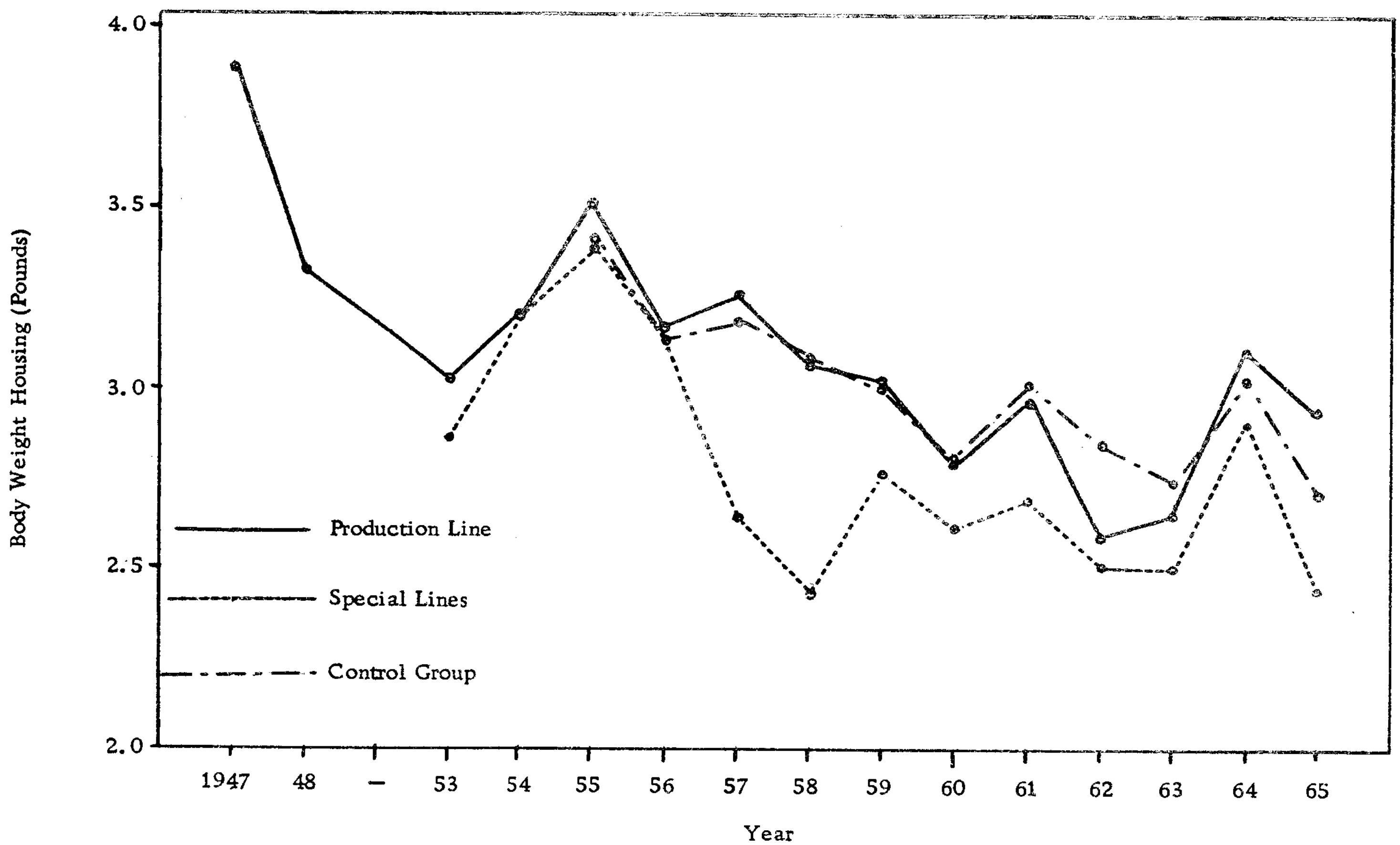


Figure 9. Production line, special lines and control group annual means for body weight at housing measured in pounds.

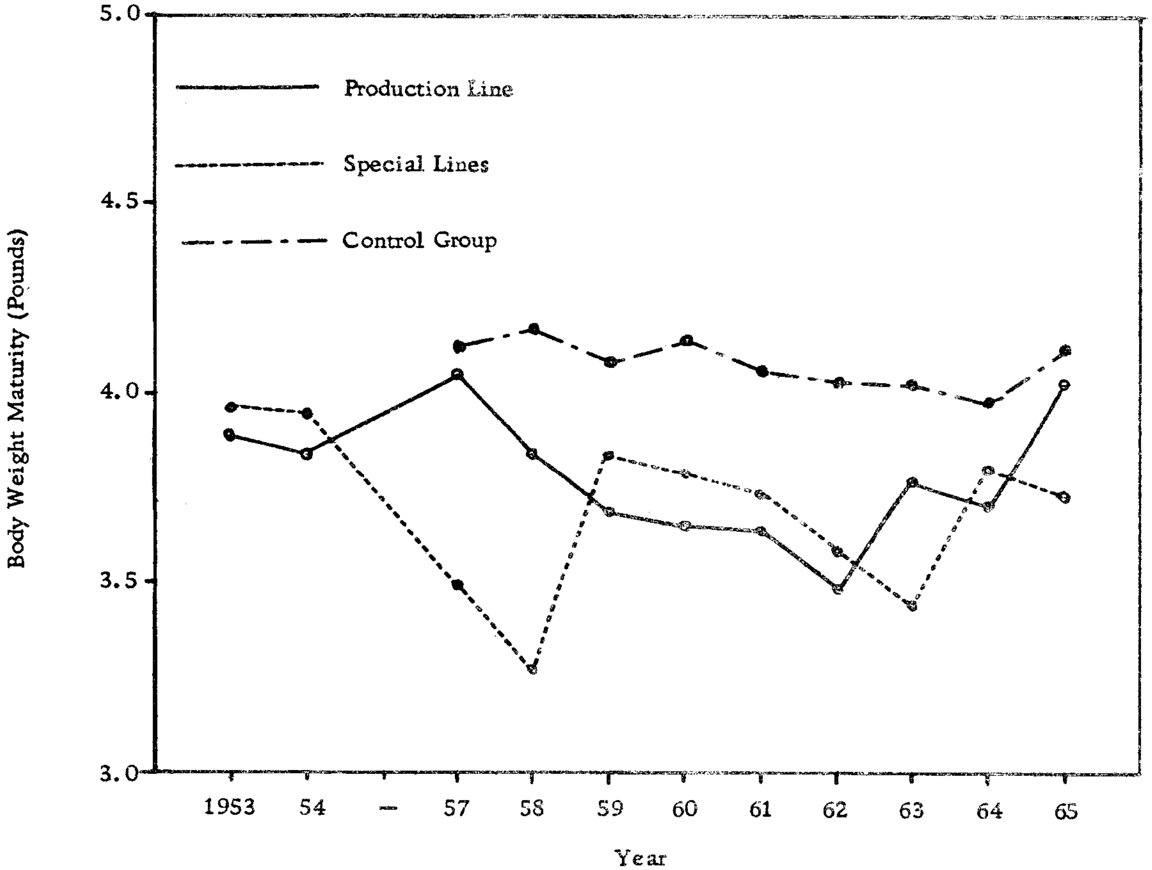


Figure 10. Production line, special lines and control group annual means for body weight at maturity measured in pounds.

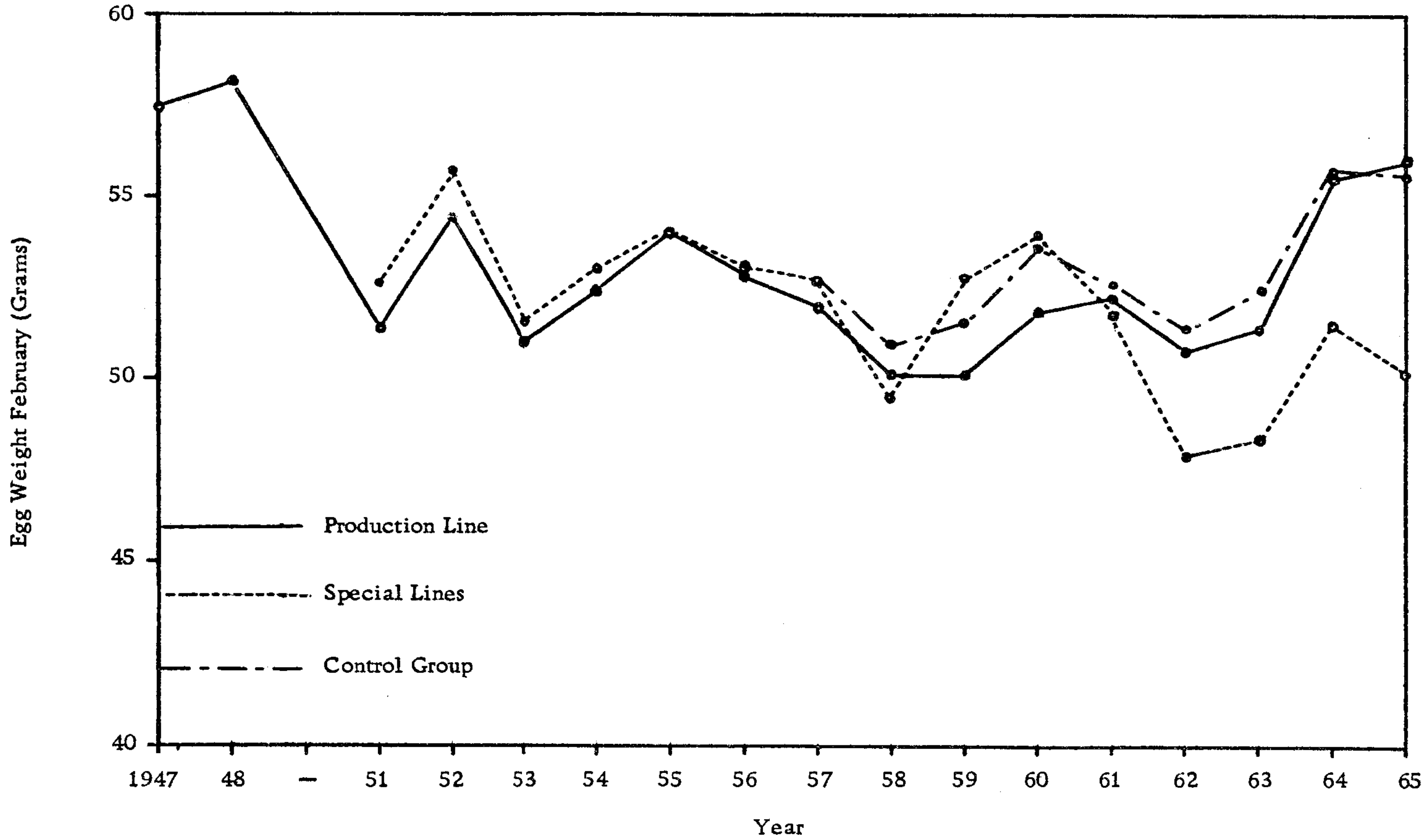


Figure 11. Production line, special lines and control group annual means for egg weight in February measured in grams.

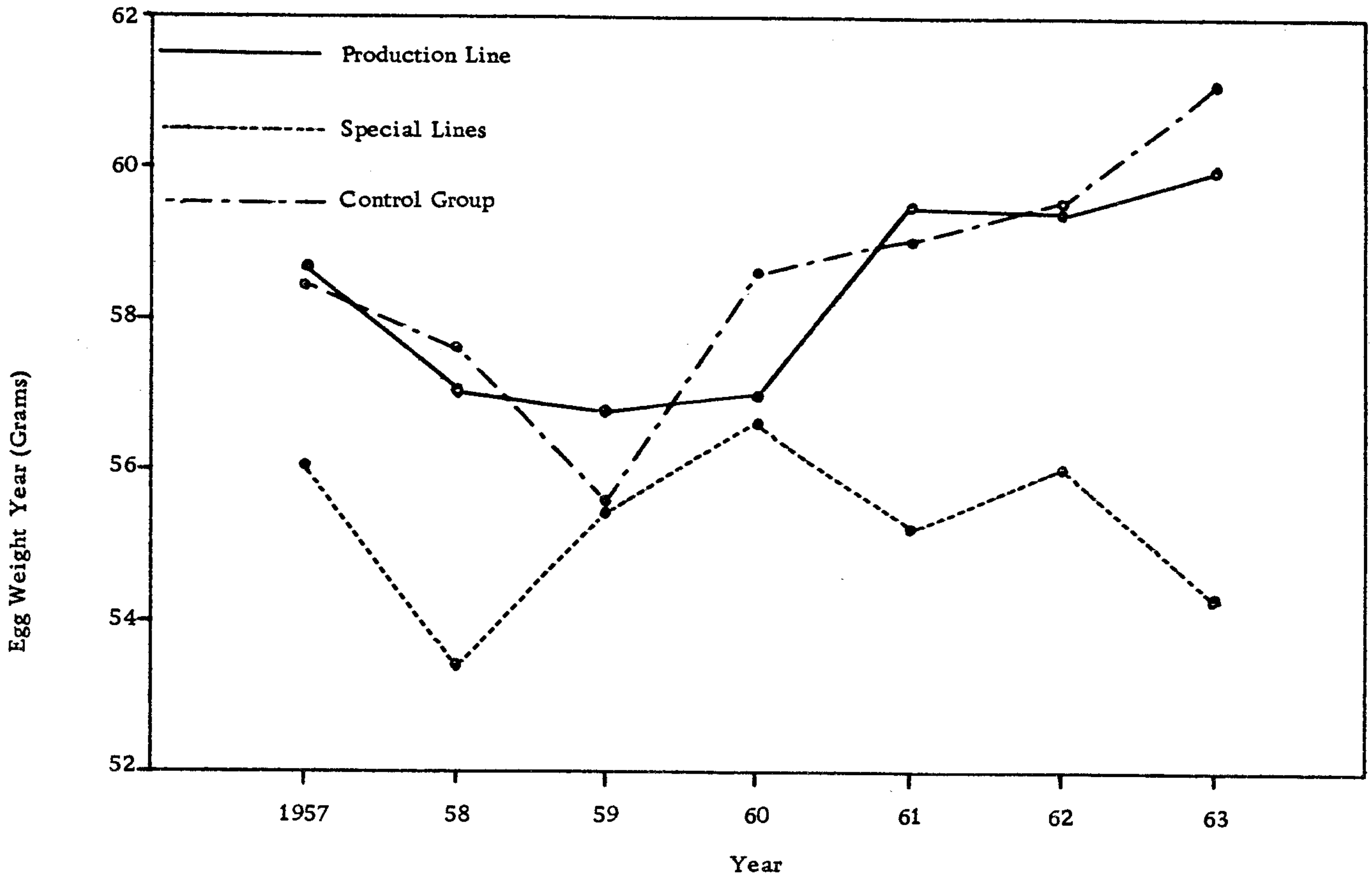


Figure 12. Production line, special lines and control group annual means for year egg weight measured in grams.

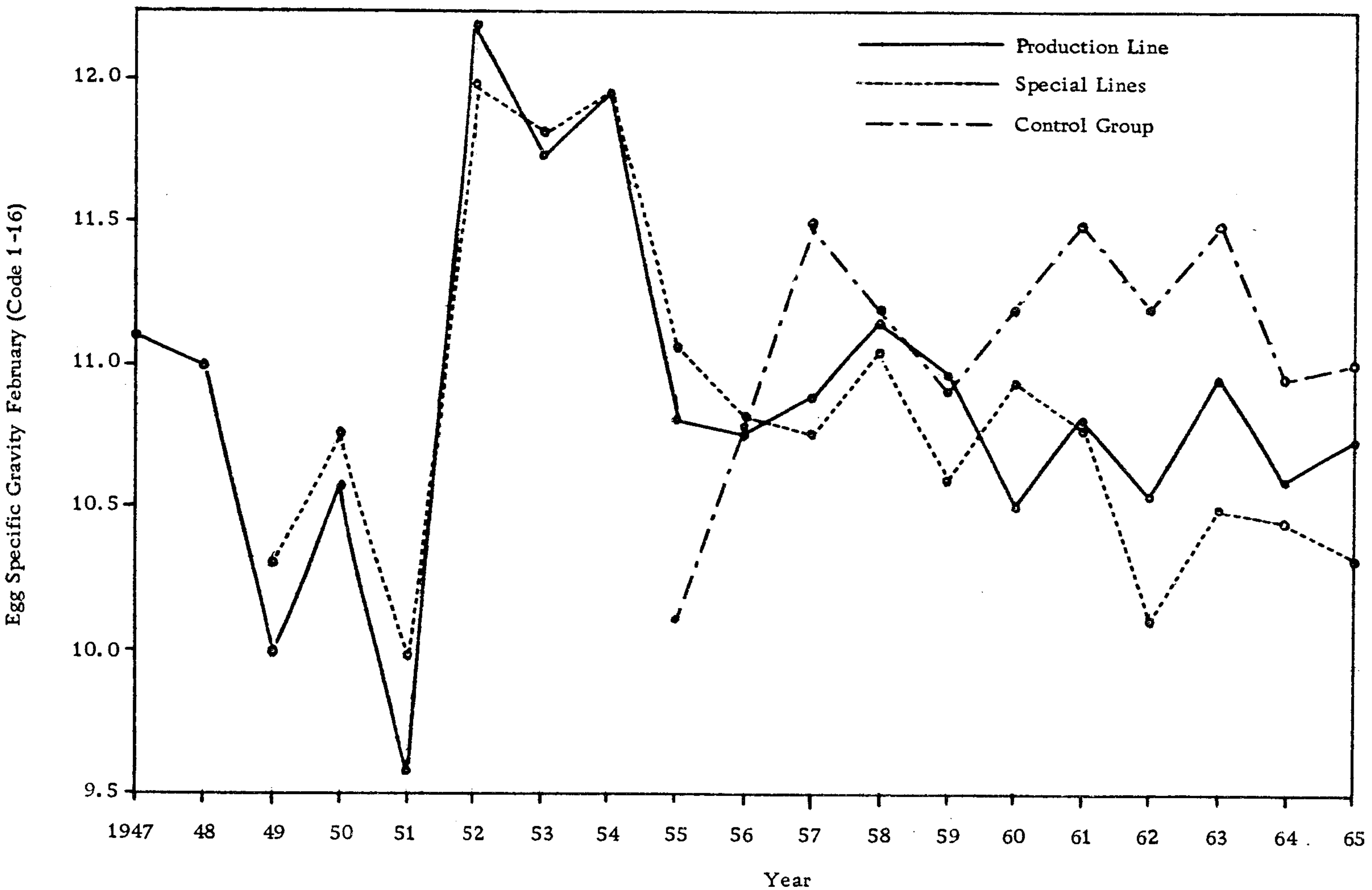


Figure 13. Production line, special lines and control group annual means for February egg specific gravity measured in 1-16 scale.

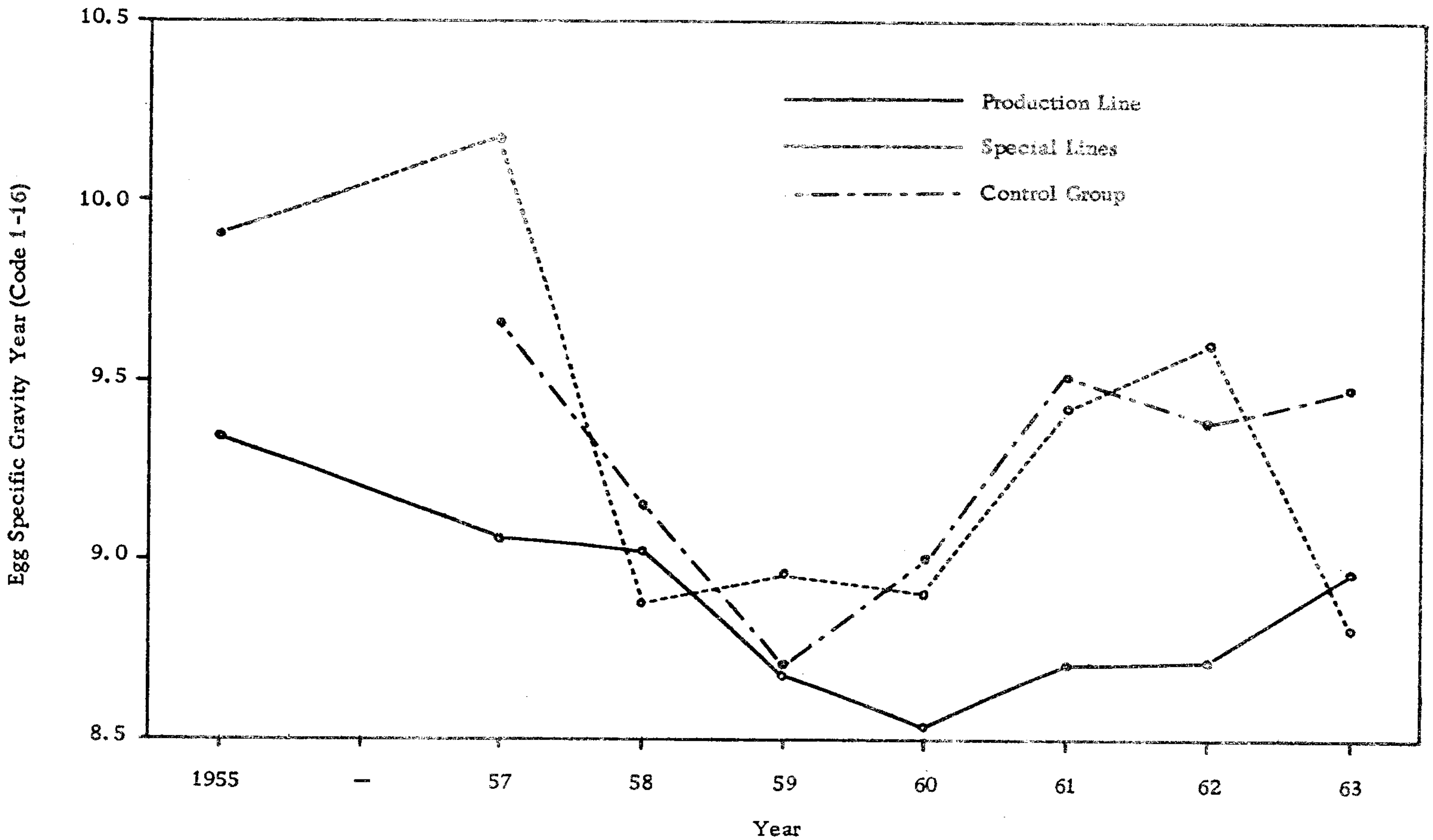


Figure 14. Production line, special lines and control group annual means for year egg specific gravity measured in 1-16 scale.

Heritability

Annual and pooled estimates of heritability (Appendix Tables 5 and 6) were calculated for each of the variables considered. Annual estimates give some indication of change in heritability during the 17 years of selection.

The annual and pooled heritability estimates were obtained from the sire component (paternal half-sib correlation) and from the combined sire and dam component (full-sib correlation). The pooled estimates and their standard errors are presented in Table 6, and the annual values are plotted in Figures 17 to 22.

The average heritability estimate of February egg production in actual number of eggs was 14 percent from half-sib correlation and 8 percent from full-sib correlation (Figure 18). When this trait was measured in percent, the values were 12 percent and 19 percent, respectively. The existence of sex-linked effects could explain the difference between these estimates of heritability. The removal of the sexual maturity effect when production was expressed in percent was reflected in the smaller value of the sire estimate compared to the combined estimate of heritability while the opposite occurred when the trait was expressed in actual number which includes the effect of sexual maturity.

The pooled estimates of heritability for annual egg production expressed in number of eggs was 11 percent from the half-sib

Table 6. Mean heritability estimates from half-sib and full-sib correlations.

Variable	h^2_S	$h^2_{(S + D)}$
Egg production to February (no. of eggs)	0.139 ± 0.021	0.079 ± 0.021
Annual egg production (no. of eggs)	0.111 ± 0.022	0.252 ± 0.022
Residual egg production (no. of eggs)	0.102 ± 0.023	0.258 ± 0.024
Egg production to February (percent)	0.119 ± 0.021	0.191 ± 0.021
Annual egg production (percent)	0.116 ± 0.023	0.269 ± 0.022
Residual egg production (percent)	0.098 ± 0.022	0.247 ± 0.024
Sexual maturity (weeks to first egg)	0.272 ± 0.031	0.383 ± 0.023
Body weight at 10 weeks of age (pounds)	0.537 ± 0.053	0.667 ± 0.028
Body weight at housing (pounds)	0.418 ± 0.042	0.548 ± 0.025
Body weight at maturity (pounds)	0.627 ± 0.063	0.664 ± 0.034
February egg weight (grams)	0.588 ± 0.050	0.515 ± 0.027
Year egg weight (grams)	0.375 ± 0.064	0.494 ± 0.045
February egg specific gravity (code 1-16)	0.291 ± 0.032	0.374 ± 0.024
Year egg specific gravity (code 1-16)	0.301 ± 0.052	0.234 ± 0.044

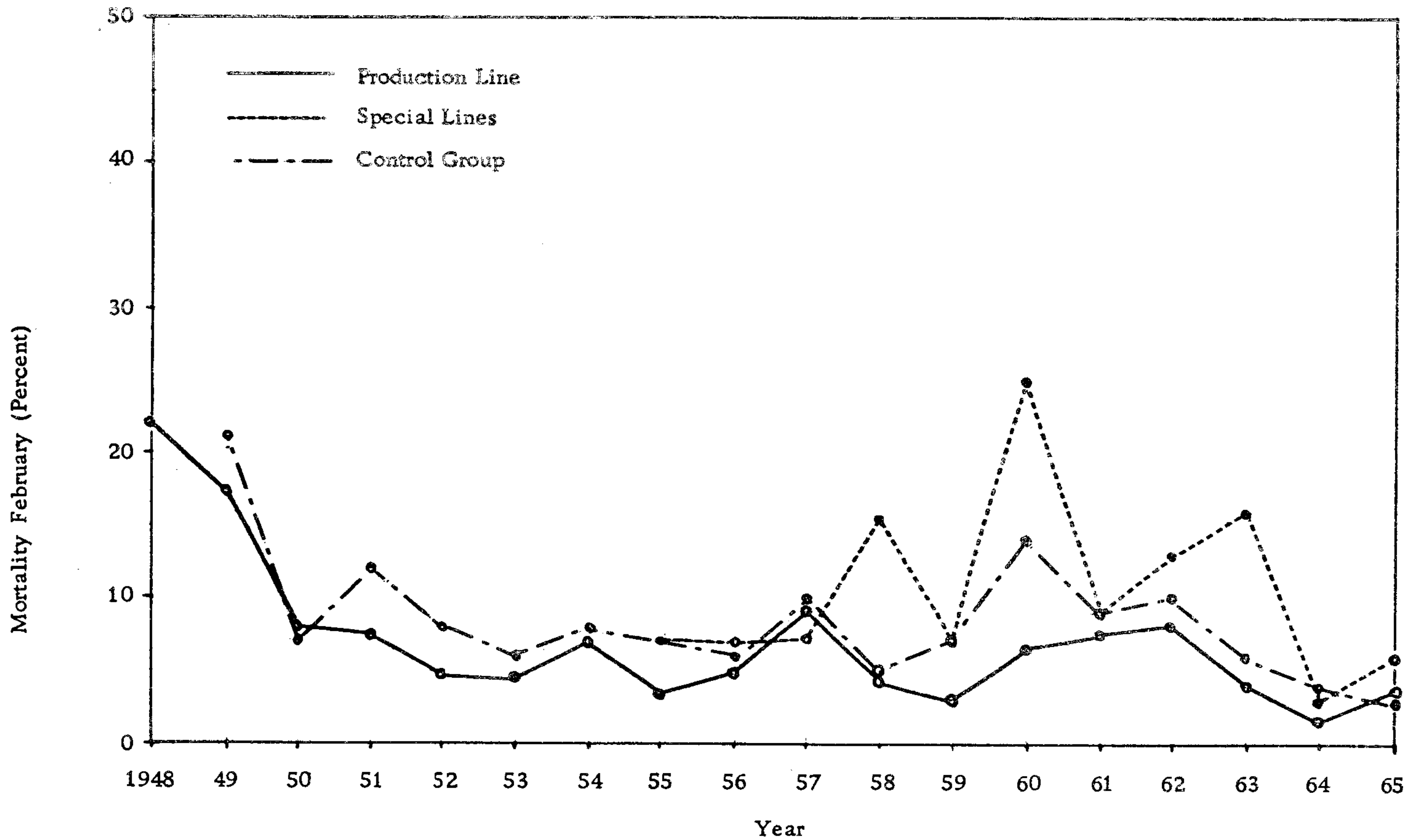


Figure 15. Production line, special lines and control group annual means for February mortality measured in percent.

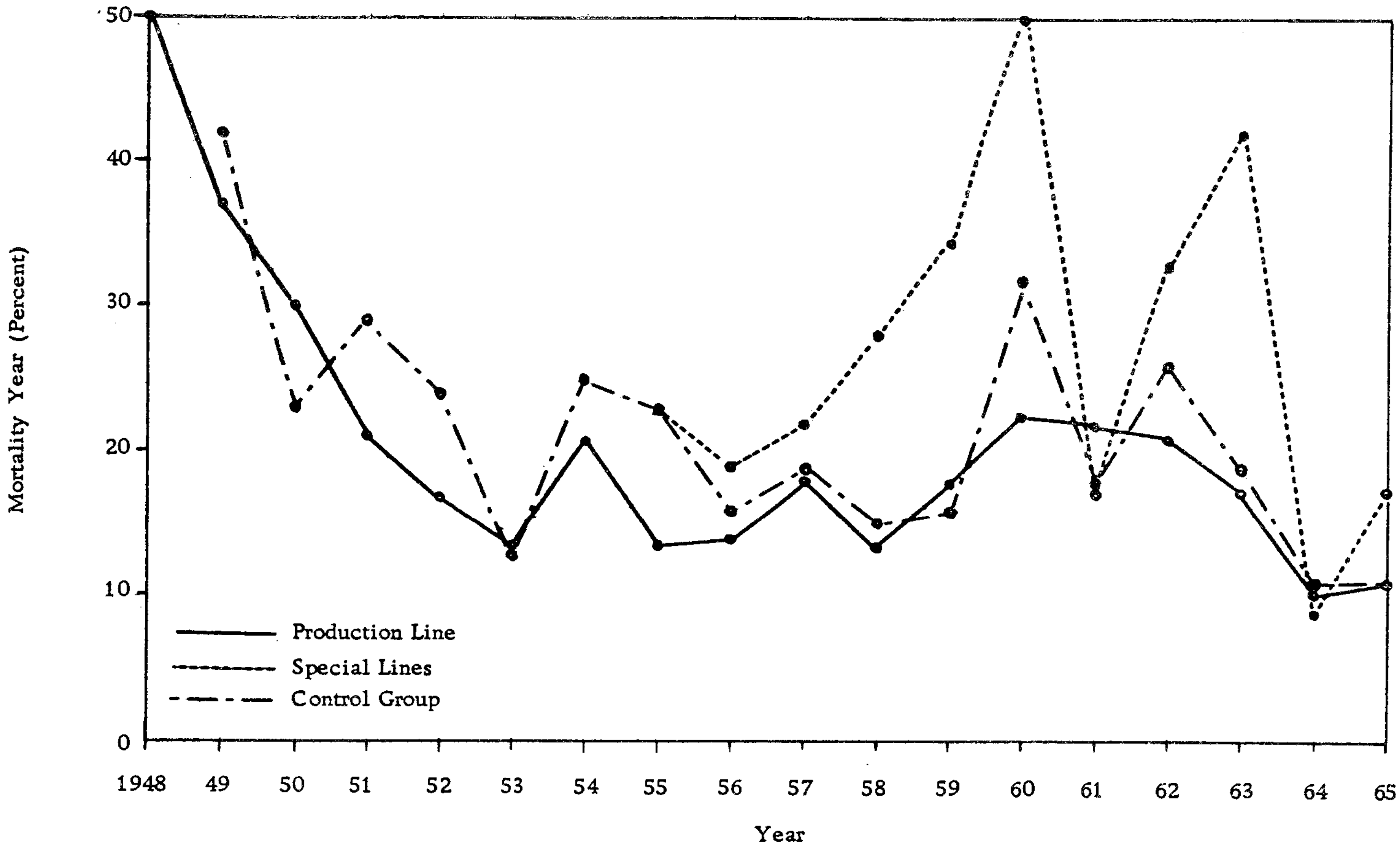


Figure 16. Production line, special lines and control group annual means for year mortality measured in percent.

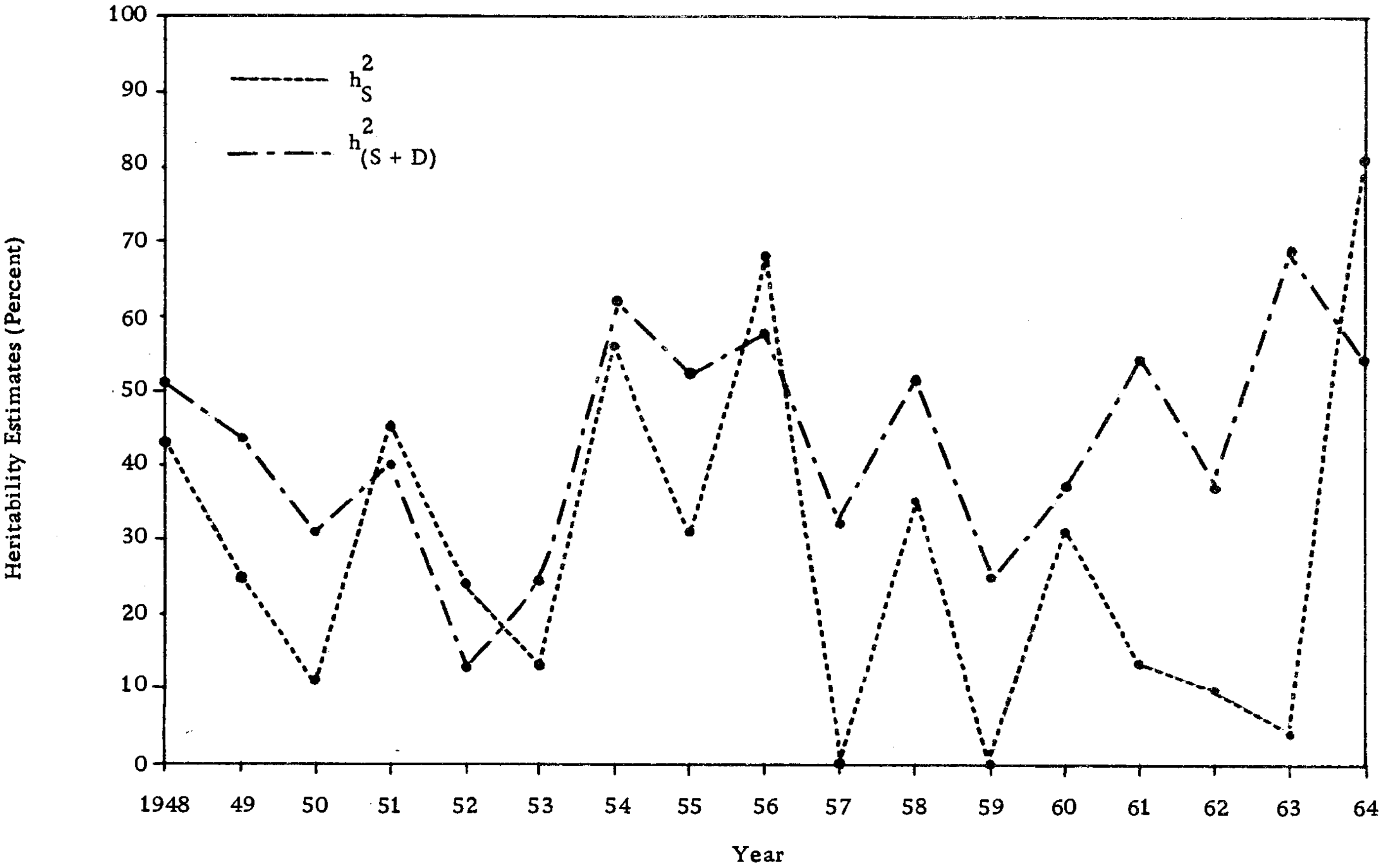


Figure 17. Production line. Annual heritability of sexual maturity.

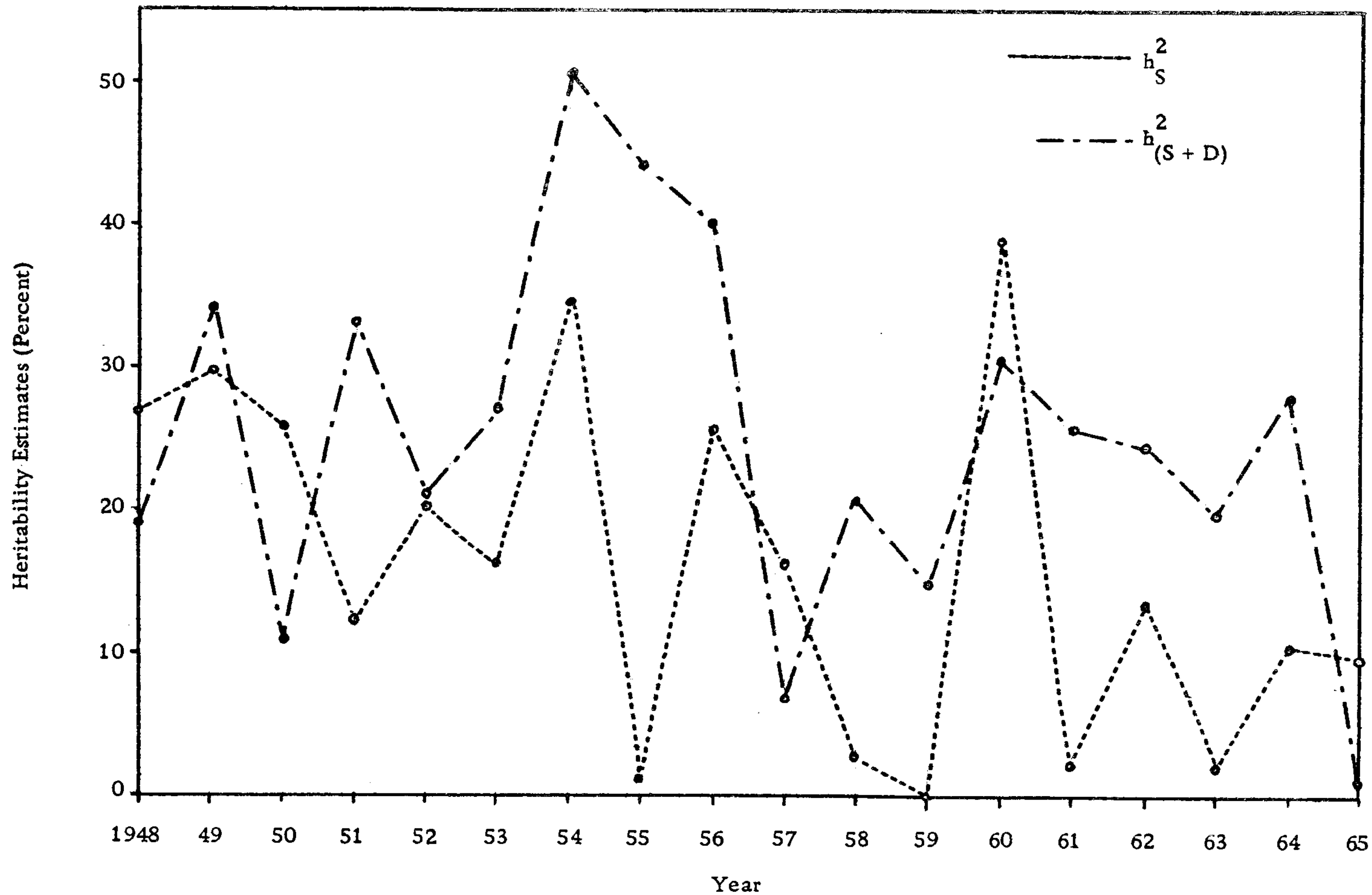


Figure 18. Production line. Annual heritability of egg production to February 1 in number of eggs.

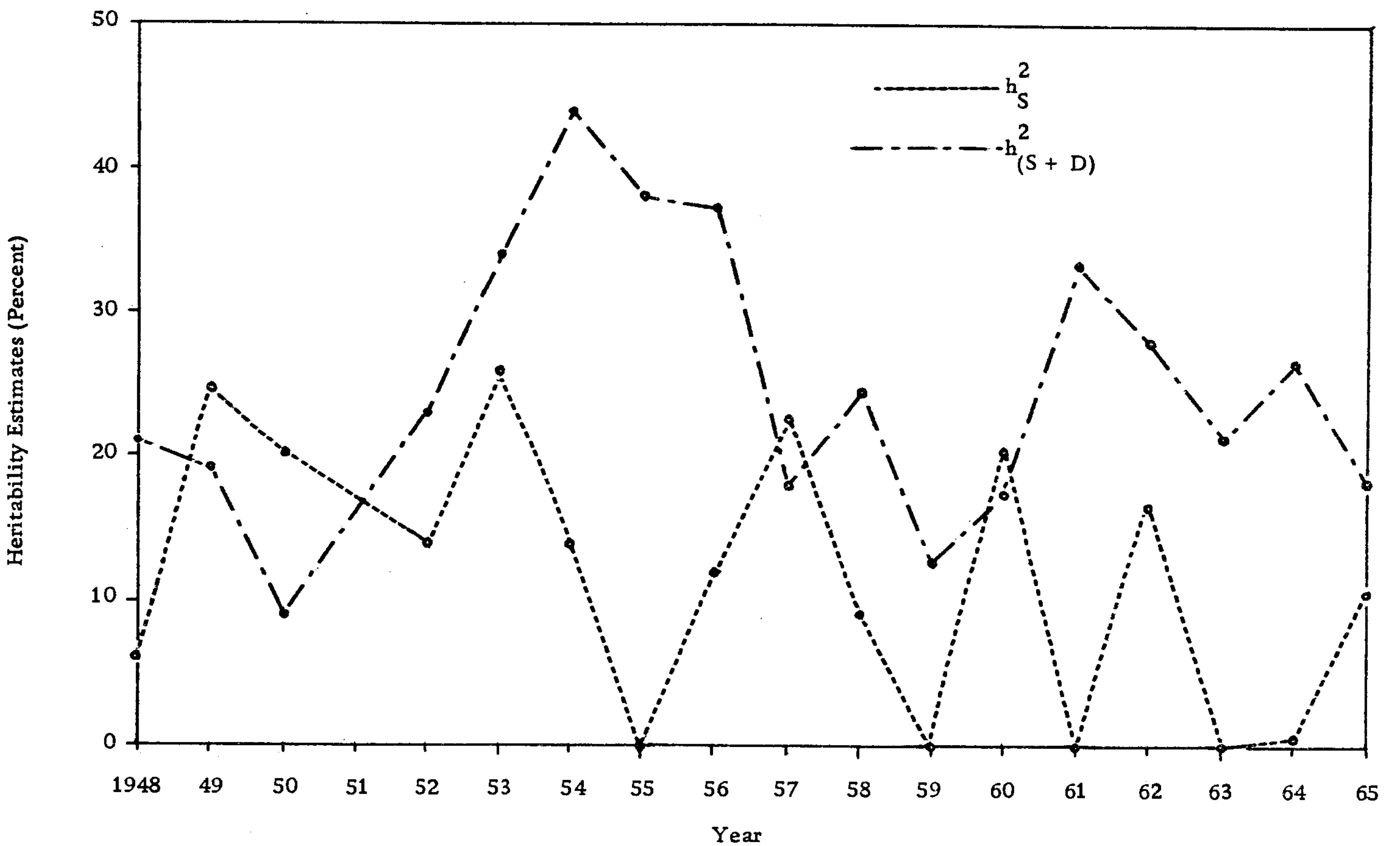
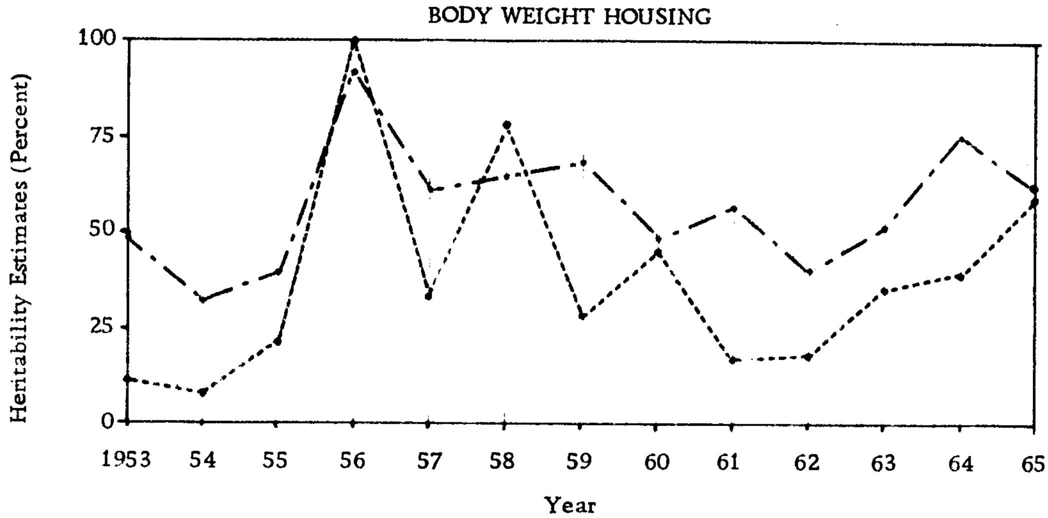


Figure 19. Production line. Annual heritability of year egg production in number of eggs.



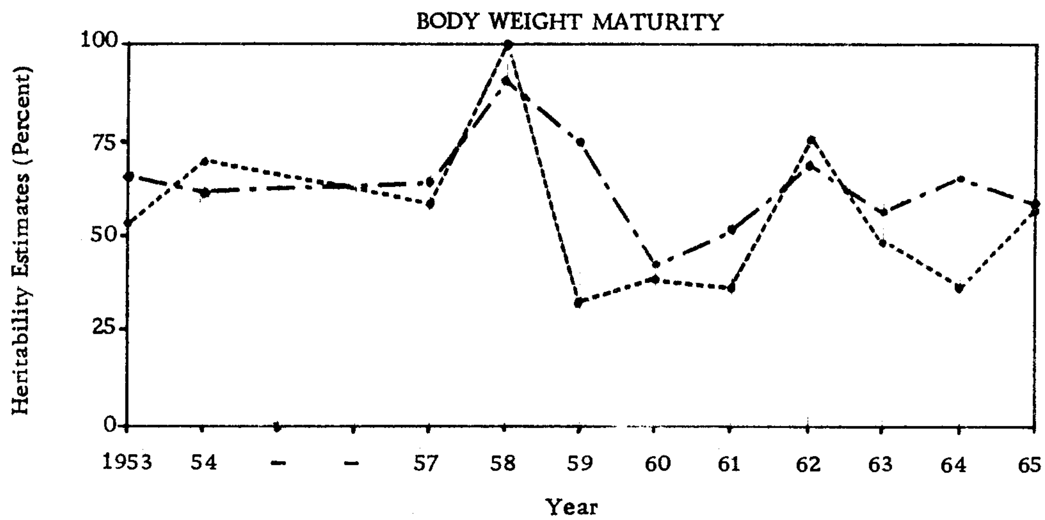
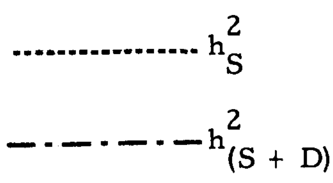
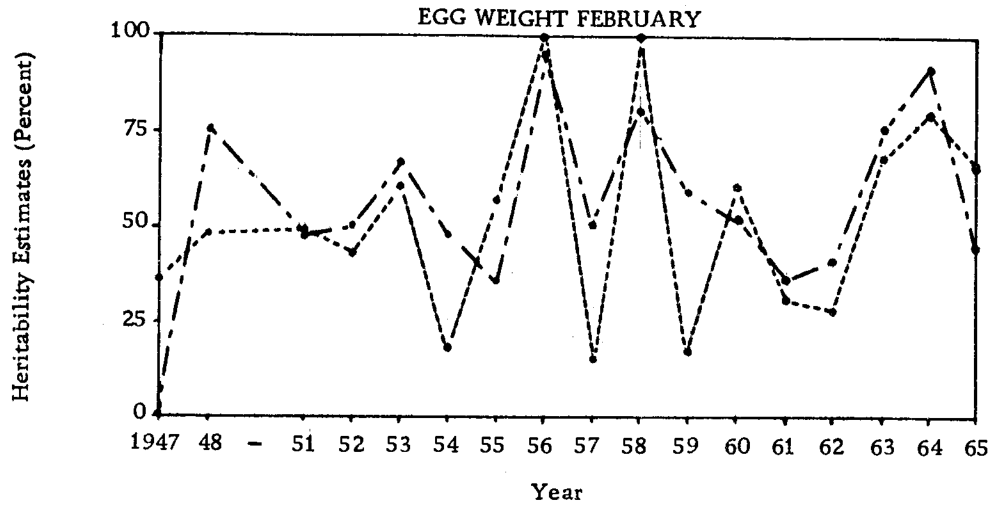


Figure 20. Production line. Annual heritability of housing and maturity body weight.





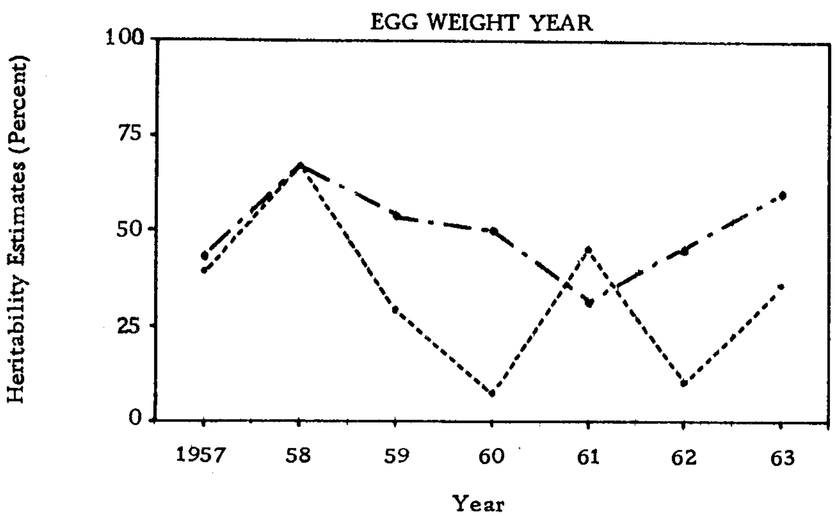
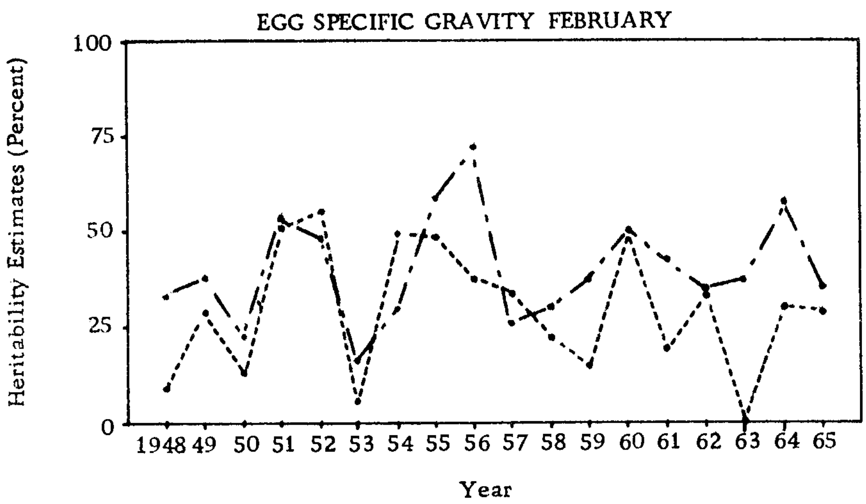


Figure 21. Production line. Annual heritability of February and year egg weight.

.... h^2_S

— · — · — · $h^2_{(S + D)}$



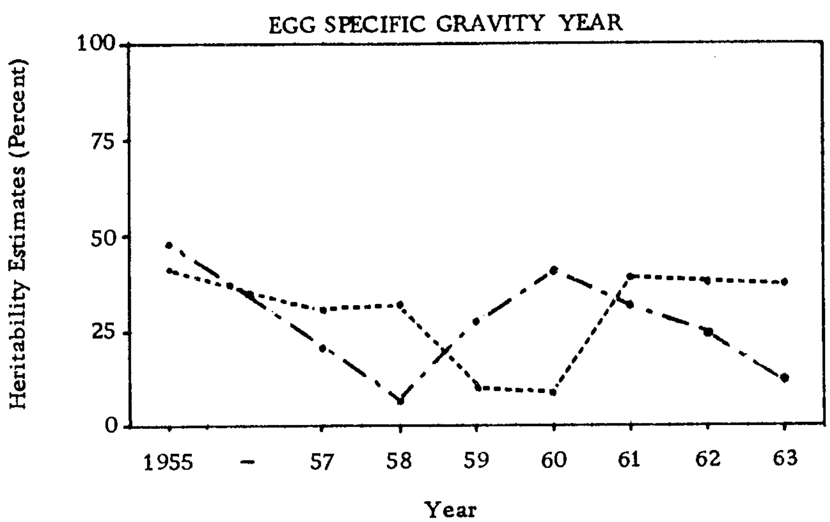
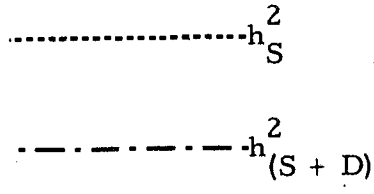


Figure 22. Production line. Annual heritability of February and year egg specific gravity.



correlation and 25 percent from the full-sib correlation (Figure 19), and similar values were obtained for the heritability of percent annual egg production.

Sexual maturity had a heritability of 27 percent when estimated from the sire component and 38 percent from the joint dam and sire component (Figure 17).

The heritability of body weight (Figure 20) was 53 percent from half-sib correlation and 63 percent from full-sib correlation.

Both estimates of heritability for egg weight and egg specific gravity averaged 32 percent and 30 percent, respectively (Figure 21 and 22).

It should be pointed out that the standard errors for both estimates of heritability are quite small for all variables. The annual fluctuation of the estimates was analyzed to evaluate the possible change, assuming a liner relationship between heritability and generation of selection. The results obtained are presented in Table 7, and they indicate a downward trend for the heritability of February and annual production when estimated from sire and joint components, but the negative regression coefficient was only statistically significant at the five percent level in the heritability of February egg production, when estimated from half-sib correlation. The trend of the heritability estimates of residual egg production were upward in both cases, but statistically non-significant. The heritability of sexual

Table 7. Regression of annual heritability estimates on years.

Variable	Regression h^2_S (b)	F-Value	Regression $h^2_{(S+D)}$ (b)	F-Value
NFE	-0.011 ± 0.005	4.70*	-0.006 ± 0.005	0.10
NYE	-0.008 ± 0.004	3.40	-0.0004 ± 0.005	0.06
NRE	0.004 ± 0.005	0.64	0.005 ± 0.005	0.07
SM	-0.002 ± 0.010	0.03	0.009 ± 0.007	1.50

NFE, egg production to February in number of eggs.
NYE, annual egg production in number of eggs.
NRE, residual egg production in number of eggs.
SM, sexual maturity, weeks to first egg.
* Significant at 5% level.

maturity decreased in the estimate obtained from the sire component and increased from the joint component, but both values of the regression coefficient were non-significant.

Correlations

Genetic, environmental and phenotypic correlations among the principal variables measured are given in Table 8. They were obtained from the pooled sire covariance and the combined sire and dam covariance components. The annual covariance components are included in Appendix Table 2, and the annual genetic correlation in Appendix Tables 7 and 8.

Early Production

The correlations between production to February and annual

Table 8. Average estimates of genetic environmental and phenotypic correlations in the production line.

Variables Correlated	Sires Covariance r_G	Sires Covariance r_E	Combined Covariance r_G	Combined Covariance r_E	Phenotypic Correlation r_P
NFE, NYE	0.864**	0.689**	1.000**	0.648**	0.746**
NFE, BWH	-0.033	0.192	0.109	0.151	0.120
NFE, EWF	-0.506*	-0.600*	-0.522*	-0.598*	-0.505*
NFE, NRE	0.159	0.083	0.882**	0.022	0.144
NFE, SM	-0.708**	-0.435	-0.930**	-0.644**	-0.486
NYE, BWH	0.022	0.132	0.026	0.137	0.089
NYE, EWF	-0.820**	-1.000**	-0.346	-1.000**	-1.000**
NYE, SM	-0.193	-0.261	-0.361	-0.227	-0.267
SM, BWH	0.075	-0.751**	-0.114	-0.765**	-0.456
SM, EWF	0.212	-0.154	-0.100	-0.037	-0.064

* Significant at 5% level
**Significant at 1% level

production were very high as would be expected and these values are in agreement with values reported in the literature (Lerner and Cruden, 1948; Maddison, 1954; Morris, 1956; and Nordskog et al., 1967). The value of the genetic correlation from the sire covariance was 0.86 and from the combined covariances exceeded slightly the limit of 1.0. The correlations between February production and residual production are small with the exception of the genetic correlation estimated from joint covariance which shows a high value of 0.88. The genetic correlation between February production and sexual maturity is very high for both estimates, -0.71 and -0.93, respectively, while the values of the same variable show a very low correlation with body weight at housing. February egg weight was negatively correlated with early production with an approximate value of -0.55.

Annual Production

Annual hen-housed egg production shows a very small correlation with housing body weight and a high, negative correlation with February egg weight. The correlations between annual production and sexual maturity were small and negative in value.

Sexual Maturity

The genetic correlations between sexual maturity and housing body weight are small, about 0.10, in contrast with the environmental correlation estimates that are high and negative with an average value of -0.75. Sexual maturity and February egg weight show a small negative correlation.

Selection Indices for Egg Production

The consideration of a selection index for early egg production and for annual production was suggested as a complementary utilization of the estimates of phenotypic and genetic parameters obtained. The economic weights used to obtain the genetic-economic value of the index are given in Table 9 and are based on current

Table 9. Relative economic weights.

Variable	Unit	Economic Value (Cents)
Sexual maturity (weeks to first egg)	1 week	+ 6.75
Egg production to February (no. of eggs)	1 egg	+ 7.80
Annual egg production (no. of eggs)	1 egg	+ 7.00
Body weight at housing (pounds)	1 pound	-15.00
Body weight at maturity (pounds)	1 pound	-35.00
February egg weight (grams)	1 gr./egg	1.00
Year egg weight (grams)	1 gr./egg	1.00

information furnished in the Commodity Data Sheet, Cooperative Extension Service, Oregon State University. The price of a large egg based on the price of a dozen averaged three cents. The price of a pound of meat was considered to be five cents, and the average value of a pound of feed was four cents. A reduction of one week in sexual maturity with a production intensity of 75 percent, and assuming an average of three days of trapnesting per week, would be an increase of 2.25 eggs or 6.75 cents. In the case of annual production, the average number of days of trapnesting per week was 2.33 and, therefore, the economic value of the same improvement by one unit would be seven cents. The increase of one pound in February body weight is worth five cents, but this means an increase in body maintenance which is equivalent to a loss of 20 cents. Therefore, the economic value of a pound of body weight is -15 cents. The cost of maintenance of a bird for a laying year is approximately 45 cents and consequently the economic value of a pound of body weight would be -35 cents.

The matrices obtained from the parameters given in Appendix Tables 1 and 2 are presented in Tables 10 and 11. The diagonal elements in the phenotypic matrix correspond to the pooled estimates of the σ_T^2 components and the other elements are the respective $cov_{T_{i,j}}$ components. In the same way, the diagonal elements in the genetic variance-covariance matrix are the estimates of the additive genetic variances estimated from the σ_S^2 components and the other elements represent the genetic covariances estimated from the components of covariance $cov_{S_{i,j}}$.

The indices derived with their standard deviations and the genetic change in each of the traits associated with one standard deviation of selection in the index are presented in Tables 12 and 13.

Table 10. Matrices for early record production index.

Matrix	Variable	SM	BWH	NFE	EWF
		Phenotypic Variance-Covariance Matrix			
P =	SM	7.896	-0.490	-14.480	-0.670
	BWH	-0.490	0.146	0.486	0.433
	NFE	14.480	0.486	112.600	-19.830
	EWF	-0.670	0.433	-19.830	13.709
		P. Inverse			
P^{-1} =	SM	0.222544	0.510754	0.033041	0.042538
	BWH	0.510754	9.641101	-0.032621	-0.326738
	NFE	0.033041	-0.032621	0.017807	0.028403
	EWF	0.042538	-0.326738	0.028403	0.126428
		Genotypic Variance-Covariance Matrix			
G =	SM	2.144	0.028	-4.080	0.880
	BWH	0.028	0.061	-0.180	0.405
	NFE	-4.080	-0.180	15.593	-5.680
	EWF	0.880	0.405	-5.680	8.057
		Economic Weights			
A =		6.75	-15.00	7.80	1.00

Table 11. Matrices for year record production index.

Matrix	Variable	NYE	NFE	EWF	EWY	BWM
				Phenotypic Variance-Covariance Matrix		
	NYE	486.566	174.656	-87.709	-152.456	-108.270
	NFE	174.656	112.600	-19.832	-18.730	-14.841
P =	EWF	-87.709	-19.832	13.709	7.043	-0.171
	EWY	-152.456	-18.730	7.043	18.094	0.653
	BWM	-108.270	-14.841	-0.171	0.653	0.277
				P. Inverse		
	NYE	0.000269	-0.002096	-0.002149	0.001353	-0.011572
	NFE	-0.002096	0.015110	0.012450	0.007422	0.015318
P^{-1} =	EWF	-0.002149	0.012450	0.099516	-0.043643	-0.008739
	EWY	0.001353	-0.007422	-0.043643	-0.075248	-0.081667
	BWM	-0.011572	0.015318	-0.008739	-0.081667	0.094781
				Genotypic Variance-Covariance Matrix		
	NYE	54.070	25.080	-17.160	-17.736	-16.880
	NFE	25.080	15.593	-5.664	-2.880	-2.400
G =	EWF	-17.160	-5.664	8.057	4.248	-0.492
	EWY	-17.736	-2.880	4.248	6.792	0.152
	BWM	-16.880	-2.400	0.492	0.152	0.174
				Economic Weights		
A =		7.0	7.8	1.0	1.0	-35.0

Table 12. Selection indices for part and annual egg production.

Index	SM	NFE	NYE	BWH	BWM	EWF	EWY
$I_{February}$	-3.178	0.087	—	-16.343	—	-2.167	—
I_{Year}	—	0.435	1.280	—	-8.267	-3.800	5.747

Table 13. Standard deviation of the selection indices and expected genetic change in the variables considered.

Index	σ_I	ΔSM	ΔNFE	ΔNYE	ΔBWH	ΔBWM	ΔEWF	ΔEWY
		(wks.)	(no. of eggs)		(pounds)		(grams)	
$I_{February}$	12.98	-0.73	2.28	—	-0.15	—	2.11	—
I_{Year}	49.27	—	1.29	3.71	—	-0.43	0.54	-0.047

DISCUSSION

Genetic Response to Accelerated Selection

The estimated genetic response in annual hen-housed egg production indicates a positive change in the basic trait in the 18 years of accelerated selection at 40 weeks of age; however, the means in the last six generations have not increased. The different values obtained when the genetic change was estimated from the special lines and the total control group were expected since about 50 percent of the total control group was composed of commercial chickens which are mostly strain crosses which probably progress consistently from year to year. The special lines represent unselected lines for egg production derived from the production line and maintained since as pure lines.

Hen-housed egg production to February or early production also showed a higher positive genetic response when estimated as deviations from the special lines than from the total control group, possibly due to the same reason.

Residual production has a positive genetic change per generation when estimated from the special lines and a negative value when estimated from the total control group. The small and statistically non-significant negative value can be attributed to the fact that the estimated genetic response in annual egg production was slightly smaller than that for February production, but the large standard error of the annual production estimate suggests that the average genetic change in the February and in annual production are nearly equal, and that little or no genetic change occurred in residual production. Similar results were observed when egg production was expressed in percent. This corroborates the proposition that there was no change in residual production.

Sexual maturity was the only other variable showing a significant correlated genetic response and it was statistically significant when the production line was compared with either the special lines or the total control group. This part of the analysis indicates that the steady progress in annual egg production was to a considerable extent the result of a progressive increase in the early production and not in the residual part that remained unchanged. The direct genetic response cannot, however, be attributed entirely to the reduction in age at sexual maturity since similar results were obtained when hen-housed production is expressed in percent, a measurement which minimizes the effect of sexual maturity.

Heritability

The values of the heritability estimates for the different variables fall within the range of those reported in the literature (among them Lerner and Cruden, 1951; King and Henderson, 1954; Jerome, 1956; Erasmus, 1962; and Lowe et al., 1966). The consistent tendency for the dam variance component to exceed the sire component was reflected consequently in the higher value of the full-sib estimates compared to those of the half-sibs, with the exception of February egg production in actual number and in February egg weight where the opposite situation was observed. The heritability based on the sire component was considered to be an estimate of additive genetic variance, which can be transmitted from parent to offspring, and the presence of non-additive variance and maternal effects will be included in the estimates from the dam component as well as in the combined sire and dam components (Falconer, 1964). For this reason, the heritability based on sire components would be a more reliable estimate of additive genetic variance than that involving the dam components. A similar situation was observed by King and Henderson (1954) and they considered the possibility that the higher selection intensity practiced on the males could account for the disparity between the two estimates of genetic variance, since the sire component would have smaller additive genetic variance than would be expected from a less highly selected sample.

The evaluation of the time trends in heritability showed a decline in the estimates for the February and annual egg production. This negative trend can be explained as a loss of genetic variation by fixation through selection or increasing homozygosity from inbreeding. The decline was larger for estimates obtained from the sire component than those from the combined sire and dam component and could be interpreted as the effect of selection decreasing additive genetic variance while non-additive genetic variance has remained constant. The positive change in the heritability for residual egg production, although small in magnitude, indicates that if we assume accelerated selection reduced genetic variance in the early period of production and total period of production, the genetic variability of the residual period was not affected.

Another possibility for the decline in the additive genetic variance could be attributed to the increase in inbreeding. Assuming that the estimated increase of two percent per year of the inbreeding coefficient is not far from the true value, it should have resulted also in a decline in the heritability estimate of residual production.

The slight decline in the estimate of heritability of sexual maturity could also have resulted from the lack of genetic response in February egg production in the most recent generations.

Correlations

The values obtained for the genetic correlations are in good agreement with most of the other published figures (Krueger *et al.*, 1952; Morris, 1956; Lowe *et al.*, 1966; Nordskog, 1967) estimated from covariance components. The occurrence of occasional negative estimates of variance components did not permit an estimation of the annual values in some cases, but when the data were pooled over years, no negative values were encountered. In some cases, estimates of the correlation coefficients were larger than unity.

The high estimate of genetic correlation between early and annual production, an average of 0.86, confirms the finding of Lerner and Cruden (1948), justifying the use of accelerated selection. The half-sib estimate of the genetic correlation between February production and residual production in actual number of eggs was very small when compared to that obtained from full-sib estimate. Although the half-sib estimate is not large, the positive sign does not support a possible decline in the residual production as a result of the response in early production.

The small negative genetic and environmental correlations between egg number to February and pullet weight are in good agreement with other reports for light breeds including Leghorn (Krueger et al., 1952; Nordskog, 1967). The negative genetic, environmental and phenotypical correlations found between egg weight and egg production also agrees well with other published reports (Jerome et al., 1956).

Sexual maturity and hen-housed egg production showed a high genetic correlation in February (-0.71), but diminished with annual egg production (-0.19), indicating that the contribution of precocious pullets to the February record faded out in the annual record. The genetic correlations between sexual maturity and housing body weight and February egg weight were larger when computed from the half-sib covariance than the full-sib covariance. This may indicate a sex-linked effect. In general, the half-sib estimates of genetic correlations were smaller than the full-sib estimates. This could be interpreted as the additive portion of the genetic covariance which has been decreased through selection while the non-additive part has remained relatively constant.

The estimates of heritability and the estimate of the genetic correlation between February hen-housed egg production and the annual record may be used to determine how effective accelerated selection has been.

The relative efficiency of direct and indirect selection may be evaluated by combining the formulas (Lerner, 1950) to estimate the expected genetic gain per year from family selection based on annual records (indirect selection) and that expected by selection on part period (direct selection), we have:

$$\Delta G_{NYE\ (direct)} = \frac{\bar{i}\ \sigma_{NYE}\ h^2_{NYE}}{2\ (\text{generation interval})}$$

$$\Delta G_{NYE\ (indirect)} = \frac{\bar{i}\ r_{G_{NFE,\ NYE}}\ \sigma_{G_{NYE}}\ h^2_{NFE}\ \sigma_{NFE}}{\sigma_{G_{NFE}}}$$

$$\frac{\Delta G_{NYE\ (indirect)}}{\Delta G_{NYE\ (direct)}} = \frac{2 r_{G_{NFE,\ NYE}} h_{NFE}}{h_{NYE}}$$

The values of the pooled estimates for heritability of February and annual production were 0.139 and 0.111, respectively, and the genetic correlation between both traits was 0.86. From these data, it can be concluded that accelerated selection based on early production provides approximately 1.8 times as much genetic gain per year as would direct selection on the basis of annual records. In reaching this conclusion, it is assumed that selection intensity is the same under both systems of selection. This assumption is valid in comparing part and full record selection in the domestic fowl (Dempster and Lerner, 1947), because the number of daughters produced by both types of dams after selection is not different and, therefore, not a limiting factor.

The environmental correlations contain environmental and non-additive effects and their magnitude is unknown. Some of the calculated values are too small to be important, but interesting consistency is observed in some of these estimates. The environmental correlations between February egg number and the residual and annual production are smaller than the values of the corresponding genetic correlations, indicating that genetic effects tend to increase egg production more than the environmental effects. In the case of egg production and egg weight, both genetic and environmental effects tended to reduce egg weight as should be expected. Sexual maturity influenced egg production more through genetic than through environmental effects while its effect on pullet weight and egg weight was mostly environmental and the difference in sign between the two correlation estimates shows that the genetic and environmental sources of variation affect the characters through different physiological mechanisms (Falconer, 1964).

The values of the phenotypic correlations show the result of genetic and environmental effects combined and are the reflection of the genetic and environmental correlations between the traits involved and also the magnitude of the heritability.

Selection Indices

The selection indices derived for both early and year production based on the estimates obtained in this study apply, of course, only to this population. Negative genetic correlations between traits, especially those involving egg production, can influence the genetic gain in this trait when attention must be paid to them for economic reasons.

In this experiment, year egg weight and body size were not adversely affected by the selection practiced on egg production. This is probably because some attention had to be paid to them to maintain their means at economically desirable levels. However, the selection index for early production based on the very reliable parameter estimates obtained in this study would insure a consistent plan of selection from generation to generation.

SUMMARY AND CONCLUSIONS

Records over an 18-year period of a population of White Leghorns at the Oregon State Agricultural Experiment Station, submitted to accelerated selection for hen-housed egg production on individual and family basis at 40 weeks of age, were studied. An analysis was made to determine the relative efficiency of accelerated selection compared to direct selection for egg production based on annual records. When annual means of the production line were compared with control populations, accelerated selection proved to be effective in obtaining genetic gains in hen-housed annual production by increasing the February or part-period egg production while the residual production remained unchanged.

Reliable estimates of genetic parameters obtained from the pooled analysis of the data demonstrated that accelerated selection on the basis of February egg production is justified and could provide 1.8 times as much genetic gain per year as would direct selection based on annual records.

The lack of genetic progress in egg production for the last six generations cannot be attributed to a decline in residual production as a result of accelerated selection since the genetic correlation between these two variables is positive.

The half-sib heritability estimates of annual hen-housed egg production and that to Feb. 1st, and also sexual maturity decreased in succeeding years. This indicates a reduction in the proportion of additive genetic variance for these three variables. However, the heritability of residual hen-housed egg production showed a positive, but statistically non-significant, regression on time.

The full-sib estimates of heritability were generally larger than the half-sib estimates. This indicates other sources of variation, such as non-additive genetic variance and maternal variance. For this reason, half-sib estimates of heritability are probably more reliable.

The increase in the coefficient of inbreeding as estimated from the effective number of sires and dams averaged two percent per generation, but this value probably overestimates the true inbreeding since half-sib and full-sib matings were avoided throughout the experiment. The effect of inbreeding caused by restrictions in population number is not clear since it should lead to a decline in fitness (Lerner, 1950) reflected in loss of fertility and livability. In this study, a progressive reduction in annual mortality from an initial 50 percent to 10 percent in the last three years has been observed. Inbreeding has not been intense and may have helped in "purging" the population of undesirable recessive genes (Nordskog, 1966).

Most of the selection experiments with laboratory organisms have been conducted to a plateau phase in about 20 generations of directional selection and, as pointed out by McBride (1965), none of the recent attempts to explain this phenomenon has yet been satisfactory.

In conclusion, the results obtained in this study demonstrate that accelerated selection for hen-housed egg production at 40 weeks of age has been more effective than direct selection based on annual records would have been. The increase in genetic merit has become more difficult in the last generations. This could be attributed to a decline in additive genetic variance due to directional selection. Such a result does not differ from theoretical expectations.

BIBLIOGRAPHY

Abplanalp, H. 1957. Genetic and environmental correlations among production traits of poultry. Poultry Science 36:226-228.

Becker, W. A. 1964. Manual of procedures in quantitative genetics. Pullman, Washington State University Press, 70 p.

Bernier, P. E. 1949. Breeding for improvement of egg production. Eggsaminer 26:2, 11.

________________. 1953. Cutting corners in poultry breeding. Proceedings of the 6th California Animal Industry Conference, Yosemite National Park, September. p. 47-54.

Binet, F. E., 1965. On the construction of an index for indirect selection. Biometrics 21:291-299.

Bray, D. F., A. E. Bell and S. C. King. 1960. The importance of genotype x environment interaction with reference to control populations. (Abstract) Genetics 45:977-978.

Clayton, E. P. 1927. Four winter months laying as a guide to yearly production. In: 40th Annual Report of the Mississippi Agricultural Experiment Station. State College. p. 34-35.

Dempster, E. R. and I. M. Lerner. 1947. The optimum structure of breeding flocks. Genetics 32:567-579.

Dickerson, G. E. and L. N. Hazel. 1944. Effectiveness of selection on progeny performance as a supplement to earlier culling in livestock. Journal of Agricultural Research 69:459-476.

Erasmus, J. E. 1962. Part record selection for egg production. In: Proceedings of XII World's Poultry Congress, Sydney, 1962. p. 17-18.

Falconer, D. S. 1964. Introduction to quantitative genetics. Rev. ed. New York, Ronald Press Company. 365 p.

Friars, G. W., B. B. Bohren and H. E. McKean. 1962. Time trends in estimates of genetic parameters in a population of chickens subjected to multiple objective selection. Poultry Science 41:1773-1784.

Gowe, R. S. 1961. Problems in environment and poultry breeding. In: The National Poultry Breeders' Round Table, 10th Annual Session, Chicago, Illinois. Kansas City, Missouri, Poultry Breeders of America, Inc. p. 175-208.

Gowe, R. S. and J. H. Strain. 1963. Effect of selection for increased egg production based on part-year records in two strains of W. L. (Abstract) Canadian Journal of Genetics and Cytology 5:99-100.

Hogsett, M. L. and A. W. Nordskog. 1958. Genetic-economic value in selecting for egg production rate, body weight and egg weight. Poultry Science 37:1404-1419.

James, J. W. and F. Foenander. 1961. Social behaviour studies on domestic animals. I. Hens in laying cages. Australian Journal of Agricultural Research 12:1239-1252.

Jerome, F. N., C. R. Henderson and S. C. King. 1956. Heritabilities, gene interactions, and correlations associated with certain traits in the domestic fowl. Poultry Science 35:995-1013.

King, S. C. and C. R. Henderson. 1954. Heritability studies of egg production in the domestic fowl. Poultry Science 33:155-169.

King, S. C. 1961. Inheritance of economic traits in the regional Cornell control population. Poultry Science 40:975-986.

Kraszewska-Domanska, B. 1963. Investigation on the correlation between the hen's initial egg-laying rate and the remaining part of their annual egg production. Roczniki Nauk Rolniczych 82(B): 375-387.

Krueger, W. F., G. E. Dickerson, Q. B. Kinder and H. L. Kemster. 1952. The genetic and environmental relationship of total egg production to its components and to body weight in the domestic fowl. (Abstract) Poultry Science 31:922-923.

Lerner, I. M. and D. M. Cruden. 1948. The heritability of accumulative monthly and annual egg production. Poultry Science 27: 67-77.

Lerner, I. M. 1950. Population genetics and animal improvement. Cambridge, University Press. 342 p.

Lerner, I. M. and D. M. Cruden. 1951. The heritability of egg weight: The advantages of mass selection and of early measurements. Poultry Science 30:34-41.

Lerner, I. M. and E. R. Dempster. 1956. An empirical test of part-record selection for egg production. Poultry Science 35: 1349-1355.

Lowe, P. C., S. P. Wilson, T. B. Kinney and B. B. Bohren. 1966. Genetic gains in annual egg production from selection on part records. 55th Annual Meeting of Poultry Science Association, Logan, Utah, August, 1966. p. 7. (Mimeographed)

Maddison, A. E. 1954. The use of partial records in poultry selection. In: Proceedings of the British Society of Animal Production, Edinburgh, 1954. p. 109-115.

McBride, G. 1966. Animal breeding in the light of recent advances in population genetics. World's Poultry Science Journal 22:314-328.

Morris, J. A. 1956. Genetic parameters associated with characters affecting egg production in the domestic fowl. II. Heritability of egg production for two part-annual period of measurement and the genetic correlation between them. Australian Journal of Agricultural Research 7:630-639.

________________. 1963. Continuous selection for egg production using short-term records. Australian Journal of Agricultural Research 14:909-925.

________________. 1964. The usefulness of early records as selection criteria for breeding. In: 1st Australasian Poultry Convention, Surfers Paradise, Queensland, Australia, May, 1964. p. 7-11.

Morris, J. A. and F. E. Binet. 1966. Heterosis and selection in the domestic fowl. Australian Journal of Biological Science 19:575-585.

Nordskog, A. W. and M. Festing. 1962. Selection and correlated responses in the fowls. In: Proceedings of the XII World's Poultry Congress, Sydney, 1962. p. 25-29.

Nordskog, A. W. 1966. The evolution of animal breeding practices - commercial and experimental. World's Poultry Science Journal 22:207-216.

Nordskog, A. W., M. Festing and M. W. Verghese. 1967. Selection for egg production and correlated responses in the fowl. Genetics 55:179-191.

Onishi, N. and Y. Kato. 1960. On the relationship between the first year egg production record and its part-time record in the domestic fowl. Bulletin of the National Institute Agricultural Science (Chiba, Japan), ser. G, 19:97-108.

Schaaf, A. and H. Wendt. 1959. Die Winterlegeleistung als Maßstab für die zu erwartende Jahresleistung von Legehennen im ersten Legejahr und als Basis für züchterische Maßnahmen. Archiv für Tierzucht 2:245-266.

Snedecor, G. W. 1956. Statistical methods. 5th rev. ed. Ames, Iowa State University Press. 534 p.

Waring, F. J., P. Hunton and A. E. Maddison. 1962. Genetics of a closed poultry flock. I. Variance and covariance analysis of egg production, egg weight and egg mass. British Poultry Science 3:151-159.

Wright, S. 1931. Evolution in Mendelian populations. Genetics 16:97-159.

Yamada, Y., B. B. Bohren and L. B. Crittenden. 1958. Genetic analysis of a White Leghorn closed flock apparently plateaued for egg production. Poultry Science 37:565-580.

APPENDIX

Appendix Table 1. Production line. Year and pooled-over-year components of variance estimates. (Sire, dam, full-sib and total components.)

	Sexual Maturity (Weeks to first egg)				Egg Production to February (No. of eggs)				Annual Egg Production (No. of eggs)			
Year	σ_S^2	σ_D^2	σ_W^2	σ_T^2	σ_S^2	σ_D^2	σ_W^2	σ_T^2	σ_S^2	σ_D^2	σ_W^2	σ_T^2
1947	.16	-.26	10.75	10.65	--	--	--	--	--	--	--	--
48	1.34	1.82	9.32	12.48	4.20	1.76	55.86	61.82	10.11	58.46	584.97	653.54
49	.80	2.02	10.11	12.93	6.01	7.83	66.55	80.39	31.30	17.10	454.52	502.92
50	.16	.73	4.87	5.76	2.68	-.43	39.01	41.26	17.95	-1.90	335.24	351.29
51	.37	.29	2.63	3.29	2.45	10.84	66.51	79.80	--	--	--	--
52	.93	.08	14.41	15.42	3.99	4.41	70.13	78.53	16.11	36.90	406.70	459.71
53	.17	.48	4.66	5.31	1.99	4.64	41.97	48.60	21.86	34.95	276.82	333.63
54	.92	1.13	4.54	6.59	4.48	8.57	38.58	51.63	16.24	84.91	359.27	460.42
55	.78	1.90	7.53	10.21	.21	14.62	52.28	67.11	-13.13	85.56	307.81	380.24
56	1.24	.86	5.17	7.27	6.64	13.94	81.93	102.51	13.01	66.21	346.92	426.14
57	-.05	1.06	5.26	6.27	5.33	-.78	125.22	129.77	34.14	20.26	545.61	600.01
58	.32	.62	2.71	3.65	.08	10.91	95.25	106.24	10.01	43.15	379.92	433.08
59	-.09	.86	5.42	6.19	-2.52	11.12	107.04	115.64	-6.85	38.52	466.17	497.84
60	.42	.58	4.32	5.32	15.90	8.93	137.53	162.36	33.26	23.54	591.12	647.92
61	.24	1.73	5.25	7.22	.93	19.72	140.24	160.89	-.27	107.88	536.30	643.91
62	.10	.67	3.38	4.15	7.21	19.12	187.66	213.99	25.97	61.18	537.13	624.28
63	.09	2.75	5.38	8.22	1.00	17.25	166.85	185.10	-7.15	64.61	482.05	539.51
64	1.28	.45	4.61	6.34	2.46	10.43	79.84	92.73	.35	38.28	249.52	288.15
65	--	--	--	--	2.69	-2.26	108.93	109.36	9.75	24.30	338.78	372.83
Pooled Mean	.54	.97	6.38	7.89	3.90	.55	108.15	112.60	13.52	47.67	425.38	486.57

Appendix Table 1. Continued.

Year	Residual Egg Production (No. of eggs)				Egg Production to February (Percent)				Annual Egg Production (Percent)			
	σ^2_S	σ^2_D	σ^2_W	σ^2_T	σ^2_S	σ^2_D	σ^2_W	σ^2_T	σ^2_S	σ^2_D	σ^2_W	σ^2_T
1947	--	--	--	--	--	--	--	--	--	--	--	--
48	9.18	32.77	281.68	323.63	31.74	46.64	516.36	594.74	14.06	59.72	617.15	690.93
49	6.61	11.68	158.59	176.88	35.26	56.72	454.14	546.12	34.33	13.66	534.08	582.07
50	-.22	.30	147.97	148.05	19.40	-3.27	243.58	259.71	21.92	-.83	446.19	467.28
51	--	--	--	--	5.08	55.14	372.10	432.32	--	--	--	--
52	1.11	17.77	138.67	157.55	5.50	.41	326.72	332.63	14.36	40.85	440.12	495.33
53	6.94	11.29	111.70	129.93	11.41	14.48	215.20	241.09	27.00	30.87	299.32	357.19
54	-3.04	27.59	146.46	171.01	4.99	55.04	262.28	322.31	10.69	92.61	414.16	517.46
55	-3.59	20.81	118.71	135.93	.07	61.64	260.02	321.73	-14.73	90.80	347.28	423.35
56	1.75	14.09	84.23	100.07	.42	20.60	245.83	266.85	7.52	51.34	314.38	373.24
57	7.72	-1.80	113.08	119.00	12.30	2.73	358.64	373.67	25.78	17.54	397.09	440.41
58	6.66	21.37	101.86	129.89	-.67	9.22	218.88	227.43	9.53	22.78	266.27	298.58
59	.94	0.85	227.32	227.41	-1.72	4.96	214.77	218.01	-2.46	15.61	289.22	302.37
60	5.76	8.90	185.61	200.27	28.16	-2.44	313.66	339.38	19.17	15.20	367.01	401.38
61	3.77	9.81	152.97	166.55	-.07	49.17	335.59	384.69	-3.06	73.87	400.96	471.77
62	9.22	14.76	88.60	112.58	20.25	29.55	405.74	455.54	24.01	46.43	343.33	413.77
63	-2.61	20.39	127.67	145.45	-1.19	48.87	372.38	420.06	-7.43	55.75	363.53	411.85
64	4.93	8.40	104.89	118.22	1.96	18.16	138.98	159.10	7.24	29.07	172.50	208.81
65	3.28	16.07	87.86	107.21	3.28	-6.83	233.18	229.63	8.24	24.17	229.96	262.37
Pooled Mean	4.05	16.37	137.79	158.21	10.41	22.86	315.35	348.62	12.25	44.28	364.11	420.64

Appendix Table 1. Continued.

	Residual Egg Production (Percent)				Body Weight - 10 Weeks of Age (Pounds)				Body Weight - Housing (Pounds)			
	σ^2_S	σ^2_D	σ^2_W	σ^2_T	σ^2_S	σ^2_D	σ^2_W	σ^2_T	σ^2_S	σ^2_D	σ^2_W	σ^2_T
1947	--	--	--	--	-.001	.007	.047	.053	.010	.062	.185	.257
48	18.85	70.37	610.70	699.92	--	--	--	--	.033	.075	.225	.333
49	20.44	31.02	490.96	542.42	--	--	--	--	--	--	--	--
50	-1.16	1.98	548.26	549.08	--	--	--	--	--	--	--	--
51	--	--	--	--	--	--	--	--	--	--	--	--
52	4.26	57.09	458.49	519.84	--	--	--	--	--	--	--	--
53	20.62	34.01	331.63	386.26	--	--	--	--	.004	.030	.105	.139
54	-8.88	81.92	444.70	517.74	.001	.004	.025	.030	.003	.019	.121	.143
55	-12.35	71.60	407.50	466.75	.001	.010	.020	.031	.008	.021	.120	.149
56	8.06	54.10	306.90	369.06	.020	.012	.022	.054	.040	.020	.070	.130
57	21.52	-5.79	314.35	330.08	.003	.009	.025	.037	.012	.032	.100	.144
58	20.30	65.82	312.87	398.99	.007	.006	.020	.033	.024	.017	.085	.126
59	1.69	-4.45	631.77	629.01	.002	.005	.016	.023	.008	.030	.074	.112
60	17.44	22.03	516.49	555.96	.004	.003	.026	.033	.013	.014	.086	.113
61	13.03	33.81	524.11	570.95	.002	.004	.021	.027	.005	.028	.084	.117
62	37.11	60.39	354.00	451.50	.001	.003	.026	.030	.004	.014	.072	.090
63	-10.09	80.17	493.20	563.28	.005	.013	.023	.041	.008	.014	.064	.086
64	18.38	30.70	388.79	437.87	.007	.015	.019	.041	.012	.035	.078	.125
65	12.21	59.68	325.26	397.15	.004	.005	.020	.029	.016	.017	.073	.106
Pooled Mean	11.95	48.44	429.06	489.45	.004	.007	.022	.033	.015	.025	.106	.146

Appendix Table 1. Continued.

Year	Body Weight - Maturity (Pounds)				Egg Weight - February (Grams)				Egg Weight - Year (Grams)			
	σ^2_S	σ^2_D	σ^2_W	σ^2_T	σ^2_S	σ^2_D	σ^2_W	σ^2_T	σ^2_S	σ^2_D	σ^2_W	σ^2_T
1947	--	--	--	--	1.86	-2.82	21.47	20.51	--	--	--	--
48	--	--	--	--	1.88	4.03	9.72	15.63	--	--	--	--
49	--	--	--	--	--	--	--	--	--	--	--	--
50	--	--	--	--	--	--	--	--	--	--	--	--
51	--	--	--	--	1.73	1.60	10.74	14.07	--	--	--	--
52	--	--	--	--	1.28	1.70	8.88	11.86	--	--	--	--
53	.035	.052	.180	.267	2.25	2.75	9.97	14.97	--	--	--	--
54	.045	.034	.182	.261	.62	2.64	10.42	13.68	--	--	--	--
55	--	--	--	--	1.72	.43	9.89	12.04	--	--	--	--
56	--	--	--	--	6.93	1.53	9.14	17.60	--	--	--	--
57	.051	.062	.238	.351	.47	2.62	9.10	12.19	1.60	1.90	12.80	16.30
58	.114	.057	.206	.377	3.21	1.76	7.36	12.33	2.79	2.77	11.08	16.64
59	.019	.067	.147	.233	.38	2.23	6.20	8.81	1.16	3.05	11.49	15.70
60	.023	.028	.193	.244	1.91	1.40	9.32	12.63	.33	2.00	16.54	18.87
61	.019	.035	.154	.208	.82	1.09	8.71	10.62	2.10	.83	15.64	18.57
62	.047	.039	.164	.250	.68	1.34	7.81	9.83	.45	3.38	13.20	17.03
63	.036	.048	.214	.298	2.51	3.06	9.07	14.64	2.57	5.88	19.69	28.14
64	.021	.055	.159	.235	3.00	3.90	8.12	15.02	--	--	--	--
65	.036	.037	.181	.254	2.00	1.19	10.98	14.17	--	--	--	--
Pooled Mean	.043	.049	.185	.277	2.01	1.52	10.18	13.71	1.70	2.77	13.62	18.09

Appendix Table 1. Continued.

Year	Specific Gravity - February (Code 1-16) σ^2_S	σ^2_D	σ^2_W	σ^2_T	Specific Gravity - Year (Code 1-16) σ^2_S	σ^2_D	σ^2_W	σ^2_T
1947	-.58	.59	1.73	1.74	--	--	--	--
48	.04	.04	1.41	1.69	--	--	--	--
49	.14	.22	1.52	1.88	--	--	--	--
50	.04	.10	1.12	1.26	--	--	--	--
51	.16	.17	.92	1.25	--	--	--	--
52	.19	.14	1.04	1.37	--	--	--	--
53	.02	.10	1.37	1.49	--	--	--	--
54	.20	.05	1.40	1.65	--	--	--	--
55	.19	.27	1.11	1.57	.19	.24	1.41	1.84
56	.14	.41	.97	1.52	--	--	--	--
57	.13	.08	1.37	1.58	.16	.05	1.92	2.13
58	.07	.13	1.11	1.31	.16	-.10	2.07	2.13
59	.05	.19	1.05	1.29	.06	.24	1.89	2.19
60	.21	.21	1.28	1.70	.05	.43	1.92	2.40
61	.09	.29	1.44	1.82	.23	.14	2.05	2.42
62	.15	.18	1.52	1.85	.22	.05	1.98	2.25
63	-.01	.32	1.35	1.66	.24	-.40	2.72	2.56
64	.10	.28	.94	1.32	--	--	--	--
65	.11	.15	1.22	1.48	--	--	--	--
Pooled Mean	.11	.18	1.26	1.55	.17	.09	1.96	2.22

Appendix Table 2. Production line. Year and pooled-over-year components of covariance estimates. (Sire, dam, full-sib and total components.)

	SM, NFE				SM, NYE				SM, BWH			
Year	cov_S	cov_D	cov_W	cov_T	cov_S	cov_D	cov_W	cov_T	cov_S	cov_D	cov_W	cov_T
1948	-1.56	-.69	-10.36	-12.61	.37	-1.92	-23.19	-24.74	.11	.46	-.20	-.37
49	-1.19	-2.47	-10.62	-14.28	-1.71	-2.51	-15.10	-19 32	--	--	--	--
50	-.28	-.52	-8.70	-9.50	-.54	-2.13	-13.76	-16.43	--	--	--	--
51	-.86	-1.23	-5.00	-7.09	--	--	--	--	--	--	--	--
52	-1.84	-2.19	-18.05	-22.08	-1.81	-4.81	-30.62	-37.24	--	--	--	--
53	-.27	-1.42	-8.03	-9.72	.30	-3.85	-8.47	-12.02	.03	-.07	-.23	-.27
54	-2.17	-1.22	-7.60	-10.99	-3.88	-4.42	-12.42	-20.72	.03	-.05	-.30	-.32
55	-.40	-4.12	-11.64	-16.16	-.44	-8.12	-16.26	-24.82	-.10	-.06	-.24	-.40
56	-2.80	-2.70	-10.98	-16.51	-2.82	-3.99	-14.31	-21.12	.12	-.04	.03	.11
57	-.30	.01	-11.01	-11.30	-.74	.67	-15.56	-15.63	-.01	-.06	-.10	-.17
58	-.41	-2.41	-6.78	-9.60	.37	-3.65	-6.82	-10.10	.02	-.02	-.11	-.11
59	.42	-2.84	-11.53	-13.95	-6.19	-3.56	-16.20	-25.95	-.02	-.02	-.16	-.20
60	-1.50	-2.68	-9.30	-13.48	-1.31	-4.21	-10.02	-15.54	-.06	-.04	-.23	-.33
61	-.57	-1.74	-10.97	-13.28	-.21	-5.28	-15.09	-20.58	-.001	-.05	-.21	-.26
62	-.07	-4.49	-11.76	-16.32	.66	-4.99	-27.30	-31.63	-.01	-.03	-.19	-.23
63	-.39	-3.38	-18.50	-22.27	-.37	-6.25	-23.08	-29.70	.02	.01	-.26	-.23
64	-1.91	-1.18	-11.28	-14.37	.58	.01	-13.00	-12.41	-.03	.02	-.11	-.12
65	--	--	--	--	--	--	--	--	--	--	--	--
Pooled Mean	-1.02	-1.39	-12.07	-14.48	-.52	-2.95	-13.05	-16.52	.007	-.033	-.462	-.502

Appendix Table 2. Continued.

Year	SM, EWF				NFE, NYE				NFE, BWH			
	cov_S	cov_D	cov_W	cov_T	cov_S	cov_D	cov_W	cov_T	cov_S	cov_D	cov_W	cov_T
1948	.38	-1.20	-1.14	-1.96	13.04	1.62	136.03	150.69	--	--	--	--
49	--	--	--	--	12.69	9.29	136.17	158.15	--	--	--	--
50	--	--	--	--	5.70	-1.06	83.92	88.56	--	--	--	--
51	.29	.20	.34	.93	--	--	--	--	--	--	--	--
52	-.11	-.01	-1.84	-1.96	5.38	.32	136.55	142.21	--	--	--	--
53	.21	-.55	-.22	-.56	5.41	13.28	73.98	92.67	-.08	.15	.38	.45
54	.93	-1.43	.09	-.41	9.71	22.72	89.29	121.72	-.03	.05	.48	.50
55	-.11	-.41	-.23	-.75	-3.86	36.56	98.52	131.22	-.06	.39	.52	.85
56	1.87	.04	-.30	1.61	7.72	33.26	130.88	171.86	-.46	.22	-.20	-.44
57	.15	-.70	-1.35	-1.90	11.09	2.07	221.12	234.28	-.05	.17	-.19	-.07
58	.13	.47	.37	.97	-.12	16.40	161.69	177.97	-.02	-.01	.36	.33
59	.17	.08	-.69	-.44	-4.42	20.89	155.96	172.43	-.03	.08	.44	.49
60	-.60	.12	-.04	-.52	21.99	12.08	240.32	274.39	.16	.19	.57	.92
61	-.09	-1.04	-.95	-2.08	.50	38.99	235.12	274.61	-.05	-.01	.79	.73
62	.06	-.16	-.51	-.61	15.41	33.58	275.51	324.50	.04	.06	1.06	1.16
63	.04	-.84	.10	-.70	-.33	22.97	248.38	271.02	.17	-.87	1.10	.40
64	.20	.05	.01	.26	-1.12	19.84	96.70	115.42	.09	-.002	.54	.63
65	--	--	--	--	3.63	-.43	149.30	152.50	.27	.07	.41	.75
Pooled Mean	.22	-.45	-.44	-.67	6.27	18.08	150.30	174.66	-.045	.054	.440	.539

Appendix Table 2. Continued.

Year	NFE, EWF				NFE, NRE				NYE, BWH			
	cov_S	cov_D	cov_W	cov_T	cov_S	cov_D	cov_W	cov_T	cov_S	cov_D	cov_W	cov_T
1948	-1.58	5.45	-11.91	-8.04	4.92	11.18	33.94	50.04	--	--	--	--
49	--	--	--	--	2.33	-.14	26.84	29.03	--	--	--	--
50	--	--	--	--	1.71	4.72	13.02	19.45	--	--	--	--
51	-1.60	-4.46	-16.38	-22.44	--	--	--	--	--	--	--	--
52	-.18	1.96	-13.08	-11.30	.77	-1.28	41.06	40.55	--	--	--	--
53	-1.34	2.88	-8.34	-6.80	.25	5.42	10.14	15.81	-.10	.42	.23	.55
54	-2.20	-1.36	-5.54	-9.10	-2.98	2.36	23.81	23.19	-.17	-.13	.86	.56
55	.24	-2.28	-8.04	-10.08	-4.08	10.94	24.91	31.77	.27	.07	1.87	2.21
56	-6.55	-.74	-16.42	-23.71	-2.66	7.02	13.71	18.07	-.65	.25	-.27	-.67
57	-2.34	.66	-32.96	-34.64	.71	-5.71	15.08	10.08	-.17	.42	-.34	-.09
58	.01	-2.44	-20.90	-23.33	-1.04	3.48	8.41	10.85	.19	.06	.39	.64
59	1.03	-4.19	-23.00	-26.16	.77	6.10	7.66	14.53	.01	-.08	.65	.58
60	-2.33	.22	-34.49	-36.60	1.79	4.68	29.36	35.83	.11	.47	.95	1.53
61	-.64	-6.32	-27.34	-34.30	-2.80	6.46	15.02	18.68	.12	-.20	1.09	1.01
62	-4.14	-7.62	-50.02	-61.78	4.73	-.79	5.86	9.80	-.02	.16	1.78	1.92
63	.08	9.64	-33.35	-23.63	-.04	11.91	39.00	50.87	-.24	-1.68	1.75	-.17
64	.12	-3.06	-9.76	-12.70	-1.29	2.10	9.04	9.85	.03	.43	.63	1.09
65	-1.02	3.18	-26.43	-24.27	2.45	3.18	2.73	8.36	.41	.06	.55	1.02
Pooled Mean	-1.42	-.65	-17.77	-19.83	.63	7.78	10.78	19.19	-.01	.05	.71	.77

Appendix Table 2. Continued.

	NYE, EWF				NYE, BWM			
Year	cov_S	cov_D	cov_W	cov_T	cov_S	cov_D	cov_W	cov_T
1948	3.87	1.56	-95.57	-90.14	--	--	--	--
49	--	--	--	--	--	--	--	--
50	--	--	--	--	--	--	--	--
51	--	--	--	--	--	--	--	--
52	-6.04	-2.08	-71.16	-79.28	--	--	--	--
53	-6.10	5.64	-45.47	-45.93	-8.514	-5.961	-65.742	-80.22
54	-9.32	-7.21	-41.82	-58.35	-7.628	-23.595	-61.536	-92.76
55	6.34	-19.42	-53.50	-66.58	--	--	--	--
56	-10.67	-3.90	-74.66	-89.23	--	--	--	--
57	-8.96	-1.91	-132.22	-143.09	-12.830	-9.244	-154.831	-176.91
58	1.12	.05	-78.84	77.67	-.587	-5.522	-112.294	-118.40
59	3.11	-11.97	-63.18	-72.04	-2.040	7.626	-127.087	-121.50
60	-9.73	10.54	-110.64	-109.83	-6.254	8.851	-129.981	-127.38
61	-3.79	-32.11	-96.00	-131.90	-2.380	-13.890	-126.982	-143.25
62	-6.01	-21.26	-133.52	-160.79	-4.582	-4.142	-123.956	-132.68
63	.47	18.08	-70.85	-52.30	-1.626	-7.698	-41.734	-51.06
64	-.34	-6.57	-27.48	-34.39	-.957	-6.598	-23.776	-31.33
65	-3.41	5.88	-88.61	-86.14	.514	-3.905	-86.313	-89.70
Pooled Mean	-4.29	-.79	-82.63	-87.71	-4.217	-5.530	-98.520	-108.27

Appendix Table 3. Production line. Annual means and standard deviation for variables analyzed.

Year	Sexual Maturity (Weeks to first egg)	Egg Production to February (No. of eggs)	Annual Egg Production (No. of eggs)	Residual Egg Production (No. of eggs)	Egg Production to February (Percent)
1947	--	--	--	--	--
48	30.07 ± 3.4	32.34 ± 27.0	89.25 ± 54.4	56.91 ± 33.2	44.23 ± 29.9
49	26.92 ± 3.5	59.71 ± 30.9	121.03 ± 57.2	61.32 ± 26.2	51.61 ± 26.8
50	26.16 ± 2.3	53.27 ± 22.2	135.38 ± 40.8	82.11 ± 23.4	55.82 ± 20.1
51	26.13 ± 1.7	78.96 ± 27.9	--	--	71.52 ± 21.9
52	27.70 ± 3.8	71.61 ± 29.4	163.03 ± 45.2	91.42 ± 26.0	66.19 ± 22.3
53	26.29 ± 2.2	89.81 ± 22.1	190.47 ± 38.4	100.66 ± 23.4	73.82 ± 18.4
54	25.72 ± 2.4	64.61 ± 26.4	149.59 ± 48.4	84.98 ± 29.0	59.33 ± 24.2
55	25.05 ± 3.0	84.14 ± 24.6	175.00 ± 39.2	90.86 ± 24.8	68.53 ± 17.9
56	24.46 ± 2.4	87.22 ± 33.9	192.43 ± 44.6	105.21 ± 25.4	72.66 ± 20.6
57	22.50 ± 2.5	102.20 ± 38.7	194.95 ± 52.0	92.75 ± 26.0	71.60 ± 22.4
58	22.43 ± 1.8	107.24 ± 39.3	214.20 ± 49.8	106.96 ± 25.8	77.32 ± 20.1
59	21.71 ± 2.5	111.37 ± 38.7	207.62 ± 49.6	96.25 ± 27.2	77.04 ± 18.5
60	21.61 ± 2.2	103.39 ± 42.9	186.41 ± 55.6	83.02 ± 27.8	71.58 ± 21.8
61	22.52 ± 2.6	99.33 ± 33.5	183.19 ± 54.4	83.86 ± 28.4	71.45 ± 22.6
62	21.50 ± 2.0	101.57 ± 48.6	182.07 ± 52.8	80.50 ± 25.4	69.41 ± 24.4
63	22.56 ± 2.9	89.53 ± 50.1	172.97 ± 55.4	83 44 ± 28.6	64.47 ± 26.4
64	22.15 ± 2.2	107.10 ± 34.2	207.41 ± 39.0	100.31 ± 23.6	75.43 ± 16.4
65	--	105.42 ± 40.2	204.96 ± 46.2	99.54 ± 23.6	75.91 ± 20.6
Pooled Mean	24.69 ± 2.7	85.56 ± 35.4	173.56 ± 48.4	88.00 ± 26.6	66.50 ± 22.4

Appendix Table 3. Continued.

Year	Annual Egg Production (Percent)	Residual Egg Production (Percent)	Body Weight 10 Weeks (Pounds)	Body Weight Housing (Pounds)	Body Weight Maturity (Pounds)
1947	--	--	1.92 ± .22	3.89 ± .43	--
48	36.87 ± 28.1	33.51 ± 30.5	--	3.32 ± .54	--
49	42.11 ± 25.4	36.19 ± 28.5	--	--	--
50	51.22 ± 23.7	48.55 ± 28.9	--	--	--
51	--	--	--	--	--
52	58.76 ± 23.8	53.94 ± 27.5	--	--	--
53	65.05 ± 20.1	59.43 ± 24.3	--	3.02 ± .40	3.89 ± .50
54	53.35 ± 26.2	50.14 ± 30.0	1.61 ± .18	3.20 ± .40	3.84 ± .46
55	59.53 ± 20.6	53.69 ± 24.9	1.59 ± .16	3.51 ± .37	--
56	67.32 ± 21.7	64.30 ± 24.7	1.92 ± .19	3.17 ± .30	--
57	62.86 ± 22.4	54.95 ± 26.1	1.80 ± .24	3.26 ± .37	4.05 ± .54
58	70.40 ± 20.8	63.14 ± 25.3	1.66 ± .16	3.06 ± .34	3.84 ± .51
59	67.04 ± 19.7	56.91 ± 27.5	1.76 ± .14	3.02 ± .34	3.69 ± .45
60	60.48 ± 22.6	49.12 ± 28.0	1.79 ± .17	2.79 ± .35	3.65 ± .50
61	61.07 ± 23.5	49.58 ± 28.5	1.69 ± .17	2.96 ± .36	3.64 ± .43
62	59.62 ± 22.9	47.79 ± 25.3	1.64 ± .18	2.59 ± .31	3.49 ± .44
63	57.36 ± 24.8	48.98 ± 28.1	1.74 ± .18	2.65 ± .28	3.77 ± .50
64	68.01 ± 17.0	59.14 ± 23.8	2.05 ± .19	3.11 ± .36	3.71 ± .46
65	67.93 ± 20.4	58.78 ± 24.6	1.75 ± .16	2.94 ± .35	4.03 ± .46
Pooled Mean	52.48 ± 22.8	46.23 ± 27.0	1.75 ± .18	3.19 ± .37	3.80 ± .48

Appendix Table 3. Continued.

Year	Egg Weight February (Grams)	Egg Weight Year (Grams)	Egg Specific Gravity - Feb. (Code 1-16)	Egg Specific Gravity - Year (Code 1-16)	Mortality February (Percent)	Mortality Year (Percent)
1947	57.52 ± 4.4	--	11.09 ± 1.2	--	16.26	--
48	58.21 ± 3.7	--	11.00 ± 1.3	--	21.91	50.50
49	--	--	9.99 ± 1.3	--	17.42	37.08
50	--	--	10.58 ± 1.1	--	8.11	29.94
51	51.36 ± 3.5	--	9.58 ± 1.1	--	7.49	21.21
52	54.53 ± 3.3	--	12.20 ± 1.1	--	4.83	17.24
53	51.03 ± 3.5	--	11.74 ± 1.2	--	4.59	13.43
54	52.56 ± 3.6	--	11.96 ± 1.2	--	6.97	20.75
55	54.08 ± 3.2	--	10.81 ± 1.2	9.34 ± 1.3	3.29	13.60
56	52.87 ± 3.3	--	10.76 ± 1.1	--	4.88	14.07
57	52.02 ± 3.4	58.67 ± 3.8	10.89 ± 1.2	9.06 ± 1.4	9.10	17.96
58	50.16 ± 3.0	57.13 ± 3.7	11.15 ± 1.1	9.03 ± 1.4	4.43	13.51
59	50.21 ± 2.9	56.82 ± 3.8	10.97 ± 1.1	8.68 ± 1.4	3.10	17.77
60	51.92 ± 3.3	57.01 ± 4.3	10.51 ± 1.2	8.54 ± 1.5	6.62	22.50
61	52.26 ± 3.1	59.52 ± 4.1	10.82 ± 1.3	8.71 ± 1.5	7.62	21.75
62	50.76 ± 3.1	59.41 ± 4.0	10.55 ± 1.3	8.72 ± 1.4	7.74	21.03
63	51.36 ± 3.4	59.99 ± 5.0	10.96 ± 1.3	8.97 ± 1.5	3.98	17.45
64	55.61 ± 3.5	--	10.60 ± 1.1	--	1.63	10.45
65	56.14 ± 3.5	--	10.75 ± 1.2	--	3.78	11.33
Pooled Mean	53.08 ± 3.4	58.14 ± 4.0	10.90 ± 1.2	8.90 ± 1.4	8.07	21.01

Appendix Table 4. Control group. Annual means and standard deviation for variables analyzed.

Year	Sexual Maturity (Weeks to first egg)	Egg Production to February (No. of eggs)	Special Lines Annual Egg Production (No. of eggs)	Special Lines Residual Egg Production (No. of eggs)	Special Lines Egg Production to February (Percent)
1949	27.46 ± 3.88	55.72 ± 30.0	109.24 ± 44.86	53.52 ± 24.46	48.62 ± 25.55
50	27.01 ± 3.35	48.79 ± 21.6	131.35 ± 39.96	82.56 ± 22.52	53.59 ± 20.70
51	26.91 ± 2.32	62.65 ± 33.1	--	--	58.64 ± 27.11
52	28.94 ± 3.97	53.90 ± 30.3	131.42 ± 49.84	77.52 ± 28.06	54.00 ± 26.67
53	27.53 ± 2.51	71.47 ± 25.5	157.87 ± 40.70	86.40 ± 23.64	63.74 ± 22.40
54	27.63 ± 2.82	48.37 ± 25.9	116.77 ± 48.48	68.40 ± 26.52	50.29 ± 26.51
55	28.78 ± 3.18	51.94 ± 26.8	116.26 ± 43.04	64.32 ± 26.36	53.78 ± 28.98
56	25.34 ± 2.71	74.41 ± 38.8	162.49 ± 50.10	88.08 ± 26.68	63.36 ± 24.76
57	26.42 ± 4.31	50.89 ± 29.8	104.65 ± 41.92	53.76 ± 21.44	44.62 ± 20.00
58	29.06 ± 3.78	39.55 ± 41.6	80.83 ± 48.22	41.28 ± 24.34	37.90 ± 30.93
59	26.91 ± 5.94	50.54 ± 44.7	99.74 ± 50.28	49.20 ± 23.84	45.69 ± 28.50
60	27.00 ± 3.66	19.46 ± 34.9	35.30 ± 40.22	15.84 ± 16.40	18.26 ± 24.47
61	25.87 ± 4.67	30.31 ± 40.2	52.39 ± 41.34	22.08 ± 16.40	25.00 ± 24.74
62	27.20 ± 5.21	28.49 ± 31.4	47.11 ± 29.90	18.62 ± 11.96	25.18 ± 20.83
63	28.79 ± 6.54	27.44 ± 38.4	46.06 ± 38.90	18.62 ± 15.44	24.29 ± 26.04
64	26.51 ± 3.90	29.26 ± 33.0	56.74 ± 36.12	27.48 ± 17.58	26.10 ± 24.74
65	--	41.44 ± 37.5	74.25 ± 39.86	32.81 ± 17.18	43.86 ± 29.00
Pooled Mean	27.32 ± 3.36	54.11 ± 30.9	119.90 ± 44.40	65.80 ± 24.14	51.43 ± 25.36

Appendix Table 4. Continued

Year	Special Lines: Annual Egg Production (Percent)	Residual Egg Production (Percent)	Body Weight 10 Weeks (Pounds)	Body Weight Housing (Pounds)	Body Weight Maturity (Pounds)
1949	38.10 ± 23.97	31.63 ± 26.63	--	--	--
50	50.41 ± 23.30	48.86 ± 27.88	--	--	--
51	--	--	--	--	--
52	48.79 ± 26.51	45.69 ± 29.51	--	--	--
53	55.63 ± 21.95	51.04 ± 24.53	--	2.86 ± .35	3.96 ± .55
54	42.23 ± 25.50	38.40 ± 27.60	1.60 ± .19	3.21 ± .39	3.94 ± .55
55	43.02 ± 25.45	42.99 ± 23.88	1.56 ± .18	3.38 ± .39	--
56	57.34 ± 24.17	57.20 ± 24.55	1.93 ± .22	3.13 ± .33	--
57	36.70 ± 18.97	31.71 ± 21.51	1.41 ± .19	2.64 ± .27	3.49 ± .54
58	28.15 ± 24.28	21.11 ± 22.68	1.30 ± .16	2.43 ± .36	3.27 ± .47
59	37.23 ± 22.18	29.42 ± 23.90	1.50 ± .22	2.76 ± .35	3.84 ± .54
60	13.06 ± 18.62	9.35 ± 16.40	1.66 ± .17	2.61 ± .31	3.79 ± .56
61	19.07 ± 19.26	12.97 ± 16.73	1.53 ± .16	2.69 ± .28	3.73 ± .43
62	17.84 ± 14.64	11.03 ± 11.92	1.62 ± .14	2.50 ± .24	3.58 ± .50
63	16.54 ± 19.21	10.32 ± 15.13	1.58 ± .23	2.50 ± .27	3.44 ± .39
64	20.35 ± 18.84	15.74 ± 17.57	1.84 ± .17	2.90 ± .30	3.80 ± .46
65	29.49 ± 20.74	18.81 ± 17.78	1.40 ± .18	2.44 ± .29	3.73 ± .46
Pooled Mean	43.08 ± 23.47	39.63 ± 24.91	1.66 ± .19	2.99 ± .34	3.84 ± .52

Appendix Table 4. Continued.

Year	Special Lines Egg Weight February (Grams)	Egg Weight Year (Grams)	Egg Specific Gravity - Feb. (Code 1-16)	Egg Specific Gravity - Year (Code 1-16)	Mortality February (Percent)	Mortality Year (Percent)
1949	--	--	10.30 ± 1.26	--	20.6	42.1
50	--	--	10.77 ± 1.13	--	7.3	23.0
51	52.59 ± 3.97	--	9.87 ± 1.11	--	12.0	29.0
52	55.70 ± 3.55	--	11.99 ± 1.12	--	8.0	24.0
53	51.55 ± 3.37	--	11.82 ± 1.35	--	6.0	13.0
54	52.98 ± 3.63	--	11.97 ± 1.36	--	8.0	25.0
55	53.95 ± 3.37	--	11.07 ± 1.39	9.91 ± 1.55	6.9	22.9
56	53.15 ± 3.71	--	10.83 ± 1.16	--	7.2	19.3
57	52.67 ± 3.12	56.04 ± 3.55	10.77 ± 1.59	10.17 ± 3.03	7.3	21.8
58	49.46 ± 2.96	53.42 ± 4.09	11.05 ± .71	8.87 ± 1.79	15.4	28.2
59	52.85 ± 3.41	55.36 ± 2.61	10.60 ± 1.44	8.96 ± 2.19	7.7	34.6
60	53.97 ± 3.33	56.60 ± 5.88	10.94 ± 1.71	8.91 ± 1.78	25.2	51.3
61	51.75 ± 2.72	55.18 ± 3.68	10.78 ± 1.69	9.43 ± 1.23	8.8	17.6
62	47.86 ± 3.82	56.00 ± 3.17	10.12 ± 1.13	9.61 ± .92	13.1	33.3
63	48.37 ± 3.01	54.31 ± 5.63	10.50 ± 1.49	8.81 ± 1.43	16.2	41.9
64	51.65 ± 3.97	--	10.45 ± 1.40	--	2.7	9.1
65	50.18 ± 2.94	--	10.33 ± 1.45	--	5.9	17.7
Pooled Mean	52.88 ± 3.59	55.42 ± 4.10	11.05 ± 4.10	11.05 ± 1.26	9.6	25.0

Appendix Table 4. Continued.

Year	Commercial Lines				
	Sexual Maturity (Weeks to first egg)	Egg Production to February (No. of eggs)	Annual Egg Production (No. of eggs)	Residual Egg Production (No. of eggs)	Egg Production to February (Percent)
1955	25.32 ± 3.48	89.53 ± 34.5	186.18 ± 47.86	96.65 ± 28.54	67.15 ± 24.93
56	24.22 ± 2.54	92.89 ± 32.0	205.31 ± 41.10	112.42 ± 24.62	77.94 ± 17.57
57	24.05 ± 2.58	88.97 ± 37.7	177.41 ± 52.92	88.44 ± 26.84	68.48 ± 23.00
58	25.11 ± 2.73	88.62 ± 37.9	202.24 ± 47.96	113.62 ± 24.70	73.07 ± 21.98
59	25.23 ± 3.50	84.98 ± 42.3	184.60 ± 54.66	99.62 ± 28.16	70.67 ± 24.26
60	25.63 ± 3.30	70.63 ± 47.0	141.98 ± 61.84	71.35 ± 30.82	59.34 ± 29.53
61	24.99 ± 3.49	82.46 ± 42.3	172.00 ± 54.26	89.54 ± 28.82	67.53 ± 25.17
62	24.32 ± 3.16	78.75 ± 43.7	159.39 ± 53.46	80.64 ± 29.28	62.79 ± 25.92
63	25.29 ± 3.36	80.99 ± 37.9	175.56 ± 46.62	94.57 ± 27.06	67.98 ± 21.33
64	24.69 ± 2.42	88.48 ± 35.5	193.52 ± 42.08	105.04 ± 24.24	71.27 ± 19.61
65	--	84.98 ± 35.1	181.89 ± 41.76	96.91 ± 21.00	73.34 ± 20.36
Pooled Mean	24.90 ± 3.09	83.86 ± 39.7	179.04 ± 50.36	95.18 ± 26.88	68.94 ± 23.26

Appendix Table 4. Continued.

Year	Commercial Lines Annual Egg Production (Percent)	Residual Egg Production (Percent)	Body Weight 10 Weeks (Pounds)	Body Weight Housing (Pounds)	Body Weight Maturity (Pounds)
1955	61.52 ± 24.76	62.67 ± 23.52	1.77 ± .17	3.76 ± .39	--
56	72.12 ± 19.26	68.19 ± 23.36	1.91 ± .18	3.07 ± .31	--
57	59.50 ± 23.68	52.37 ± 26.93	1.93 ± .26	3.26 ± .38	4.21 ± .53
58	69.92 ± 21.83	66.83 ± 24.50	1.80 ± .19	3.13 ± .32	4.22 ± .50
59	64.31 ± 24.25	58.68 ± 28.65	1.91 + .17	3.00 ± .35	4.09 ± .57
60	49.62 ± 28.07	41.77 ± 31.27	1.84 ± .25	2.72 ± .35	4.08 ± .51
61	60.27 ± 24.96	53.01 ± 28.83	1.81 ± .21	2.98 ± .47	4.02 ± .47
62	55.47 ± 25.41	48.10 ± 29.77	1.86 ± .23	2.80 ± .30	3.90 ± .52
63	61.68 ± 22.36	55.52 ± 26.71	1.91 ± .18	2.76 ± .25	4.06 ± .49
64	66.66 ± 20.06	61.90 ± 24.34	2.08 ± .19	3.02 ± .32	3.98 ± .51
65	65.14 ± 19.85	57.19 ± 23.89	1.75 ± .17	2.78 ± .26	4.20 ± .52
Pooled Mean	62.33 ± 23.26	56.27 ± 27.12	1.88 ± .20	2.95 ± .32	4.08 ± .52

Appendix Table 4. Continued.

Year	Commercial Lines					
	Egg Weight February (Grams)	Egg Weight Year (Grams)	Egg Specific Gravity - Feb. (Code 1-16)	Egg Specific Gravity - Year (Code 1-16)	Mortality February (Percent)	Mortality Year (Percent)
1955	55.25 ± 3.43	--	11.70 ± 1.33	9.90 ± 1.38	7.4	18.5
56	51.98 ± 3.42	--	10.74 ± 1.18	--	3.2	8.1
57	52.68 ± 3.14	58.62 ± 3.67	11.56 ± 1.26	9.60 ± 1.46	10.3	19.0
58	51.06 ± 3.32	57.73 ± 3.78	11.23 ± 1.11	9.16 ± 1.26	3.9	13.8
59	51.55 ± 3.34	55.66 ± 3.89	10.93 ± 1.20	8.71 ± 1.45	6.9	15.7
60	53.22 ± 3.63	57.74 ± 4.48	10.88 ± 1.36	8.63 ± 1.68	11.9	28.1
61	52.30 ± 3.43	58.83 ± 4.01	11.46 ± 1.24	9.45 ± 1.31	10.1	17.8
62	51.54 ± 3.31	59.82 ± 4.26	11.05 ± 1.24	9.28 ± 1.28	9.8	24.6
63	53.31 ± 3.52	62.10 ± 4.50	11.33 ± 1.22	9.41 ± 1.48	3.1	13.5
64	56.35 ± 3.33	--	10.95 ± 1.07	--	3.6	9.9
65	56.73 ± 3.72	--	11.12 ± 1.23	--	2.5	10.2
Pooled Mean	53.06 ± 3.42	58.60 ± 4.08	11.14 ± 1.21	9.18 ± 1.41	6.5	16.2

Appendix Table 4. Continued.

Year	Sexual Maturity (Weeks to first egg)	Egg Production to February (No. of eggs)	Annual Egg Production (No. of eggs)	Residual Egg Production (No. of eggs)	Egg Production to February (Percent)
			Cornell R. B.		
1960	26.07 ± 3.19	73.50 ± 42.8	149.77 ± 55.70	76.27 ± 29.58	63.89 ± 24.79
61	25.62 ± 4.72	94.01 ± 32.0	204.89 ± 35.92	110.88 ± 20.84	77.99 ± 16.27
62	24.91 ± 2.28	80.01 ± 42.0	162.40 ± 51.02	82.39 ± 27.98	65.66 ± 24.92
63	27.18 ± 3.84	70.14 ± 40.2	166.60 ± 44.48	96.46 ± 24.46	65.95 ± 23.23
64	25.84 ± 2.77	75.04 ± 39.6	167.63 ± 49.38	92.59 ± 28.90	64.44 ± 23.82
65	--	75.53 ± 24.7	185.04 ± 31.72	109.51 ± 20.50	78.85 ± 10.85
Pooled Mean	25.91 ± 3.42	77.96 ± 39.3	169.23 ± 47.70	91.27 ± 26.46	67.79 ± 22.66
			Exchange Lines		
1960	26.48 ± 3.90	58.59 ± 44.7	114.49 ± 58.64	55.90 ± 28.42	52.13 ± 29.26
61	26.58 ± 3.74	60.48 ± 45.2	121.27 ± 56.78	60.79 ± 28.88	53.34 ± 28.72
62	25.18 ± 3.99	65.66 ± 47.4	129.08 ± 54.80	63.42 ± 28.00	54.01 ± 28.46
63	26.58 ± 4.23	55.37 ± 46.8	123.97 ± 57.72	68.60 ± 30.64	48.66 ± 28.65
Pooled Mean	26.04 ± 4.01	60.52 ± 46.3	123.44 ± 56.72	62.92 ± 28.94	52.00 ± 28.72
Pooled Mean Total	26.06 ± 3.30	68.93 ± 36.6	148.21 ± 48.32	79.28 ± 25.90	59.95 ± 24.62

Appendix Table 4. Continued.

Year	Annual Egg Production (Percent)	Residual Egg Production (Percent)	Body Weight 10 Weeks (Pounds)	Body Weight Housing (Pounds)	Body Weight Maturity (Pounds)
	Cornell R. B.				
1960	53.40 ± 25.24	44.79 ± 30.10	2.02 ± .22	2.96 ± .40	4.32 ± .56
61	72.56 ± 13.59	65.96 ± 20.48	1.97 ± .18	3.25 ± .32	4.45 ± .62
62	57.26 ± 24.28	48.98 ± 27.99	1.90 ± .22	2.94 ± .32	4.34 ± .72
63	61.46 ± 21.49	56.78 ± 23.91	1.96 ± .21	2.90 ± .32	4.46 ± .65
64	59.35 ± 23.89	54.68 ± 27.76	2.09 ± .27	3.16 ± .40	4.32 ± .72
65	70.95 ± 14.45	64.70 ± 21.42	1.66 ± .18	2.62 ± .30	4.19 ± .66
Pooled Mean	60.70 ± 22.09	53.96 ± 26.31	1.97 ± .22	3.00 ± .35	4.37 ± .66
	Exchange Lines				
1960	41.30 ± 26.56	32.91 ± 28.66	2.01 ± .23	3.00 ± .39	4.30 ± .70
61	44.52 ± 26.89	35.92 ± 28.91	1.89 ± .23	3.19 ± .38	4.24 ± .60
62	45.97 ± 26.14	37.75 ± 27.96	1.92 ± .22	2.98 ± .30	4.24 ± .57
63	44.20 ± 28.21	40.18 ± 30.08	1.81 ± .18	2.72 ± .29	3.99 ± .58
Pooled Mean	44.27 ± 26.93	37.15 ± 28.86	1.90 ± .21	2.94 ± .33	4.18 ± .60
Pooled Mean Total	52.48 ± 23.64	47.40 ± 26.31	1.83 1 .20	2.96 ± .33	4.05 ± .53

Appendix Table 4. Continued.

Year	Egg Weight February (Grams)	Egg Weight Year (Grams)	Egg Specific Gravity - Feb. (Code 1-16)	Egg Specific Gravity - Year (Code 1-16)	Mortality February (Percent)	Mortality Year (Percent)
	Cornell R. B.					
1960	55.55 ± 4.15	59.60 ± 4.27	12.01 ± 1.79	9.52 ± 1.72	9.8	23.9
61	54.26 ± 2.99	60.39 ± 3.73	11.62 ± 1.31	9.49 ± 1.37	0.0	5.9
62	52.36 ± 3.79	60.86 ± 5.42	11.49 ± 1.12	9.22 ± 1.24	6.4	16.1
63	52.50 ± 3.53	61.99 ± 4.60	11.73 ± 1.15	9.68 ± 1.31	7.3	13.4
64	54.35 ± 3.86	--	11.43 ± 1.14	--	4.8	14.5
65	54.38 ± 3.19	--	11.36 ± 1.24	--	0.0	0.0
Pooled Mean	53.79 ± 3.67	60.73 ± 4.56	11.66 ± 1.34	9.48 ± 1.42	5.8	14.6
	Exchange Lines					
1960	53.69 ± 4.04	60.01 ± 4.58	11.34 ± 1.36	9.52 ± 1.36	13.9	31.2
61	52.86 ± 3.33	59.66 ± 3.99	11.72 ± 1.42	9.96 ± 1.24	11.9	29.8
62	51.18 ± 3.78	59.31 ± 4.54	11.45 ± 1.35	9.59 ± 1.30	9.5	28.0
63	50.74 ± 3.22	58.13 ± 3.95	11.90 ± 1.33	9.70 ± 1.49	9.3	24.2
Pooled Mean	51.82 ± 3.63	59.16 ± 4.33	11.59 ± 1.36	9.65 ± 1.36	10.7	27.8
Pooled Mean Total	52.92 ± 3.52	58.71 ± 4.13	11.16 ± 1.25	9.31 ± 1.53	8.00	21.0

Appendix Table 5. Production line. Annual heritability estimates from half-sib correlations (h^2_S).

Year	Sexual Maturity (Weeks to first egg)	Egg Production to February (No. of eggs)	Annual Egg Production (No. of eggs)	Residual Egg Production (No. of eggs)	Egg Production to February (Percent)
1947	--	--	--	--	--
48	.431	.272	.062	.113	.213
49	.248	.299	.249	.149	.258
50	.111	.260	.204	-.006	.299
51	.450	.123	--	--	.047
52	.241	.203	.140	.028	.066
53	.131	.164	.262	.214	.189
54	.559	.347	.141	-.070	.062
55	.306	.013	-.138	-.106	.001
56	.682	.259	.122	.070	.006
57	-.034	.164	.228	.259	.132
58	.354	.003	.092	.205	-.012
59	-.060	-.087	-.055	.017	-.032
60	.313	.392	.205	.115	.332
61	.134	.023	-.002	.091	-.001
62	.101	.135	.166	.328	.178
63	.043	.022	-.053	-.072	-.011
64	.809	.106	.005	.167	.049
65	--	.098	.105	.122	.057
Pooled Mean	.272 ± .03	.139 ± .02	.111 ± .02	.102 ± .02	.119 ± .02

Appendix Table 5. Continued.

Year	Annual Egg Production (Percent)	Residual Egg Production (Percent)	Body Weight 10 Weeks (Pounds)	Body Weight Housing (Pounds)	Body Weight Maturity (Pounds)
1947	--	--	-.107	.160	--
48	.081	.108	--	.399	--
49	.236	.151	--	--	--
50	.188	-.008	--	--	--
51	--	--	--	--	--
52	.116	.033	--	--	--
53	.302	.214	--	.116	.531
54	.083	-.069	.137	.076	.695
55	-.139	-.106	.129	.215	--
56	.081	.087	.148	1.230	--
57	.234	.261	.285	.326	.584
58	.128	.204	.852	.769	1.211
59	-.033	.011	.277	.283	.323
60	.191	.126	.428	.451	.380
61	-.026	.091	.357	.170	.363
62	.232	.329	.092	.193	.750
63	-.072	-.072	.466	.349	.480
64	.139	.168	.716	.386	.362
65	.126	.123	.552	.596	.565
Pooled Mean	.116 ± .02	.098 ± .02	.537 ± .05	.418 ± .04	.627 ± .06

Appendix Table 5. Continued.

Year	Egg Weight February (Grams)	Egg Weight Year (Grams)	Egg Specific Gravity - February (Code 1-16)	Egg Specific Gravity - Year (Code 1-16)
1947	.362	--	-1.320	--
48	.480	--	.089	--
49	--	--	.292	--
50	--	--	.127	--
51	.492	--	.512	--
52	.432	--	.555	--
53	.601	--	.047	--
54	.183	--	.488	--
55	.571	--	.484	.413
56	1.575	--	.368	--
57	.153	.392	.338	.303
58	1.042	.671	.226	.308
59	.171	.295	.147	.102
60	.606	.069	.501	.091
61	.310	.452	.194	.388
62	.277	.106	.330	.385
63	.686	.365	-.034	.372
64	.798	--	.301	--
65	.565	--	.289	--
Pooled Mean	.588 ± .05	.375 ± .06	.291 ± .03	.301 ± .05

Appendix Table 6. Production line. Annual heritability estimates from full-sib correlations $\left[h^2_{(S+D)}\right]$.

Year	Sexual Maturity (Weeks to first egg)	Egg Production to February (No. of eggs)	Annual Egg Production (No. of eggs)	Residual Egg Production (No. of eggs)	Egg Production to February (Percent)
1947	--	--	--	--	--
48	.506	.193	.210	.259	.264
49	.436	.344	.192	.207	.337
50	.309	.109	.091	.001	.124
51	.401	.333	--	--	.279
52	.131	.214	.231	.240	.036
53	.245	.273	.341	.281	.215
54	.622	.506	.439	.287	.372
55	.525	.442	.381	.253	.384
56	.577	.402	.372	.317	.158
57	.322	.070	.181	.199	.080
58	.515	.207	.245	.432	.075
59	.249	.149	.127	.001	.030
60	.376	.306	.175	.146	.152
61	.546	.257	.334	.163	.255
62	.371	.246	.279	.426	.219
63	.691	.197	.213	.244	.227
64	.546	.278	.268	.226	.253
65	--	.008	.183	.361	-.031
Pooled Mean	.383 ± .023	.079 ± .021	.252 ± .022	.258 ± .024	.191 ± .021

Appendix Table 6. Continued.

Year	Annual Egg Production (Percent)	Residual Egg Production (Percent)	Body Weight 10 Weeks (Pounds)	Body Weight Housing (Pounds)	Body Weight Maturity (Pounds)
1947	--	--	.226	.560	--
48	.213	.255	--	.649	--
49	.165	.190	--	--	--
50	.090	.003	--	--	--
51	--	--	--	--	--
52	.223	.236	--	--	--
53	.324	.283	--	.489	.652
54	.399	.282	.333	.308	.605
55	.359	.254	.710	.389	--
56	.315	.249	1.180	.923	--
57	.197	.095	.649	.611	.644
58	.216	.432	.788	.651	.907
59	.087	-.009	.609	.678	.738
60	.171	.142	.424	.478	.418
61	.300	.164	.444	.564	.519
62	.340	.432	.267	.400	.688
63	.235	.249	.878	.512	.564
64	.348	.224	1.073	.752	.647
65	.247	.362	.621	.623	.575
Pooled Mean	.269 ± .022	.247 ± .024	.667 ± .028	.548 ± .025	.664 ± .034

Appendix Table 6. Continued.

Year	Egg Weight February (Grams)	Egg Weight Year (Grams)	Egg Specific Gravity - February (Code 1-16)	Egg Specific Gravity - Year (Code 1-16)
1947	-.094	--	.011	--
48	.756	--	.331	--
49	--	--	.383	--
50	--	--	.222	--
51	.473	--	.528	--
52	.503	--	.482	--
53	.668	--	.161	--
54	.477	--	.303	--
55	.357	--	.586	.467
56	.961	--	.724	--
57	.507	.429	.266	.197
58	.806	.668	.305	.056
59	.592	.536	.372	.274
60	.524	.247	.494	.400
61	.360	.316	.417	.306
62	.411	.450	.357	.240
63	.761	.600	.373	-.125
64	.919	--	.576	--
65	.450	--	.351	--
Pooled Mean	.515 ± .027	.494 ± .045	.374 ± .024	.234 ± .044

Appendix Table 7. Production line. Annual genetic correlations $\left(r_{G_S}\right)$.

	SM, NFE	SM, NYE	SM, BWH	SM, EWF	NFE, NYE	NFE, BWH	NFE, EWF	NFE, NRE	NYE, BWH	NYE, EWF
1948	-.658	.100	.523	.239	2.001	1.585	-.562	.788	1.680	.888
49	-.543	-.342	--	--	.925	--	--	.370	--	--
50	-.428	-.319	--	--	.822	--	--	2.227	--	--
51	-.903	--	--	.362	--	--	-.777	--	--	--
52	-.955	-.468	--	-.101	.671	--	-.080	.366	--	-1.330
53	-.464	.156	1.229	.340	.820	-.901	-.633	.067	-.338	-.870
54	-1.069	-1.004	.578	1.231	1.138	-.259	-1.320	-.807	-.771	-2.937
55	-.988	-.137	-1.271	-.095	-2.325	-1.500	.399	-4.700	-.833	--
56	-.976	-.702	.539	.638	.831	-.893	-.966	-.780	-.901	-1.124
57	-.581	-.566	-.410	.979	.822	-.198	-1.478	.111	-.266	-2.237
58	-2.562	.207	.218	.128	-.134	-.460	.020	-1.425	.388	.198
59	.882	--	-.757	.919	--	-.212	--	.500	.043	--
60	-.580	-.351	-.817	-.670	.956	.352	-.423	.187	.167	-1.221
61	-1.207	-.825	.029	-.203	.998	-.737	-.733	-1.495	-3.333	--
62	-.082	.410	-.500	.230	1.126	.236	-1.870	.580	-.062	-1.430
63	-1.300	-.461	.757	.084	-.123	1.901	.050	-.025	-1.004	.111
64	-1.076	.866	-.243	.102	-1.207	.524	.044	-.370	.463	.332
65	--	--	--	--	.709	1.302	-.440	.825	1.038	-.772
Pooled Mean	-.708	-.193	.075	.212	.864	-.033	-.506	.159	.022	-.820

Appendix Table 8. Production line. Annual genetic correlations $\left[r_{G_{(S+D)}}\right]$.

	SM, NFE	SM, NYE	SM, BWH	SM, EWF	NFE, NYE	NFE, BWH	NFE, EWF	NFE, NRE	NYE, BWH	NYE, EWF
1948	-.518	-.105	.976	-.190	.725	2.692	.652	1.018	--	.270
49	-.586	-.361	--	--	.849	--	--	.138	--	--
50	-.565	-.706	--	--	.772	--	--	--	--	--
51	-.706	--	--	.331	--	--	-.911	--	--	--
52	-1.384	-.905	--	-.069	.270	--	.356	-.040	--	-.646
53	-.814	-.584	-.269	-.189	.963	.148	.267	.516	.230	-.027
54	-.655	-.576	-.094	-.193	.893	.037	-.546	-.035	-.201	-.910
55	-.717	-.614	-.574	-.217	.998	.504	-.361	.429	.235	-1.041
56	-.837	-.528	.225	.453	1.015	-.216	-.552	.241	-.184	-.563
57	-.135	-.009	-.332	-.311	.836	.268	-.448	-.963	.162	-.838
58	-.877	-.464	-.015	.278	.673	-.045	-.329	.139	.169	.072
59	-.940	-1.975	-.234	.176	.998	.087	-.667	--	-.064	-.974
60	-.839	-.732	-.609	-.264	.907	.428	-.233	.339	.468	.059
61	-.362	-.377	-.192	-.582	.838	-.073	-1.108	.218	-.042	-1.975
62	-1.013	-.529	-.340	-.080	1.023	.145	-1.613	.157	.112	-2.055
63	-.524	-.518	.120	-.201	.699	-1.105	.964	.659	-1.708	1.037
64	-.654	.072	-.035	.072	.839	.113	-.312	.062	.342	-.423
65	--	--	--	--	.836	2.857	1.844	1.952	.444	.237
Pooled Mean	-.930	-.361	-.114	-.100	1.467	.109	-.522	.882	.026	-.346