ESTIMATES OF HERITABILITY, REPEATABILITY AND GENETIC CORRELATIONS OF PRODUCTION AND TYPE OF GUERNSEY CATTLE

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CHAPTER I

THE PROBLEM

Although steady progress has been made in increasing the productive performance of dairy cattle, the rate of improvement has been slow. This is evidenced by yearly D.H.I.A. averages published annually by the United State Department of Agriculture, Bureau of Dairy Industry, as well as those statistics released by various breed associations.

The improvement that has been made can be attributed to both improved environmental conditions through better feeding and management practices and to better selection and breeding methods. It is extremely difficult, if not impossible, to credit correctly each of these for its rightful contribution to any observed improvement. It is known, however, that the improvement brought about by improved environment is only of a temporary nature in that any recession in these conditions will be immediately reflected in decreased production. On the other hand, improvement in cattle brought about through better inheritance is more of a permanent nature in that such improvement alone may be transmitted from generation to generation. The importance of studies of inheritance in dairy cattle are therefore quite obvious.

Productive performance in dairy cattle is measured by records of milk and fat production per lactation. The differences in performance between cows are widespread. By measuring the differences between cows of known relationship, the animal breeding investigator has devised means of estimating that portion of the differences that is due to inheritance. This value is called "heritability."

The problem for the research worker is to devise means to partition more accurately the variance of records. Standardizing records by adjusting for the age of the cow, times milked per day and length of lactation is of great value, but is not enough because all environmental effects have not been removed.

The ability of the research investigator to estimate more accurately the heritable fraction of the variance of records was greatly enhanced by Lush (1940) when he presented certain methods of estimating heritability. By calculating the correlation or regression of offspring on dam on an intra-herd, intra-sire basis much of the error due to environmental differences between herds and sires are eliminated.

Since the dairy cow is capable of having more than one lactation, it is possible to measure her productive performance a number of times. The records made by the same cow may vary considerably since she performs under a different set of conditions each year. The correlation of records made by the same cow is termed "repeatability" and more or less sets the upper limits of "heritability." Investigations in breeds other than Guernsey, have yielded heritability estimates of milk and fat production in the order of 12 to 32 percent and repeatability at 30 to 50 percent.

Although milk production is the primary function of the dairy cow, most breeders of purebred cattle are also concerned with the type of their animals. Like milk production, it is a highly variable character and is influenced by both hereditary and environmental factors in its final expression. Although research investigations are somewhat limited in number, estimates of heritability and repeatability of type ratings are similar to those reported for milk production.

Accepted ideas of type and/or beauty in dairy cattle are the results of what have been taught from the cumulative efforts of previous generations, plus any modifications added by our own. Beauty has always been highly prized in all forms of human endeavor. Breeding dairy cattle is no exception. Although our ideas of type or beauty may change, the premium for success remains as evidenced by prices commanded by animals of superior type in the sales ring.

Perhaps the greatest challenge to the dairy cattle breeder is to breed cows of high production with the highest degree of excellence in type. This immediately brings to mind the association of the two in terms of correlation. That there is a positive phenotypic correlation of production and type can be evidenced by averaging the production of classified cows according to type ratings. That multiple factored traits of low heritability, such as milk production and type, may have a positive phenotypic correlation and yet have little or no genetic correlation is a fact that escapes the imagination of many breeders. The degree of success the breeder has in selecting on the basis of one trait with the expectation of obtaining a second will be governed by the degree of genetic correlation rather than the phenotypic correlation between the two. Unfortunately for the breeder who is interested in coupling high production with superior type, most studies to date show very little genetic correlation between them.

Since no investigations of consequence of the inheritance of either production or type have been reported in the Guernsey breed, this study was initiated in an attempt to furnish information on this subject. It has as its objective to determine estimates of heritability, repeatability and genetic correlations of milk and fat production, as well as all type classification breakdown ratings. The results should be of interest and importance to Guernsey breeders and give animal breeding investigators further information on this subject.

CHAPTER II

REVIEW OF THE LITERATURE

Heritability of Milk and Butterfat Production

To determine the inheritance of milk and butterfat in dairy cattle has been the quest of research investigators for quite some time. It was recognized early that to do this it would be necessary to measure the variations in production between relatives.

One of the earlier investigations in which biometrical methods were employed to measure the resemblance between relatives for milk production was made by Gowen (1924) and is summarized in the book Milk Secretion. Holstein-Friesian Advanced Registry records made from 1902-20 and published in Volumes 13 to 31 were studied. All cows that completed 365 day lactations were studied. If a cow had one record it was used. If she had two or more 365 day records the one made nearest eight years of age was selected. Records of less than 365 days were omitted; immature records were corrected for age. Correlations between dam and daughter, full sisters, paternal half sisters and maternal half sisters were determined as follows:

	r	Number in study
Dam and daughter	0.497 ± 0.021	611
Full sisters	0.548 ± 0.027	302
Paternal half sisters	0.362 ± 0.015	1700
Maternal half sisters	0.381 ± 0.033	498

He discussed the influence of environment and heredity on milk production and concluded from his correlation studies that heredity was the larger element of the two in governing the permanence of performance of dairy cattle. He did recognize that environment could have a large effect, but since he obtained only gross correlations and herd differences were not removed, his conclusions overestimated the importance of heredity.

Gowen (1934) made a later study of the inheritance of milk yield on about 14,000 Jersey Register of Merit cattle. He concluded that heredity accounted for about one-half of the variations in milk yield. Once again differences between herds were not discounted and since some of these differences are due to environment these estimates must again be considered too high. Any estimate as to how much too high his values were can only be speculative, but Plum (1935) found the variance due to herd differences to be 33.0 percent of the intra-breed variance in his data. Legates and Lush (1954) found the herd component comprised 39 percent of the total variance in their study of 12,405 Jersey cows in 293 herds.

In an early report on the study of the progeny performance of Jersey sires and dams in the Register of Merit, Turner (1927) found the total correlation of 3707 daughter-dam pairs to be 0.346 ± 0.011. He recognized that the sires were affecting the estimate and that the total correlation would be in error as an estimate of the quantitative relationship between the production of dams with their daughters. He grouped the sires according to the performance of their daughters and obtained correlation coefficients ranging from 0.05 to 0.29.

In a study of the first 38 volumes of the Advanced Registry of the Holstein-Friesian Association, Gifford (1930) reported a coefficient of correlation of 0.32 ± 0.013 on 2041 daughter-dam pairs. By grouping the sires according to the performance of their daughters he obtained a weighted average coefficient of correlation of 0.197. He also worked out the weighted values for the regression lines and pointed out that there was an increase of approximately 20 pounds of butterfat in the yearly production of the daughters for an increase of 100 pounds of fat in the average yearly records of the dams above the potential transmitting ability of the sire.

Plum (1935) made two separate studies in analyzing the variance of records. In one study of 683 daughter-dam pairs from 81 herds he found the correlation between daughter and dam to be 0.31 when based on the first available record and without regard to herd differences. The corresponding correlation within herds was 0.06 thus giving an estimate of heritability within herd of 0.12. In 246 instances in 68 herds the dam had a record starting within 3 months from the time her daughter's record started and each dam also had an earlier record. The total correlation was 0.32 when the first record of each was used and the within herd correlation was 0.10. When the contemporary records were used the total correlation was 0.40 and the correlation within herds was .27, thus showing the effect of simultaneous environment. In the second study with 2,394 pairs used in proving 355 sires in Iowa Cow Testing Associations, Plum (1935) reported an intra-sire correlation of 0.18 between the butterfat production records of daughter and dam. Doubling this would give an estimate of heritability of 0.36.

In an earlier report Plum (1934) found an intra-sire correlation of 0.20 between daughter and dam on 158 daughter-dam pairs in a single Jersey herd. There were 183 cows in the study and all cows had Register of Merit records. Twenty-two bulls were represented. Plum reported that the sires accounted for 22.6 percent of the intra-herd variance.

Lush, Norton and Arnold (1941) obtained estimates of heritability on an intra-herd basis by dividing the mates of each sire into a high half and a low half, on the basis of their milk and fat records. If a bull had an even number of mates all were used. If they had an odd number of mates, the one whose record was median in size was discarded. Twice the ratio of the average of the daughters of the low group subtracted from the average of the daughters from the high group over the difference between the average of the two groups of dams was used to give an estimate of heritability. In one study of 676 daughter-dam comparisons used in proving 103 sires in Iowa Dairy Herd Improvement Association and based on single records, they obtained estimates of 0.28 on fat production and 0.33 on milk production. In a second study of 3,010 daughter-dam pairs obtained from the first eight volumes of the Holstein-Friesian Herd Improvement Registry Year Book, they obtained heritability estimates on fat production of 0.25 and 0.30 on first and second records respectively. There were 209 sires in the second study and all had at least six daughters each. In the first study all records were corrected for age and in the second study all records were converted to maturity and to three-times-milking per day.

Using data from Iowa Dairy Herd Improvement Associations during the period of January 1, 1936 to December 31, 1939, Lush and Straus (1942) obtained a heritability value of 0.174 on 2154 daughter-dam comparisons. All records were for the first 305 days of the lactation and corrected for age and were on the basis of twice-a-day milking. Seven breeds were represented in proving 283 sires. The dams averaged 3.15 lactations and the daughters 1.68 lactations. An estimate was made from the intra-sire regression of daughter on dam and was reduced to a single record basis. The regression coefficient was reduced from 0.134 to 0.087 through the use of the formula and was further reduced to 0.07 when calculated on an intra-herd, intra-sire basis since some sires had daughters in more than one herd. The intra-group variance was larger among daughters than among dams. This was due in part to a closer relationship of daughters to each other thus reducing the variance within groups of daughters. They pointed out that another possible cause for group differences that was more important among the daughters was that the dams averaged more lactations each, thus reducing the variance between groups of dams.

Berry (1945) obtained an intra-herd correlation between daughter and dam of 0.07 on fat production. This study was on a selected group of 454 Holstein-Friesian Advanced Registry cows with at least six records each, along with 954 dams or daughters of these cows with records, among which 661 dams or daughters had at least two records. This gives a heritability estimate of 0.14 on a single record basis.

Data on the production of 6888 daughters and mates of 374 Ayrshire sires were studied by Tyler and Hyatt (1947). All records were converted to 305 day mature equivalent twice-a-day milking basis. By doubling the intra-sire regression of daughter's production on dam's production on a single unselected basis, they obtained heritability estimates of 0.31 and 0.28 for milk and fat production respectively.

In a study of the genetic factors affecting milk production in a selected Holstein-Friesian herd, Laben and Herman (1950) obtained a heritability estimate of 0.29 for butterfat production and 0.36 for milk production by doubling the intra-sire regression of daughter on dam. The study included 270 daughter-dam pairs and the daughters were the progeny of 34 sires. The production records were standardized to 305 day, twice-a-day milking, mature equivalent basis. The average of all available normal records up through the eighth lactation was used. The heritability estimates were reduced to a single record basis as outlined by Lush and Strauss (1942).

In a study to evaluate the curvilinearity of heritability of butterfat production, Beardsley et al. (1950) used data from 176 proved sires of the Guernsey, Holstein-Friesian and Jersey breeds. Each bull was represented by at least five daughter-dam pairs in each of two or more herds. There were 3307 daughter-dam comparisons in 390 herds. By doubling the linear regression of daughter on dam within breeds, within sires and within herds, they obtained a heritability estimate of 0.27. They reported that the estimates of heritability on the basis of curvilinear regression gave values decreasing with increased production. They gave two possible explanations for this. One possibility was that high production may be a result of homozygosity and in such case a smaller proportion of the observed variability is transmitted from generation to generation as the homozygosity increases. The second possible explanation was that high production may represent some non-additive genetic deviations in addition to additive genetic influences, and this could be attributed to dominance, over-dominance, epistasis and gene-environmental actions. Rennie (1951) found the heritability of butterfat production in Canadian Jerseys to be 0.36; over-all type scores to be 0.16; and the genetic correlation between the two to be 0.24. The heritability estimates were calculated by doubling the intra-sire regression of daughter on dam and were based on 776 dams with 858 daughters from 360 sires. The genetic correlations were based on 3328 cows.

A very extensive study with Jersey cows on Herd Improvement Registry test for at least four of the five years from 1943 to 1947 inclusive was made by Harvey and Lush (1952). From 2044 dams which had 2786 daughters in 226 herds they obtained an intra-herd regression of daughter's fat production on dam's fat production of 0.12 when presumably freed from year differences. The dams averaged 2.46 lactations each and the daughters averaged 1.89 records each. From this they calculated the heritability of differences in fat production records to be 0.18 ± 0.03 when made in the same herd and year and adjusted to a single record basis. By ignoring the effect of years the estimate was 0.17 ± 0.03. They listed two primary reasons to account for the heritability of fat production being only slightly smaller when the effect of years was ignored. One was that the averaging of all records available on the dam diminishes the amount of the year component remaining in the intra-herd variance of the dam. The other was that the difference between years within herd accounted for only a small portion of the intra-herd variance.

Legates and Lush (1954) made a study of fat production on 23,330 lactation records for 12,405 Jersey cows on Herd Improvement Registry Test in 293 herds. The period studied was 1943-47 and all cows had to be on test at least four years. No doubt some of the same cows were sampled in both this study and the one reported by Harvey and Lush (1952). In this study Legates and Lush obtained a repeatability estimate of 0.412; correlation between maternal half sisters 0.073; and correlation between paternal half sisters 0.120. They obtained a heritability estimate of 0.201 from the intra-sire regression of 4764 daughters on 3363 dams. All the above statistics were calculated on an intra-herd basis.

Stone, Rennie and Raithly (1955) reported heritability values of 0.25 and 0.27 for milk and fat on a mature equivalent basis. They studied 1500 Holstein-Friesian cows in Canada of which 300 were from each of the five type classes, Excellent to Fair, and their 1037 daughters. The heritabilities were calculated from the regressions of daughter on dam on an intra-sire basis. It is assumed that the values were on 1037 daughter-dam pairs.

An analysis was made of all Guernsey, Holstein-Friesian, and Jersey D.H.I.A. records made in Idaho during 1940-52 by Johnson, et al. (1956). From 2025 daughter-dam comparisons of the three breeds combined they calculated the heritability for milk and butterfat production to be 0.26 and 0.30 respectively. Separate breed values of 0.36 and 0.32 were obtained for 431 Guernsey pairs; 0.26 and 0.22 for 868 Holstein pairs; and 0.21 and 0.39 for 726 Jersey pairs.

Legates (1957) reported the intra-herd, intra-sire estimates of heritability of fat production computed from daughter-dam pairs. His data included 1824 Guernsey, 5451 Holstein, and 3465 pairs and were from D.H.I.A. records. He divided each into nine production levels, but found no significant relationship between the heritability values and production level of the herds. By pooling the results for each breed, he obtained the following heritability estimates: Guernsey 0.20 $\pm$ .06, Holstein 0.21 $\pm$ .04, and Jersey 0.24 $\pm$ .04.

Mitchell, et al. (1957) presented data from a study of 11,370 Holstein-Friesian daughter-dam pairs including heritability estimates and genetic correlations. There were 877 herds and 1824 sires. The herds were stratified according to high (above 13,230 pounds), medium (11,960-13,230 pounds), and low (below 11,960 pounds) levels of milk production.

Estimates were made from the intra-sire, intra-herd variances and co-variances of daughters and dams. All coefficients were adjusted to a single record basis. The estimates of heritability are presented in Table I and the genetic correlations in Table V.

TABLE I

HERITABILITY ESTIMATES BASED ON INTRA-HERD, INTRA-SIRE REGRESSIONS OF DAUGHTER ON DAM (MITCHELL ET AL., 1957)

	Low Group	Medium Group	High Group
Milk	.20	.24	.19
Butterfat	.19	.21	.17
Final Rating	.24	.20	.18
General Appearance	.24	.19	.21
Dairy Character	.09	.09	.06
Body Capacity	.15	.12	.14
Mammary System	.21	.18	.14
Feet and Legs	.18	.16	.12
Rump	.31	.27	.24
Number Herds	263	317	297
Number Sires	585	652	587
Number Pairs	3831	3991	3548

Repeatability of Milk and Fat Production

The review of literature for the repeatability estimates for milk and fat production are presented in Table II.

TABLE II

MILK AND FAT REPEATABILITY ESTIMATES REPORTED IN THE LITERATURE

Authority	Year	Characteristic	Est. of Repeat.	No. Cows	Breed	Notes and Remarks
Lush, Norton & Arnold	1950	Fat	.43	1352	-	Iowa D.H.I.A. Age corrected 676 dau.-dam pairs
Lush, Norton & Arnold	1950	Milk	.48	1352	-	Iowa D.H.I.A. Age corrected 676 dau.-dam pairs
Plum	1935	Fat	.40	2316	G,H,J	Intra-herd, age corrected 5860 lactations
Dickerson	1940	Fat	.34	274	H	Intra-herd, age corrected 305 day record
Berry	1945	Fat	.41	454	H	Gross correlation all cows had 6 or more HIR records
Berry	1945	Fat	.29	454	H	Intra-herd corr. All cows had 5 or more HIR records
Johansson	1950	Fat	.32 to .39	31 herds	Swedish Red& Wh.	Within herd no corrections
Johansson	1950	Milk	.38 to .40	31 herds	Swedish Red& Wh.	Within herd no corrections
Legates & Lush	1954	Fat	.41	12,405	J	Intra-herd, age & year corrected. 23,330 records
Stone, Rennie & Raithby	1955	Fat	.52	2537	H	Canada
Stone, Rennie & Raithby	1955	Milk	.50	2537	H	Canada
Castle & Searle	1957	Fat	.49	2436	J	New Zealand. Intra-herd, age corr. 5,557 rec.
Castle & Searle	1957	Fat	.61	2436	J	N.Zealand. Intra-herd, age corr. 5,557 rec. Also year corrected

Repeatability and Heritability of Type Ratings

Johnson and Lush (1942) conducted a study to determine the repeatability of type ratings made at yearly intervals. These unofficial ratings were made on the Iowa State College Holstein-Friesian herd and each animal was first classified at approximately six months of age. The study covered the period 1930-40 and included 229 females. By omitting all classifications made under ten months of age, they found a repeatability of .34 on the remaining classifications when classified by experienced judges. They found that consecutive ratings were only slightly if any more alike than ratings separated by two to four years. They found that some judges agreed with each other more closely than they did with other judges but not significantly so. Health of the cow and changes in udder caused the largest shifts in type ratings.

Hyatt and Tyler (1948) studied the type ratings of 101 Ayrshire cows classified three times a year by official inspectors. The repeatabilities of ratings of these 101 cows was 0.55. Eighty of these cows were classified three times or more. They averaged five classifications over a 4.5 year period. Of these 58.7 percent had a range of one grade, 32.5 percent had a range of two or three grades, and 8.8 percent were rated the same each time. The repeatabilities between ratings given a cow by the same inspector at different times were 0.73, 0.82, and 0.62, for three different inspectors. Thus it seems that some of the differences between type ratings of the same cow are due to differences in inspectors. Age, stage of lactation and degree of fleshing of the animal all contributed to these variations.

A study by Tyler and Hyatt (1948) has shown that the heritability of single type ratings in Ayrshire cows probably lies between 0.19 and 0.42.

From 1601 cows sired by 789 bulls and whose dams were classified on the same day by the same classifier, they obtained a heritability value of 0.28 by doubling the regression of daughter's rating on dam's rating within sires. They also studied the paternal sisters of sires with six or more daughters classified on the same day. They found the correlation between paternal half sisters to be $0.12 \pm .04$. Then they assumed the genetic relationship of the paternal half sisters in their study to be 0.30. With this information they estimated the heritability to be somewhat less than 0.40. By combining the two studies they estimated the heritability of single type ratings to be about 0.30 with fiducial limits of 0.19 and 0.42.

They obtained within-herd correlation coefficients of 0.16, 0.16, and 0.19 between type and first production record, nearest record to classification date, and average of all records respectively.

Harvey (1949) found the heritability of official type ratings to be 0.14 on an intra-herd basis. He obtained genetic correlations between type and fat production of 0.18 as estimated from the genetic variances and covariance of type and production. These data were from the same sample reported by Harvey and Lush (1952). Stone, et al. (1955) reported a heritability estimate of 0.21 from a study of 1500 Holsteins in Canada.

In July, 1950, the Ayrshire Breeders' Association modified their type classification program by providing for a numerical score of ten components of type, which are averaged to determine the final type score. Freeman and Dunbar (1955) studied all the daughter-dam comparisons available from the records from that date to September 1952. Single type and butterfat records were used in all instances, and all production records were converted to mature equivalent, twice-a-day, 305 day basis. The average within-herd regression of daughter's trait on dam's trait was doubled to estimate heritability. The estimates of heritability for each type component and final rating are given in Table III.

TABLE III

HERITABILITIES OF THE COMPONENTS OF TYPE AND FINAL TYPE RATING WITH THEIR RESPECTIVE 95% CONFIDENCE LIMITS (FREEMAN AND DUNBAR, 1955)

Trait	Number of Pairs	Herita- bility	95% Confidence Limit
Head and neck	1190	0.30	0.12
Shoulders and chest	1180	0.15	0.14
Middle and loin	1182	0.31	0.18
Rump and thighs	1182	0.32	0.16
Feet and legs	1173	0.18	0.15
Udder size and shape	1176	0.08	0.14
Udder attachments	1175	0.06	0.11
Udder teats, veins, & quality	1182	0.27	0.16
General quality	1182	0.13	0.15
Breed character	973	0.32	0.16
Final rating	1184	0.31	0.15

Genetic Correlations

Freeman and Dunbar (1955) also calculated the genetic correlations between the components of type, final type rating, and butterfat production. The results of this study are found in Table IV.

It is interesting to note that most type components are positively correlated genetically with each other and final type rating. Some of the correlations surpassed 1.00 which indicatespossible sampling errors. With only one exception, middle and loin, all type components and final type rating were negatively correlated with butterfat production. They also obtained the phenotypic correlations for the various combinations

TABLE IV

GENETIC CORRELATIONS BETWEEN THE COMPONENTS OF TYPE, FINAL TYPE RATING, AND BUTTERFAT PRODUCTION
(Freeman and Dunbar 1955)

Trait	Shoulders and Chest	Middle and Loin	Rump and Thighs	Feet and Legs	Udder size and Shape	Udder Attach-ments	Udder Teats Veins and Quality	General Quality	Breed Character	Final Rating	Butterfat Production
Head and Neck	0.09	0.29	0.30	0.18	0.48	1.03	0.27	0.89	0.64	0.64	-0.51
Shoulders and Chest		-0.17	0.45	0.42	0.83	0.51	0.38	0.61	0.31	0.60	-0.60
Middle and Loin			0.86	0.51	0.87	0.36	0.47	0.90	0.75	0.73	0.22
Rump and Thighs				0.61	0.32	-0.15	0.02	0.68	0.87	0.65	-0.40
Feet and Legs					0.18	0.27	-0.18	0.41	0.41	0.55	-0.09
Udder size and Shape						1.19	1.20	6.43	1.04	1.07	-0.64
Udder Attachments							1.10	1.13	0.59	0.93	-0.25
Udder Teats, Veins and Quality								0.53	0.64	0.64	-0.39
General Quality									1.05	1.00	-0.86
Breed Character										0.91	-0.50
Final Rating											-0.52

and the value between final type rating and butterfat production was 0.05. They concluded from their data that in selecting for butterfat production alone nothing could be gained by giving positive emphasis to final type rating.

The genetic correlations on 11,370 Holstein-Friesian daughter-dam pairs from the report of Mitchell et al. (1955) mentioned earlier are found in Table V.

In a study of unofficial type ratings of the Iowa State College Holstein herd over a period from 1932-45, Touchberry (1951) found no correlation between the ratings of daughter and dam. However, there were only 187 pairs in the study and he mentions that the lack of correlation could have been due to sampling errors or to errors in making the type ratings. He also calculated the phenotypic and genetic correlations between type and production as follows:

Between	Phenotypic Correlation	Genetic Correlation
Type rating and milk production	.18	0
Type rating and fat production	.26	0
Milk production and fat production	.87	.71

Tabler and Touchberry (1955) studied all Jersey cows officially classified for type and that had Herd Improvement Registry lactation records completed during the years 1947-50. From these cows they obtained data on 2810 daughter-dam pairs where the records of daughter and dam were both made in the same herd. There were 756 sires and 414 herds represented. All production records were on a mature equivalent, 305-day, twice-a-day milking basis and only the first single lactation record available was used. Heritability estimates of 0.25 and 0.20 were obtained for milk yield and fat yield respectively by doubling the intra-sire regression of daughter on dam.

TABLE V

GENETIC CORRELATIONS BETWEEN MILK AND BUTTERFAT PRODUCTION AND TYPE RATINGS AMONG HERDS STRATIFIED ACCORDING TO LEVEL OF MILK PRODUCTION
(Mitchell *et al*. 1957)

	Milk	Fat	Final Rating	General Appearance	Dairy Character	Body Capacity	Mammary System	Feet and Legs
			LOW GROUP					
Fat	.76							
Final Rating	.08	.09						
General Appearance	.01	.04	.99					
Dairy Character	.61	.63	.79	.75				
Body Capacity	-.06	-.01	.65	.66	.26			
Mammary System	.11	.15	.97	.90	.69	.05		
Feet and Legs	-.17	-.18	.52	.53	-.07	.44	.46	
Rump	-.05	-.03	.76	.78	.35	.51	.60	.37
			MEDIUM GROUP					
Fat	.80							
Final Rating	.28	.25						
General Appearance	.02	.03	.97					
Dairy Character	.82	.84	.87	.65				
Body Capacity	.33	.31	.73	.76	.37			
Mammary System	.23	.17	.89	.74	.64	.55		
Feet and Legs	.26	-.07	.68	.80	.25	.65	.40	
Rump	.12	.08	.72	.92	.27	.35	.41	.83
			HIGH GROUP					
Fat	.72							
Final Rating	-.04	.02						
General Appearance	-.02	.02	.96					
Dairy Character	.61	.36	.33	.31				
Body Capacity	.12	.19	.77	.85	.55			
Mammary System	-.13	-.08	.89	.72	.07	.39		
Feet and Legs	.07	-.01	.44	.64	-.19	.32	.13	
Rump	-.01	.07	.65	.70	.42	.55	.50	.19

The heritability estimate of type classification was 0.25.

Phenotypic and genetic correlations were as follows:

	Phenotypic	Genetic
Milk yield and fat yield	0.88	0.72
Milk yield and type	0.08	0.07
Fat yield and type	0.11	0.08

CHAPTER III

METHODS AND PROCEDURE

Source and Adjustment of Data

Through the courtesy of the American Guernsey Cattle Club and Mr. Robert D. Stewart, Secretary, the author spent six months during 1956 at the home office in Peterborough, New Hampshire, collecting the data for this study. Here the writer had free access to their record files for research purposes. Having been a Guernsey breeder for over two decades, the author was well acquainted with the various breed programs and records.

After becoming fully acquainted with the various record files and the information they contained, the author developed a routine to collect the desired data. The data collected were all the H.I.R. production records and type classification ratings on all daughter-dam pairs on an intra-herd intra-sire basis. In order for a herd to qualify it had to have been previously classified and have been on Herd Improvement Registry test. In order for a sire to qualify he had to have at least two daughters who along with their dams were both classified and tested in the same herd. The number was originally set at five but this was found to eliminate too many sires. If a cow qualified in one herd and was later sold into a second herd where she made more records, these latter records were omitted.

It was the opinion of the author that the herds entered in the Herd Improvement Registry furnished the most complete information available, since every cow in these herds was tested. It also was thought that these were the best data available since it furnished relatively unbiased information when compared to herds on a selective testing program.

All H.I.R. records are filed alphabetically on cards by cow name. Each card contains one record. The information on the card includes the name and number of the cow, date of birth, sire's name and number, dam's name and number, the record in pounds actual milk, fat and fat %, age of cow, and the date the record is approved or becomes official. (All records since January 1, 1956, are being punched on IBM cards.)

All type classification reports are filed alphabetically by herd owner. This report includes the owner's name and address, date of classification, name of cow, age to nearest one-half year at time of classification, and the detailed classification ratings based on the dairy cow score card, namely:

- General Appearance Rating
    - Shoulders
    - Feet and legs
        - Fore
        - Hind
    - Rump
- Dairy character
- Body capacity
- Mammary system rating
    - Fore udder
    - Rear udder
    - Teat placement
- Over-all rating

There is also a remarks column in which, among other information, is noted if the cow was dry. If a sire has five or more daughters in the herd, his name is given and his daughters are listed under him. Each report is signed by the classifier and the recording clerk.

Type classification is voluntary on the breeder's part. He must make application to have his herd classified, and pay a fee on a per head basis. He agrees to present all registered Guernsey females that have freshened at the time of classification. Among the early rules in the program the rating was official immediately after classification but was not published until the cow had an official production record providing such record was completed or the cow started on official test within two years of the date of classification. This rule was eliminated later.

The classification standards and ratings are as follows:

Rating	Score Card Points
Excellent	90-100
Very Good	85- 90
Desirable	80- 85
Acceptable	75- 80
Fair	70- 75
Poor	less than 70

Guernsey herds may be reclassified no sooner than five months after previous classification. On subsequent classification the rating may remain the same, be raised or lowered. On subsequent classification all eligible cows not previously classified must be presented and, in addition, all cows previously classified Very Good or Excellent, except those eight years or older. The owner may present any cows previously classified.

The American Guernsey Cattle Club reserves the right to reclassify all Excellent cows regardless of changes in location or ownership, but not sooner than one year after date of classification, except those eight years of age or over.

The period covered in this study pertaining to type classification records was from 1947 through 1955. During this space of time there were 73,658 cow classifications including reclassifications in 1316 herds. A majority of these cows were production tested in the Advanced Registry

Division. A summary of the above classifications for all traits as published by the American Guernsey Cattle Club (1955) may be found in Tables VI and VII. By using a score of 92.5 for all Excellent ratings, 87.5 for Very Good, 82.5 for Desirable, 77.5 for Acceptable, 72.5 for Fair and 67.5 for Poor, the average score was 82.29 on over-all rating for the 73,658 classifications.

Each of the 1316 classification reports was checked to see if the cows classified had H.I.R. records and, if so, their parentage was checked and all qualifying daughter-dam pairs were recorded. Each qualifying herd was given a number. The information on each animal was punched on International Business Machine cards. Lactation and type data were punched on separate cards. A card was made for each separate lactation record and each type classification.

The production information that was recorded and how it was punched on the International Business Machine cards was as follows:

Column Number	Information recorded
1- 4	Herd number
5-11	Cow number
12-17	Sire number
18-24	Dam number
25	Code for board to use in figuring M.E. records*
26-31	Blank
32-34	Days in lactation**
35-39	Pounds of milk
40	x punch to identify lactation card
41-44	Pounds of fat
45-66	Blank
67-72	Calving date
73-78	Date of birth
79	Blank
80	x punch dams only

*Different boards are used in calculating mature equivalent records depending on length of record and reason for record that is less than 305 days in length.

**The A.G.C.C. defines a lactation as any cow that has been on test 180 days or more. If such a cow goes dry before the 305th day no adjustment is made. However if she is sold or dies, conversion factors are employed to complete the lactation to a 305 day basis.

TABLE VI

BREAKDOWN BY NUMBERS FOR ALL CLASSIFICATIONS 1947 - 1955

	GENERAL APPEARANCE											
			Feet & Legs					MAMMARY SYSTEM				
	Rating	Shoulders	Fore	Hind	Rump	Dairy Character	Body Capacity	Rating	Fore Udder	Rear Udder	Teat Placement	Over-all Rating
Excellent	2407	3882	5291	1913	5115	15514	12418	2051	2942	4936	2730	1843
Very Good	19033	20300	24395	10127	21545	32964	31266	15179	15409	20567	15160	18153
Desirable	33462	29236	21275	23120	27118	19974	22470	31886	27923	28843	28352	33306
Acceptable	15645	15024	5830	17416	14599	4351	6333	19372	20158	14766	20911	16263
Fair	2874	4426	601	4137	4472	770	1069	4431	5931	3704	5471	3709
Poor	237	790	55	734	809	85	102	739	1295	842	1034	384
Total Classified	73658	73658	57447*	57447*	73658	73658	73658	73658	73658	73658	73658	73658

*These totals are smaller because Feet and Legs were combined into one rating when the program was first initiated. The first 16,211 classifications were made using the combined rating.

TABLE VII

BREAKDOWN BY PERCENTAGES FOR ALL CLASSIFICATIONS 1947 - 1955

	General Appearance	Shoulders	Fore Legs	Hind Legs	Rump	Dairy Character	Body Capacity	Mammary System	Fore Udder	Rear Udder	Teat Placement	Over-all Rating
Excellent	3.3	5.3	9.2	3.3	6.9	21.1	16.9	2.8	4.0	6.7	3.7	2.5
Very Good	25.9	27.6	42.5	17.6	29.3	44.8	42.4	20.6	20.9	27.9	20.6	24.6
Desirable	45.4	39.7	37.1	40.3	36.8	27.1	30.5	43.3	37.9	39.2	38.5	45.3
Acceptable	21.2	20.4	10.1	30.3	19.8	5.9	8.6	26.3	27.4	20.1	28.4	22.1
Fair	3.9	6.0	1.0	7.2	6.1	1.0	1.5	6.0	8.1	5.0	7.4	5.0
Poor	.3	1.0	.1	1.3	1.1	.1	.1	1.0	1.7	1.1	1.4	.5

The correctness of the punched information was verified by a second person. The cards were then processed by machine and the butterfat percentage was punched in columns 48-49; pounds mature equivalent milk in 54-58; pounds mature equivalent fat in 59-62; and the age of the cow in columns 63-66.

The conversion factors used to adjust all records to twice-a-day milking, 305 days mature equivalent basis, are shown in Tables VIII, IX, and X. The same factors were used as employed by the American Guernsey Cattle Club and are taken mostly from Kendrick (1953).

The type classification data for each cow and each classification were recorded on International Business Machine cards as follows:

Column Number	Information Recorded
1- 4	Herd number
5-10	Date classified
11	Classifier
12-18	Cow number
19-21	Age when classified
22-34	Classification breakdown ratings
35	In milk or dry
36	x punch, dams only

The classification ratings were given consecutive numerical scores from one for an "Excellent" to six for a "Poor" cow. The classifier and whether the cow was in milk or dry were also coded by numbers. All cards were verified in a like manner of the lactation cards.

Both decks were then checked for any duplicate cards by use of the collator. There was a total of 8533 lactation cards and 4172 type classification cards. Following this, cow summary decks were prepared from the production and type cards. There proved to be 3202 summary cards in each deck.

From the production cow summary deck, the average fat and milk production of the cows were calculated. A procedure was then worked out to

TABLE VIII

AGE-CONVERSION FACTORS USED BY THE A. G. C. C.
FOR 305-DAY PRODUCTION RECORDS

GUERNSEY

Age	Factor	Age	Factor	Age	Factor
1 - 9	1.31	5 - 4	1.01	10 - 7	1.05
1 - 10	1.28	5 - 5	1.01	10 - 8	1.05
1 - 11	1.26				
2 - 0	1.24	5 - 6	1.01	10 - 9	1.05
2 - 1	1.23	5 - 7 to		10 - 10	1.05
2 - 2	1.22	7 - 5	1.00	10 - 11	1.05
2 - 3	1.21	7 - 6	1.01	11 - 0	1.06
2 - 4	1.20	7 - 7	1.01	11 - 1	1.06
2 - 5	1.19	7 - 8	1.01	11 - 2	1.06
2 - 6	1.18	7 - 9	1.01	11 - 3	1.06
2 - 7	1.17	7 - 10	1.01	11 - 4	1.06
2 - 8	1.16	7 - 11	1.01	11 - 5	1.06
2 - 9	1.15	8 - 0	1.01	11 - 6	1.07
2 - 10	1.14	8 - 1	1.02	11 - 7	1.07
2 - 11	1.13	8 - 2	1.02	11 - 8	1.07
3 - 0	1.12	8 - 3	1.02	11 - 9	1.07
3 - 1	1.11	8 - 4	1.02	11 - 10	1.07
3 - 2	1.10	8 - 5	1.02	11 - 11	1.07
3 - 3	1.09	8 - 6	1.02	12 - 0	1.08
3 - 4	1.09	8 - 7	1.02	12 - 1	1.08
3 - 5	1.09	8 - 8	1.02	12 - 2	1.08
3 - 6	1.08	8 - 9	1.02	12 - 3	1.08
3 - 7	1.08	8 - 10	1.02	12 - 4	1.08
3 - 8	1.08	8 - 11	1.02	12 - 5	1.08
3 - 9	1.07	9 - 0	1.02	12 - 6	1.09
3 - 10	1.07	9 - 1	1.03	12 - 7	1.09
3 - 11	1.07	9 - 2	1.03	12 - 8	1.09
4 - 0	1.06	9 - 3	1.03	12 - 9	1.09
4 - 1	1.06	9 - 4	1.03	12 - 10	1.09
4 - 2	1.06	9 - 5	1.03	12 - 11	1.09
4 - 3	1.05	9 - 6	1.03	13 - 0	1.10
4 - 4	1.05	9 - 7	1.03	13 - 1	1.10
4 - 5	1.05	9 - 8	1.03	13 - 2	1.10
4 - 6	1.04	9 - 9	1.03	13 - 3	1.10
4 - 7	1.04	9 - 10	1.03	13 - 4	1.10
4 - 8	1.04	9 - 11	1.03	13 - 5	1.10
4 - 9	1.03	10 - 0	1.04	13 - 6	1.11
4 - 10	1.03	10 - 1	1.04	13 - 7	1.11
4 - 11	1.03	10 - 2	1.04	13 - 8	1.11
5 - 0	1.02	10 - 3	1.04	13 - 9	1.11
5 - 1	1.02	10 - 4	1.04	13 - 10	1.11
5 - 2	1.02	10 - 5	1.04	13 - 11	1.11
5 - 3	1.01	10 - 6	1.05		
				14 - 0	1.12

combine the production and type data on the same card for each cow. The necessary information was then reproduced and a deck of daughter-dam cards was prepared. There were 1981 daughter-dam cards each representing a daughter-dam pair. Of these 1981 pairs there were 1441 dams with one or more daughters (in this report these are referred to as single or individual dams); 317 with two; 69 with three; 23 with four; and 4 with five daughters. Some cows served as both dams and daughters in different pairs.

Summary cards were then made for Sire X Herd of which there were 511. Herd totals were then calculated and punched and there were 239 herds represented. The location of these herds by state are listed in Appendix A and a list of the farms or owners are listed alphabetically in Appendix B.

TABLE IX

FACTORS USED BY THE AMERICAN GUERNSEY CATTLE CLUB TO ADJUST RECORDS TO A 305-DAY BASIS

Days	Factor
180-194	1.408
195-209	1.301
210-224	1.235
225-239	1.180
240-254	1.135
255-269	1.093
270-284	1.051
285-299	1.025
300-305	1.000
306-320	.977
321-335	.940
336-350	.910
351-364	.880
365 only	.850

TABLE X

FACTORS USED BY THE A. G. C. C. TO CONVERT 3-TIMES-A-DAY MILKING TO 2-TIMES-A-DAY MILKING

Number of Days Milked	Factor		
	2 to 3 years of age	3 to 4 years of age	4 years of age and over
5 to 15	0.99	0.99	0.99
16 to 25	.98	.99	.99
26 to 35	.98	.98	.98
36 to 45	.97	.98	.98
46 to 55	.97	.97	.97
56 to 65	.96	.97	.97
66 to 75	.95	.96	.96
76 to 85	.95	.95	.96
86 to 95	.94	.95	.96
96 to 105	.94	.94	.95
106 to 115	.93	.94	.95
116 to 125	.92	.93	.94
126 to 135	.92	.93	.94
136 to 145	.91	.93	.93
146 to 155	.91	.92	.93
156 to 165	.90	.92	.93
166 to 175	.90	.91	.92
176 to 185	.89	.91	.92
186 to 195	.89	.90	.91
196 to 205	.88	.90	.91
206 to 215	.88	.89	.90
216 to 225	.87	.89	.90
226 to 235	.87	.88	.90
236 to 245	.86	.88	.89
246 to 255	.86	.88	.89
256 to 265	.85	.87	.88
266 to 275	.85	.87	.88
276 to 285	.84	.86	.88
286 to 295	.84	.86	.87
296 to 305	.83	.85	.87

Comparative Information on Daughter-Dam Pairs

The average production of the dams and their daughters in the study may be found in Table XI.

TABLE XI

COMPARISON OF AVERAGE MILK AND BUTTERFAT PRODUCTION OF DAUGHTER-DAM PAIRS

Number	Milk	% B.F.	Fat	Milk	% B.F.	Fat
	Dams			Daughters		
1981*	8803	4.83	425	8688	4.90	426
1441	8792	4.83	425	8689	4.91	427
540	8834	4.80	424	8684	4.89	425

*The 1981 dams in this study were represented by 1441 cows. Of these 1441 dams, 317 had two daughters in the study therefore these dams were represented twice in the daughter-dam pairs. In addition, 69 dams had three daughters; 23 had four; and 4 dams had five daughters each. This made a total of 540 daughter-dam pairs in which the dams were repeated. Table XI shows the average production of the dams and their daughters when the dams are grouped as total dams (1981); individual dams, whereby each dam is included only once (1441); and the repeated dams (540).

From this table it is seen that there was relatively little difference in the average production of the dams and their daughters. It is normally expected that the dams will be a more selected group and will have a higher average. In this case, the 1981 dams averaged approximately 100 pounds of milk more than their daughters. The milk from the daughters, in turn, had a slightly higher butterfat percentage which resulted in an average of one more pound of butterfat per lactation. It will be noted, however, that the dams that had more than one daughter in the study averaged the highest in milk production although their fat production was the lowest. The differences in all cases, however, are small.

The average production of the 1441 dams combined with their 1981 daughters was 8732 pounds of milk and 426 pounds of butterfat with a butterfat percentage of 4.88%.

Based on the first available type rating of each cow, a summary of the average milk production data of all daughters and the single dams combined according to over-all type classification ratings is presented in Table XII.

TABLE XII

THE AVERAGE PRODUCTION OF DAUGHTERS AND SINGLE DAMS COMBINED ACCORDING TO OVER-ALL TYPE CLASSIFICATION RATINGS

Over-all Classification Rating	Number of Cows	Milk in Pounds	% B.F.	Butterfat in Pounds
Excellent	34	9412	5.05	475
Very Good	638	9179	4.88	448
Desirable	1638	8814	4.87	429
Acceptable	909	8390	4.87	410
Fair	188	8096	4.89	396
Poor	15	7818	4.81	376
Total	3422			
Average		8732	4.88	426

The same information on the dams and daughters separately may be found in Table XIII.

The average score based on final over-all classification rating was 81.33 percent for the 1981 daughters. The average score for the 1981 dams was 82.08% which might indicate a slightly greater selection among those cows with more than one daughter. The difference between

82.08% and 81.94% is quite small, however.

The average number of lactation records per single dam was 3.27 and 3.41 when dams with more than one daughter were repeated. The average per daughter was 2.39 records.

TABLE XIII

THE AVERAGE PRODUCTION ACCORDING TO OVER-ALL TYPE RATINGS FOR DAMS AND DAUGHTERS

Over-all Classification Rating	Number	Milk	B.F.	Number	Milk	B.F.
		Dams			Daughters	
Excellent	27	8784	444	15	10048	504
Very Good	425	9167	443	342	9159	451
Desirable	975	8858	426	936	8794	432
Acceptable	467	8483	411	551	8344	409
Fair	82	8131	396	126	8054	394
Poor	5	8348	417	11	7636	354
Total	1981			1981		
Average		8803	425		8688	426

The range in numbers of records per cow ranged from one to nine for the dams and one to eight for the daughters. Table XIV shows the number and percentage of cows and their average production per number of lactations each.

TABLE XIV

AVERAGE PRODUCTION BY NUMBERS OF RECORDS PER COW
FOR DAMS AND DAUGHTERS

Number Records Per Cow	No. Cows	% Cows	Avg. Milk (lbs)	Avg. B.F. (lbs)	No. Cows	% Cows	Avg. Milk (lbs)	Avg. B.F. (lbs)
		Dams				Daughters		
1	319	16.1	8378	406	686	34.6	8615	423
2	418	21.1	8652	412	535	27.0	8622	424
3	365	18.4	8777	426	361	18.2	8730	430
4	346	17.5	8814	424	209	10.6	8772	429
5	246	12.4	9047	440	119	6.0	9012	442
6	168	8.5	9407	454	45	2.3	8918	431
7	81	4.1	9379	457	18	0.9	8878	427
8	35	1.7	8758	421	8	0.4	8636	432
9	3	0.2	8307	425	0	0.0		
Total	1981				1981			
Average			8803	425			8688	426
Average No. Records/Cow			3.41				2.39	

Statistical Procedures

One of the chief problems in animal breeding studies is to control the environment so that the phenotypic measurements used to evaluate genotype will not be greatly confounded. In a study of the nature presented here, it is impossible to physically control the environmental conditions under which the phenotypic measurements were made. It therefore behooves the investigator to adopt those statistical methods whereby environmental corrections can be made as accurately as possible for those variations that have occurred. This is done through the use of correction factors where they may be applied to individual records to remove known phenotypic differences due to different environmental conditions and through the use of the statistical analysis that is best adapted to the project undertaken. As mentioned in an earlier section of this report, all lactation records were corrected to twice-a-day milking, 305 day, mature equivalent basis in this study. These corrections standardize all the production records and, as nearly as possible, remove the variations due to age of cow, length of lactation, and times milked per day. However, the environmental variation between cows and herds due to differences in feeding and management practices remains untouched.

Heritability Estimates

Heritability has been defined in both a broad and narrow sense by Lush (1940). In the broad sense, heritability refers to the functioning of the whole genotype as a unit and includes the effects due to dominance deviations, epistatic deviations, and joint effects (interactions) between heredity and environment. Heritability in the narrow sense is the ratio of only the additive genetic variance to the total phenotypic variance. The differences between the two definitions can be more clearly seen in Figure 1 from Lush (1940).

Since only that portion of the total variations between individuals that is due to the additive genetic variance is transmissible from generation to generation, heritability estimates as close to the narrow sense as possible are desired. The remaining sources of variations due to dominance, epistasis, environment, and interactions between heredity and environment have only temporary effects and thus phenotype may largely mask genotype.

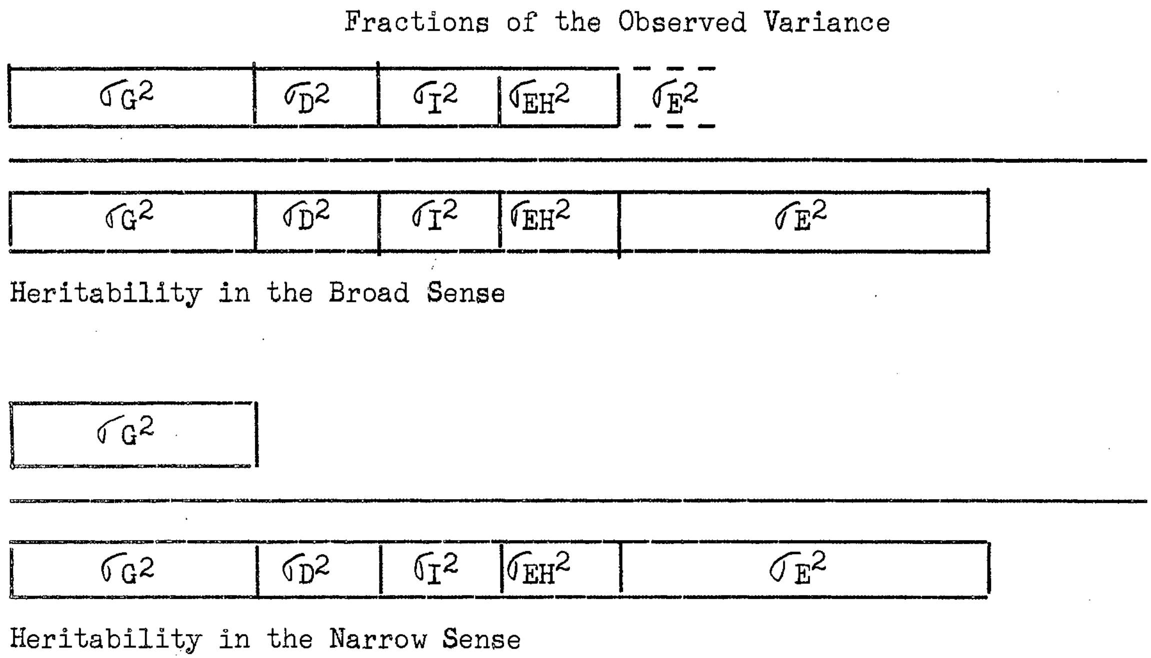

FIGURE 1. Meanings of Heritability in the Broad and Narrow Sense Where:

σ_G^2 = additively genetic variance

σ_D^2 = variance due to dominance deviations

σ_I^2 = variance due to epistatic interactions

σ_{EH}^2 = variance due to non-linear interactions of heredity and envirnoment

σ_E^2 = variance due to environmental variations

The relative proportions chosen by Lush to illustrate the partitioning of the observed variance are arbitrary.

Most numerical estimates of heritability fall between the broad and the narrow definitions. Depending on the method used, the estimate will usually include a little of the epistatic variance and sometimes a little of the dominance variance according to Lush (1948).

There are several methods of estimating heritability and all are based on the degree to which animals with similar genotypes resemble each other more than less closely related animals. The methods used in this study were the intra-sire correlation and regression of daughter on dam and were first introduced by Lush (1940). The estimate of heritability is obtained by doubling the correlation and/or regression coefficient. As pointed out by Lush (1940) the resemblance between parent and offspring is generally most useful because it does not include dominance deviations. By computing heritability on an intra-sire basis it goes far toward automatically discounting environmental contributions and also any peculiarities of mating system. This is done by actually dodging these difficulties by restricting the analysis to the variance that is found within groups of females which are mated to the same sire. If differences exist between the true means of the groups mated to the same sire, they are simply left unanalyzed as to the extent to which they are environmental or hereditary in origin.

The intra-sire regression dodges most of the environmental correlation because the daughters and mates of a sire are usually kept in the same herd. In this study this fact was assured by making the analysis on an intra-herd basis. Since the offspring of one sire are usually nearly contemporary, this keeps time trends in management from contributing very much to the resemblance between daughter and dam. The intra-sire regression dodges departures from random mating because heritability is expressed as a fraction of the variance which existed among females mated to the same sire.

The methods of estimating heritability by the resemblance of offspring and parent have another advantage in that the regression and/or correlation coefficient is multiplied by two as compared to a half-sib correlation in which it is multiplied by four. Therefore, sampling errors are less serious in parent-offspring resemblance than in half-sib relationships.

Lush and Straus (1942) presented a formula from Professor W. G. Cochran for converting heritability estimates calculated from the average of n records to a single-record basis. The formula is

$$b = b' \left[\frac{1 + (\bar{m} - 1)r_{dd}}{\bar{m}} + \frac{\sigma^2_m (1 - r_{dd})}{\bar{m}^3} \right]$$

where

b = the regression of daughter on dam when single records are used
b' = the regression of daughter on dam when lifetime records are used
m = number of lactation records for dams
r_{dd} = repeatability of records within herds

The sums of squares and cross products that were required for the calculation of correlation and regression coefficients in this study were calculated in such a way that each value was computed and recorded at least two times. This was done as a means of an accuracy check.

Repeatability Estimates

Repeatability estimates were determined for milk and butterfat production and all type sub-ratings using data on all cows by using the analysis of variance.

There were 3202 cows from 239 herds in the study with a total of 8533 lactation records and 4172 type classification ratings. The distribution of the number of lactations per cow is found in Table XV and the number of type classifications in Table XVI.

TABLE XV

CLASSIFICATION OF COWS ACCORDING TO NUMBER OF LACTATIONS PER COW

Number Lactations	Number Cows	Total Number Lactations
1	926	926
2	825	1650
3	583	1749
4	421	1684
5	247	1235
6	132	792
7	49	343
8	17	136
9	2	18
Total	3202	8533

TABLE XVI
CLASSIFICATION OF COWS ACCORDING TO NUMBER AND TYPE CLASSIFICATION RATINGS

No. Times Classified	Number Cows	Total Number Classifications
1	2498	2498
2	506	1012
3	146	438
4	38	152
5	12	60
6	2	12
Total	3202	4172

The model for the Analysis of Variance was as follows:

Source	d.f.	Expected Mean Square
Total	$n_{...} - 1$	
Herds	$h - 1$	$\sigma_e^2 + k_2 \sigma_c^2 + k_3 \sigma_h^2$
Cows (within herds)	$\sum_i c_i - h$	$\sigma_e^2 + k_1 \sigma_c^2$
Records (within cows)	$\sum_i \sum_j n_{ij.} - \sum_i c_i$	σ_e^2

where:

$$\hat{\sigma}_c^2 = \frac{\text{M.S. between cows} - \text{M.S. records}}{k_1}$$

and:

$$k_1 = \frac{n_{...} - \sum_i \left[\frac{\sum_j n_{ij.}^2}{n_{i..}} \right]}{\text{d.f.(cows)}}$$

$$k_2 = \frac{\sum_i \left[\frac{\sum_j n_{ij.}^2}{n_{i..}} \right] - \frac{\sum_{ij} n_{ij.}^2}{n_{...}}}{\text{d.f.(herds)}}$$

$$k_3 = \frac{n_{...} - \frac{\sum_i n_{i..}^2}{n_{...}}}{\text{d.f.(herds)}}$$

were obtained as described by Snedecor (1946).

h = number herds

c_i = number cows in i^{th} herd

$n_{ij.}$ = number of records for the j^{th} cow in the i^{th} herd

$n_{i..}$ = number of records made in the i^{th} herd

$n_{...}$ = total number of records.

The correlation coefficient (r) = $\frac{\sigma_c^2}{\sigma_c^2 + \sigma_e^2}$

r = repeatability.

Estimates of Genetic Correlations

The procedure for estimating genetic correlations ($r_{G_iG_j}$) was developed by Hazel (1943), and was based on the method of path coefficients presented by Wright (1921). He states, "To measure the genetic correlations it is necessary to correlate one trait in one animal with the other in a relative."

In working with swine data he presented the formula:

$$r_{G_iG_j} = \sqrt{\frac{b_{i_2j_1} \cdot b_{j_2i_1}}{b_{i_2i_1} \cdot b_{j_2j_1}}} =$$

$$= \sqrt{\frac{(\text{cov } I_2J_1)(\text{cov } J_2I_1)}{(\text{cov } I_2I_1)(\text{cov } J_2J_1)}}$$

The genetic correlations may be calculated from either the regression or correlation coefficients.

The estimation of genetic correlations was applied to dairy cattle data by Touchberry (1951) and Harvey and Lush (1952). Harvey and Lush (1952) used the following formula to estimate the genetic correlation from the genetic variances and covariance of type and production as follows:

$$\frac{\text{Cov } (G_tG_p)/2}{\sqrt{(G_t/2)(G_p/2)}} =$$

Freeman and Dunbar (1955), upon suggestion from Dr. C. R. Henderson, used the same procedure except that the appropriate crossproducts were used rather than regression or correlation coefficients. They used the following formula:

$$r_{g_i g_j} = \frac{\sigma_{g_i g_j}}{\sqrt{\sigma^2_{g_i} \sigma^2_{g_j}}} = \frac{\frac{1}{2}(\Sigma X_i Z_j + \Sigma X_j Z_i)}{\sqrt{(\Sigma X_i Z_i)(\Sigma X_j Z_j)}}$$

where:

X_i denotes the i^{th} trait on the daughter and

Z_j the j^{th} trait on the dam.

The latter formula was the one used in this study using the intra-sire and herd sums of squares and crossproducts.

CHAPTER IV

RESULTS AND DISCUSSION

The regression coefficients (b) and the correlation coefficients (r) needed to estimate heritability are given for the various traits in Tables XVII and XVIII. The estimate of heritability may be calculated for any given trait by doubling the coefficient in the heavy bordered cells of the diagonal where the column of the dams and the line of the daughters for the same trait intersect. From the same tables it is likewise possible to trace the phenotypic regressions or correlations of the various combinations of production and type traits between dam and daughter.

Heritability of Production

The regression of milk production of daughter on milk production of dam within herds was 0.13. The correlation of milk production of daughter and milk production of dam was 0.14. By doubling these values the heritability of differences in milk production within herd is estimated to be 0.26 and 0.28 respectively, from these data. In like manner the estimates of heritability of butterfat production becomes 0.30 and 0.28 respectively. These estimates, however, are based on the average of all records of the daughters and dams. When adjusted to a single-record basis by the formula given by Lush and Straus (1942), the heritability of differences in milk production in the same herd becomes 0.17

TABLE XVII

SUMMARY OF INTRA-SIRE, INTRA-HERD
REGRESSIONS OF DAUGHTER ON DAM

(Daughters) \ (Dams)	Milk	Fat	General Appearance	Shoulders	Rump	Dairy Character	Body Capacity	Mammary System	Fore Udder	Rear Udder	Teat Placement	Overall Rating
Milk	.13	2.23	-34.10	-13.90	44.11	-76.58	44.93	-69.46	-50.31	-31.04	-44.51	-57.30
Fat	.00	.15	-.84	-.21	2.15	-2.32	.71	-1.86	-.85	-1.18	-2.07	-1.55
General Appearance	.00	.00	.12	.01	.07	.07	.07	.08	.05	.06	.07	.11
Shoulders	.00	.00	.09	.10	.02	.02	.05	.04	.03	.03	.03	.09
Rump	.00	.00	.13	.04	.14	.09	.05	.10	.08	.09	.05	.12
Dairy Character	.00	.00	.07	.01	.04	.08	-.01	.02	.00	.01	.02	.04
Body Capacity	.00	.00	.09	.03	.05	.05	.14	.00	.01	.01	.01	.06
Mammary System	.00	.00	.13	-.01	.08	.07	.02	.12	.08	.11	.09	.11
Fore Udder	.00	.00	.13	-.01	.07	.05	.03	.14	.11	.08	.10	.12
Rear Udder	.00	.00	.13	-.02	.07	.08	.03	.10	.05	.13	.05	.11
Teat Placement	.00	.00	.18	.03	.09	.10	.04	.15	.09	.09	.15	.16
Overall Rating	.00	.00	.17	.02	.10	.10	.06	.12	.08	.09	.09	.14

TABLE XVIII

SUMMARY OF INTRA-SIRE, INTRA-HERD
CORRELATIONS OF DAUGHTER ON DAM

(Dams) / (Daughters)	Milk	Fat	General Appearance	Shoulders	Rump	Dairy Character	Body Capacity	Mammary System	Fore Udder	Rear Udder	Teat Placement	Overall Rating
Milk	.14	.10	-.02	-.01	.03	-.05	.03	-.04	-.04	-.02	-.03	-.03
Fat	.08	.14	-.01	.00	.03	-.03	.01	-.02	-.01	-.02	-.03	-.02
General Appearance	-.05	-.07	.12	.02	.09	.08	.08	.09	.07	.08	.10	.11
Shoulders	.00	-.02	.08	.11	.02	.02	.05	.04	.04	.03	.03	.08
Rump	-.08	-.08	.10	.04	.14	.08	.05	.09	.08	.09	.05	.10
Dairy Character	-.03	-.02	.07	.02	.05	.08	-.01	.02	.00	.01	.03	.04
Body Capacity	-.02	.00	.08	.03	.05	.05	.14	.00	.01	.01	.01	.06
Mammary System	.01	.01	.12	-.02	.09	.06	.02	.12	.09	.12	.10	.10
Fore Udder	.02	.00	.11	-.01	.07	.04	.03	.12	.12	.08	.11	.10
Rear Udder	-.02	-.01	.11	-.02	.08	.07	.03	.10	.06	.13	.06	.09
Teat Placement	.00	.00	.15	.03	.10	.08	.03	.13	.09	.09	.16	.13
Overall Rating	.01	-.02	.16	.03	.12	.10	.06	.12	.10	.10	.11	.14

and 0.18 from the regression and correlation studies respectively and 0.19 and 0.18 for fat production respectively. The average of the estimates from the two studies would be 0.175 for milk production and 0.185 for fat production which when rounded off becomes 0.18 for milk production and 0.19 for fat production. The repeatability values used in the formula were those calculated in this study.

Differences in the estimates of heritability of the same trait may arise from sampling error or from the selection that may have been practiced among the dams. In these data the variance of the dams (1,951,458) within herd for milk production was greater than the variance of the daughters (1,631,887); however, the variance of fat production within herd for dams (3,454) was less than the variance of the daughters (3,793). This might indicate that the dams may have been more intensely selected on a fat production basis. In view of the closeness of the averaged production of the dams (8803 milk - 425 fat) with their daughters (8688 milk - 426 fat) and the fact there was greater variance in milk of the daughters it would seem unlikely that selection among the dams created much of a problem. That the dams average 3.41 records per cow compared to 2.39 records per daughter would lead one to expect less variance among the dams. Appendix C shows the intra-herd, intra-sire variances and covariances for the dams and daughters on all traits studied.

In averages of two or more records per cow it is likely that the environmental variance will be decreased in that differences due to the circumstances under which lactation records are made will tend to cancel each other, according to Lush and Straus (1942). Since the daughters in this study average 2.39 records per cow, it would seem that the formula for adjusting the regression and correlation coefficients to a single record basis may have underestimated the estimates of heritability of milk and fat production presented herein.

The heritability of milk and fat production from these data of 0.18 and 0.19 compares favorably with the estimate of 0.20 for fat production reported by Legates (1957) for Guernseys (1,824 pairs), but is below the estimates of 0.36 and 0.32 (431 pairs) reported by Johnson et al. (1956) for this breed.

The results of this study are also in close agreement with the estimates of 0.19 to 0.24 for milk and 0.17 to 0.21 for fat reported by Mitchell, et al. (1957) in their extensive study of 11,370 Holstein daughter-dam pairs. They are also in close agreement with the estimate of Harvey and Lush (1952) of 0.18 for fat production in Jerseys; the 0.20 estimate by Legates and Lush (1954) for the same breed; and the estimate of 0.17 reported by Lush and Straus (1942) for seven breeds. They do not approach the 0.31 and 0.28 for milk and fat in the Ayrshire data reported by Tyler and Hyatt (1947).

Heritability of Type

The heritability estimates of type components calculated by doubling the regression and correlation coefficients in Tables XVII and XVIII are listed below in Table XIX.

These estimates are from single classification ratings (first available rating) and therefore need no adjustment. The estimates from the regression and correlation studies are in close agreement and those differences that do appear may be largely due to rounding and/or sampling error.

TABLE XIX

ESTIMATES OF HERITABILITY OF TYPE COMPONENTS BASED ON 1981 DAUGHTER-DAM PAIRS

Trait	2(b)	2(r)
General Appearance	0.24	0.24
Shoulders	0.20	0.22
Rump	0.28	0.28
Dairy Character	0.16	0.16
Body Capacity	0.28	0.28
Mammary System	0.24	0.24
Fore Udder	0.22	0.24
Rear Udder	0.26	0.26
Teat Placement	0.30	0.32
Over-all Rating	0.28	0.28

The heritability estimate of 0.28 for over-all type rating is in close agreement with the estimates of 0.28 and 0.30 reported by Tyler and Hyatt (1948) and the 0.31 reported by Freeman and Dunbar (1955) with Ayrshire cows. It is double the 0.14 on Jersey cattle from Harvey (1949) and moderately higher than the estimates of 0.18 to 0.24 reported by Mitchell *et al.* and the 0.21 reported by Stone *et al.* (1955) on Holsteins. There are no other studies with Guernsey cattle reported to date.

There are only two other studies which have reported heritability estimates for the components of type. Although there are differences in the terminology of type components rated in the Ayrshire study reported by Freeman and Dunbar (1955), it is interesting to draw some comparisons between it and the Holstein study reported by Mitchell *et al.* (1957) and the Guernsey data reported herein. The Ayrshire study includes data on over 1100 daughter-dam pairs; the Holstein study includes 11,370 pairs divided into low, medium and high production groups with 3831, 2991 and 3548 pairs respectively. The present study involves 1981 Guernsey pairs.

In singling out these reports it is well to compare the heritability estimates for over-all type rating which was 0.31 for Ayrshire and 0.24, 0.20, 0.18 for Holstein data and 0.28 in this study.

The estimates for rump were 0.32 (rump and thighs) for Ayrshires, 0.31, 0.27, 0.24 for Holsteins and 0.28 in this study for Guernseys.

The mammary system estimates were 0.21, 0.18 and 0.14 in the three Holstein groups and 0.24 for Guernseys in this study. For Ayrshires, udder size and shape 0.08, udder attachments 0.06 and udder teats, veins and quality 0.27.

Body capacity rated 0.15, 0.12 and 0.14 for Holsteins and 0.28 in this study. Ayrshires rated 0.31 for middle and loin which was the closest component for comparison.

Heritability estimates for feet and legs were 0.18, 0.16 and 0.12 for Holsteins and 0.18 in the Ayrshire data. Feet and legs were not included in this study because the method of reporting this trait was changed by the American Guernsey Cattle Club. It was originally recorded as feet and legs and later changed to a separate classification rating for hind legs and fore legs. Since all cows were not compared for the same trait, this component was omitted.

The most striking similarity of the three studies and the one with the most serious implications is that the heritability estimates for dairy character are all quite low. The estimates on Holsteins were 0.09, 0.09 and 0.06 for the three groupings and 0.16 was obtained in this report. These were the lowest estimates for any of the type components for both breeds. Dairy character is not listed among the Ayrshire type components but general quality is listed and the heritability estimate was 0.13, which, other than udder size and shape and udder attachments, is the lowest estimate for that breed.

These low heritability estimates indicate, genetically speaking, that the transmission of dairy character from generation to generation within herds is quite low. Since dairy character most nearly represents the function of dairy cattle, it seems ironical that it should have such a low heritability. Because of the low heritability value of this trait it would be expected that it would be extremely difficult to improve in breeding stock. From Table VII, however, it is seen that dairy character has the highest percentage of cows in the highest two type ratings (Excellent and Very Good) than any other trait for all Guernseys classified from 1947-1955. Actually, 21.1% of all Guernseys classified during this period rated Excellent in dairy character. Ten times more cows were rated Excellent in dairy character than were rated Excellent for over-all type.

If the highest percentage of cows received the higher classification ratings and the heritability estimate for the trait was the lowest, it would appear that either (1) error in measurement must have existed or (2) that the trait is greatly influenced by environment. Error in measurement might arise from differences in the ideal for this trait among different classifiers. If this last assumption is true, and if many of the dams and their daughters were rated by different classifiers, it partially would account for a lower heritability value.

The data of this study show that of the 1981 daughter-dam pairs classified 18.6% of the single dams and 16.7% of the daughters were

Excellent for dairy character and 44.8% and 45.0% were rated Very Good respectively. Fifty and six-tenths percent of the daughters and dams were rated by the same classifier. This same percentage holds for the other components of type, too. However, the fact that more cows had high ratings in dairy character yet the heritability estimate is lower indicates that more of the dams with high ratings had daughters with lower ratings and vice versa than was the case for the other traits with higher heritability estimates.

The 1441 single dams were sorted by dairy character rating and grouped according to the six classifications. The ratings of the daughters of each group of dams were then sorted for dairy character. The findings of this procedure are presented in Table XX.

TABLE XX

CLASSIFICATION RATINGS FOR DAIRY CHARACTER ON 1441 SINGLE DAMS AND THE SUBSEQUENT RATINGS OF THEIR DAUGHTERS

Dams		Number of Daughters Per Each Rating						Av. rating of daus.
Rating	Number	E	VG	D	A	F	P	
Excellent	268	76	132	47	11	2	0	2.00*
Very Good	645	98	303	182	52	9	1	2.34
Desirable	426	65	177	143	36	5	0	2.39
Acceptable	83	11	32	27	9	3	1	2.57
Fair	18	2	11	3	1	1	0	2.33
Poor	1	0	0	1	0	0	0	3.00

*The average rating score of the daughters was determined by giving a value of 1 for each Excellent; 2 for Very Good; 3 for Desirable; 4 for Acceptable; 5 for Fair and 6 for each Poor daughter.

From Table XX it is readily seen that there was a relatively small difference between average classification ratings of the daughters in dairy character, regardless of the widespread differences between their dams in this trait. Excluding the one dam with a Poor rating, there was a difference of only approximately one-half of one classification rating between the average score of the daughters of the dams with the five different ratings from Excellent down to Fair. The fact that dams with high ratings had daughters with low ratings, and vice versa, tends to illustrate the low heritability of this trait.

Estimates of Repeatability of Production

Estimates of repeatability of production were made from the 8533 lactation records of the 3202 cows in this study. The estimates were derived from an intra-class correlation using the analysis of variance shown in Chapter III, Methods and Procedure. The repeatability of milk and fat production of different records made by the same cow can be calculated as the ratio of the variance between cows to the total variance.

$$\text{(milk) Repeatability} = \frac{\sigma_c^2}{\sigma_c^2 + \sigma_e^2} = \frac{1179207.791}{2514384.559} = 0.47$$

$$\text{(fat) Repeatability} = \frac{2427.3520}{5972.1355} = 0.41$$

The repeatability estimate of 0.47 for milk production is in very close agreement with the 0.48 value obtained by Lush, Norton and Arnold (1950) on 1352 cows with D.H.I.A. records in Iowa. It is also in close agreement with the results of the study made by Stone, Rennie and Raithby (1955) in which they obtained a repeatability estimate of 0.50 for 2537 Holstein cows in Canada.

The estimate from the present study was above the 0.38 to 0.40 values reported by Johansson, (1950) on Swedish Red and White cattle. From the results of this study and those mentioned above it would seem that the repeatability value of 0.40 usually associated with dairy production records might be somewhat low as an estimate of repeatability for milk production.

The repeatability estimate of 0.41 for fat production from these data is in close agreement with the estimates of 0.40 by Plum (1935) made from records of 2316 Guernsey, Holstein and Jersey cows with 5860 records, the 0.40 reported by Lush, et al. (1950) from 6020 Holsteins, the 0.41 estimate made by Legates and Lush (1954) on 12,405 Jerseys with 23,330 records and the estimate of 0.43 reported by Lush et al. (1950) from 676 daughter-dam pairs with Iowa D.H.I.A. records. It also agrees with the estimate of 0.41 by Berry (1945) based on gross correlations but is higher than his estimate of 0.29 on an intra-herd basis. It is likewise higher than the values of 0.32 to 0.39 reported by Johansson (1950) on Swedish Red and White cattle.

The repeatability estimates of 0.52 for fat production reported by Stone et al. (1955) and those by Castle and Searle (1957) are above the estimates obtained in this study. The latter obtained estimates of 0.49 using 5,557 Jersey records made in New Zealand by 2,436 cows when corrected for age and on an intra-herd basis. When they added a correction for year effect they obtained an estimate of 0.61. They mentioned, however, that the cows in all herds were similarly managed in that the feed was nearly all supplied from roughages, mostly pasture and probably accounted for the higher estimates.

The results from the present study are in close agreement with the accepted value of 0.40 for repeatability of fat production usually associated with records made by cows in the United States.

Estimates of Repeatability of Type

From the 4172 classification ratings on the 3202 cows in this study, estimates of repeatability for type characteristics were obtained as follows:

General Appearance	- 0.40
Shoulders	- 0.38
Rump	- 0.52
Dairy Character	- 0.20
Body Capacity	- 0.33
Mammary System	- 0.41
Fore Udder	- 0.39
Rear Udder	- 0.34
Teat Placement	- 0.44
Over-all Rating	- 0.43

These estimates of repeatability for over-all rating (0.43) lie between the 0.34 estimate of Johnson and Lush (1942) and the 0.55 estimate of Hyatt and Tyler (1948). Although the number of cows in both of these studies was relatively small, 229 and 101 respectively, actually the number of cows in this study with two or more classification ratings is not too great as seen in Table XVI. However, repeatability in this study was estimated by means of an intra-class correlation using the analysis of variance, repeatability being the ratio of variance between cows to the total variance. In this sense, all cows contributed. Nevertheless, this study and the two above mentioned reports reveal what information is available on the subject.

The estimates of repeatabilities of the type components from the data of this study represent the first values of this nature to be reported. It is interesting to note that, in general, they do not vary greatly from the repeatability estimates for milk and fat production, the main exception being the estimate made from the ratings of dairy character which is by far the lowest estimate, being only 0.20. The estimates of 0.33 for body capacity and 0.34 for rear udder are also somewhat below 0.40. The estimates of the remaining type traits range from 0.38 (shoulders) to 0.44 (teat placement) with the exception of rump which went to a high of 0.52. The estimated repeatability for over-all type rating of 0.43 fits in quite closely with the 0.41 and 0.47 for fat and milk production respectively. Further studies of the repeatability of type classification break down sub-ratings are needed to compare with the above findings in order to develop reliable repeatability values for dairy cattle type in general.

Comparison of Heritability and Repeatability Estimates

Since the heritability estimates and the estimates of repeatability were both made from the same population, direct comparisons of the two can be made. In a sense, repeatability is also an estimate of heritability. It represents that fraction which includes the additively genetic portion of the variance, the variance due to dominance and epistasis, as well as any permanent environmental effects which are not transmissible to the offspring. Thus repeatability should set the upper limit of heritability. A comparison of the two sets of estimates may be found in Table XXI.

From this table it is seen that the repeatability estimate exceeds the corresponding heritability estimate in every case. It is of importance to note that both values are quite low for dairy character. This would indicate that one of the reasons for the low heritability value for this trait is due to its low repeatability. The lowered repeatability value would indicate a lack of ability of the same classifier to

TABLE XXI

COMPARISON OF HERITABILITY AND REPEATABILITY ESTIMATES MADE FROM THE SAME 3202 GUERNSEY COWS

Trait	Heritability Value	Repeatability Value
PRODUCTION		
Milk	0.26 & 0.28	0.47
Fat	0.28 & 0.30	0.41
TYPE		
General Appearance	0.24	0.40
Shoulders	0.20 & 0.22	0.38
Rump	0.28	0.52
Dairy Character	0.16	0.20
Body Capacity	0.28	0.33
Mammary System	0.24	0.41
Fore Udder	0.22 & 0.24	0.39
Rear Udder	0.26	0.34
Teat Placement	0.30 & 0.32	0.44
Over-all Rating	0.28	0.43

classify a cow the same each time and/or because of a greater difference of opinion in different classifiers scoring the same cow than was found for the other traits in this study. Naturally, this lowered repeatability would be reflected in the measure of transmission from dam to daughter and result in a lowered heritability value.

In the case of body capacity a relatively low repeatability (0.33) corresponded with a relatively high heritability (0.28) when the estimates of this study were considered alone. The heritability of shoulders was relatively low even though the repeatability was moderately high. This would indicate that even though the scoring of this trait in the same cow was comparatively consistent, the transmission of the same rating from dam to daughter was inconsistent.

Genetic Correlations

The genetic correlations presented in Table XXII were computed by the method outlined in the appropriate section under Methods and Procedure.

All combinations of milk and fat production and type components were correlated with one another.

The present estimate of 0.63 for the genetic correlation between milk production and fat production may be compared with 0.71 reported by Touchberry (1951), 0.72 by Tabler and Touchberry (1955), 0.72 to 0.80 by Mitchell et al. (1957). From these comparisons it seems that the present estimate is slightly lower than those reported for Holstein and Jersey cattle. This would indicate that milk production and fat production are not as closely associated genetically with each other within the same cow as the above mentioned breeds.

The present study shows no genetic correlation between production and over-all type. This is in agreement with the report by Touchberry (1951) who found no correlation between type rating and milk or fat production in Holsteins at the Iowa Station herd and Freeman and Dunbar (1950) who reported a negative genetic correlation between fat production and final type rating in Ayrshire cattle. Tabler and Touchberry (1955) reported genetic correlations in Jerseys of only 0.07 and 0.08 between over-all type rating and milk yield and fat yield respectively in their low group and 0.04 and 0.02 respectively in their high producing group.

In the present study there was no genetic correlation between production and the various type components. The only positive genetic correlation obtained was the 0.03 between milk yield and body capacity.

TABLE XXII

GENETIC CORRELATIONS BETWEEN MILK AND BUTTERFAT PRODUCTION AND TYPE RATINGS

	Milk	Fat	General Appearance	Shoulders	Rump	Dairy Character	Body Capacity	Mammary System	Fore Udder	Rear Udder	Teat Placement
Fat	.63										
General Appearance	-.28	-.28									
Shoulders	-.06	-.07	.38								
Rump	-.19	-.16	.73	.27							
Dairy Character	-.36	-.25	.76	.21	.60						
Body Capacity	.03	-.02	.63	.32	.35	.18					
Mammary System	-.14	-.06	.85	.10	.66	.42	.09				
Fore Udder	-.05	-.05	.74	.14	.59	.23	.13	.91			
Rear Udder	-.15	-.10	.73	.06	.60	.42	.16	.84	.54		
Teat Placement	-.12	-.11	.90	.25	.49	.50	.14	.84	.74	.51	
Over-all Type	-.15	-.14	1.08	.40	.78	.80	.43	.87	.78	.73	.82

The only positive genetic correlation between fat production and a type component in the report on Ayrshire cattle by Freeman and Dunbar (1955) was between fat production and shoulders and chest 0.22. Mitchell et al. (1957), however, reported positive genetic correlations between both milk and fat production and several type components in their data on Holstein cows. They reported genetic correlations of 0.61 to 0.82 between milk production and dairy character and 0.36 to 0.84 between fat production and dairy character. In their low and medium groups they obtained genetic correlations of 0.11 (low group), 0.23 (medium group) and 0.13 (high group) between milk production and mammary system. They also reported genetic correlations between milk production and body capacity in the medium and high groups but not so in the low groups. The genetic correlations between fat production and dairy character and body capacity were similar to those with milk production. They also reported small genetic correlations between milk and fat production and general appearance, feet and legs, and rump in at least one of their three groups. However, in no case was this true for all three groups.

In reviewing the genetic correlations between over-all type and the various type components, one finds that the highest correlation is between over-all type and general appearance in the present study. In fact, these appear to be perfectly correlated (1.08*). The genetic correlations of over-all type with other type components were: mammary system 0.87, teat placement 0.82, dairy character 0.80, rump 0.78, fore udder 0.78, rear udder 0.73, body capacity 0.43 and shoulder 0.40.

*Actually, a correlation cannot exceed 1.00. In this case the value 1.08 is too large and is probably due to sampling error.

These compare quite favorably, in general, with Mitchell et al. (1957) who reported genetic correlations between final type rating and general appearance 0.96 to 0.99, mammary system 0.89 to 0.97, body capacity 0.65 to 0.77, dairy character 0.33 to 0.87 and rump 0.65 to 0.76. They also reported the genetic correlation between final type rating and feet and legs to be 0.44 to 0.68. Freeman and Dunbar (1955) also found the highest genetic correlations with final type rating to be udder size and shape 1.07 and general quality 1.00. Their lowest value 0.55 was with feet and legs.

From the present study it is seen that shoulders are lowly correlated genetically with the other components of type. Rump, dairy character and body capacity are lowly correlated with one another with the exception of the 0.60 genetic correlation between rump and dairy character. Mammary system is naturally highly correlated with the components of the udder, but is only moderately (0.42) correlated with dairy character. It is interesting to note that rump is more highly correlated with mammary system and the udder components than is either shoulders, dairy character or body capacity.

In the study by Mitchell et al. (1957) body capacity and dairy character, feet and legs, and rump are considerably less correlated genetically with each other in general than they are with general appearance and final type rating.

CHAPTER V

APPLICATION OF RESULTS

The value of any study such as the one reported herein is dependent upon whether the results are applicable to breeding plans and selection methods for the class of livestock investigated. This study deals with dairy cattle and the selection of breeding stock takes place at various stages during the female's lifetime, and is dependent on several variables. First, the selection of which heifers will be allowed to reproduce and perform is usually dependent upon the performance of the dam, paternal and maternal sisters, and other close relatives. Second, whether the heifer remains in the herd as a cow will depend primarily on her own performance as a producer, beginning as a two year old. Third, in many cases later selections will be dependent upon the lifetime performance of the dam and/or the individual. Consequently, dairy cattle selection is somewhat of a continual process.

The amount of permanent improvement that may be accomplished by selection is dependent on the ability of the breeder to recognize the genetic differences between individuals. Since genotype cannot be measured directly, all selection must be based upon phenotypic expression. From the results of this and similar studies estimates of the intra-sire, intra-herd heritability of milk and fat production are on the order of 0.2 to 0.3. This implies that only 20-30% of the differences in production of cows in the same herd are due to transmissible inheritance. Consequently, the majority of the differences are non-hereditary in origin and may completely mask the true breeding value of the individual.

The rate of improvement that can be made in a herd is dependent upon (1) the heritability of the trait, (2) the selection differential, and (3) the genetic variability. The higher the heritability value of a trait, the more reliable is phenotype as an estimate of genotype. However, in dairy cattle where all productive traits appear to be of low-medium heritability, the rate of improvement should be expected to be slow unless the selection differential is extremely large.

Some of the differences that show up among cows may be due to the differences within cows. For example, even though milk and fat production records are adjusted there will be differences in the amount produced by the same cow for different lactations. These variations are largely due to environmental changes since the genotype of the cow remains unchanged throughout her lifetime. Every record will include some error due to the influence of environment. These errors may cause the record to be higher or lower than the true producing ability of the cow, therefore they tend to cancel out when the lifetime averaged record of the cow is used. By averaging all records of the same cow, the variability between cows is reduced. How much faith can be placed in basing selections on one record as compared to the average of several records depends upon how repeatable these records are.

According to Lush (1945), the most probable producing ability of the cow equals the herd average plus $\frac{nr}{1 + (n-1)r}$ times (her own average minus the herd average). Here, n is the number of records and r is the repeatability of the trait under consideration. The fraction $\frac{nr}{1 + (n-1)r}$ shows how much confidence is placed on the cow's own average as an indication of her real producing ability. If a cow has no record the herd average is the only estimate available of her producing ability. If she has only one record this is an indication of what she will produce in future lactations. However if repeatability is low, this indication is not very reliable and the herd average should still be given consideration. As the number of records of the individual cow increases, their average becomes more reliable as a measure of producing ability and there is less need for the herd average.

The use of lifetime averages reduces the amount of variation due to temporary circumstances and thereby makes selection more efficient. This is shown graphically by Lush (1945) in Figure 2.

It is thus seen that as n increases the heritability fraction increases. In the data of this study the estimates of heritability of milk and fat production in Guernsey cattle was 0.26 & 0.28 and 0.28 & 0.30 respectively when based on averaged records. These estimates were reduced to 0.18 and 0.19 when adjusted to a single record basis.

The heritability fraction is larger when averaged records are used and this increases the efficiency of selection. On the other hand variability is lessened which reduces the selection differential. As a result, according to Lush (1945) the net gain which can be attained with the same percentage of culling is that progress per generation when selection on an average of n records is $\frac{n}{1 + (n-1)r}$ times as much as if selections were made on only one record per animal. Table XXIII from Lush (1945), shows the values of this fraction for a few selected values of n and r.

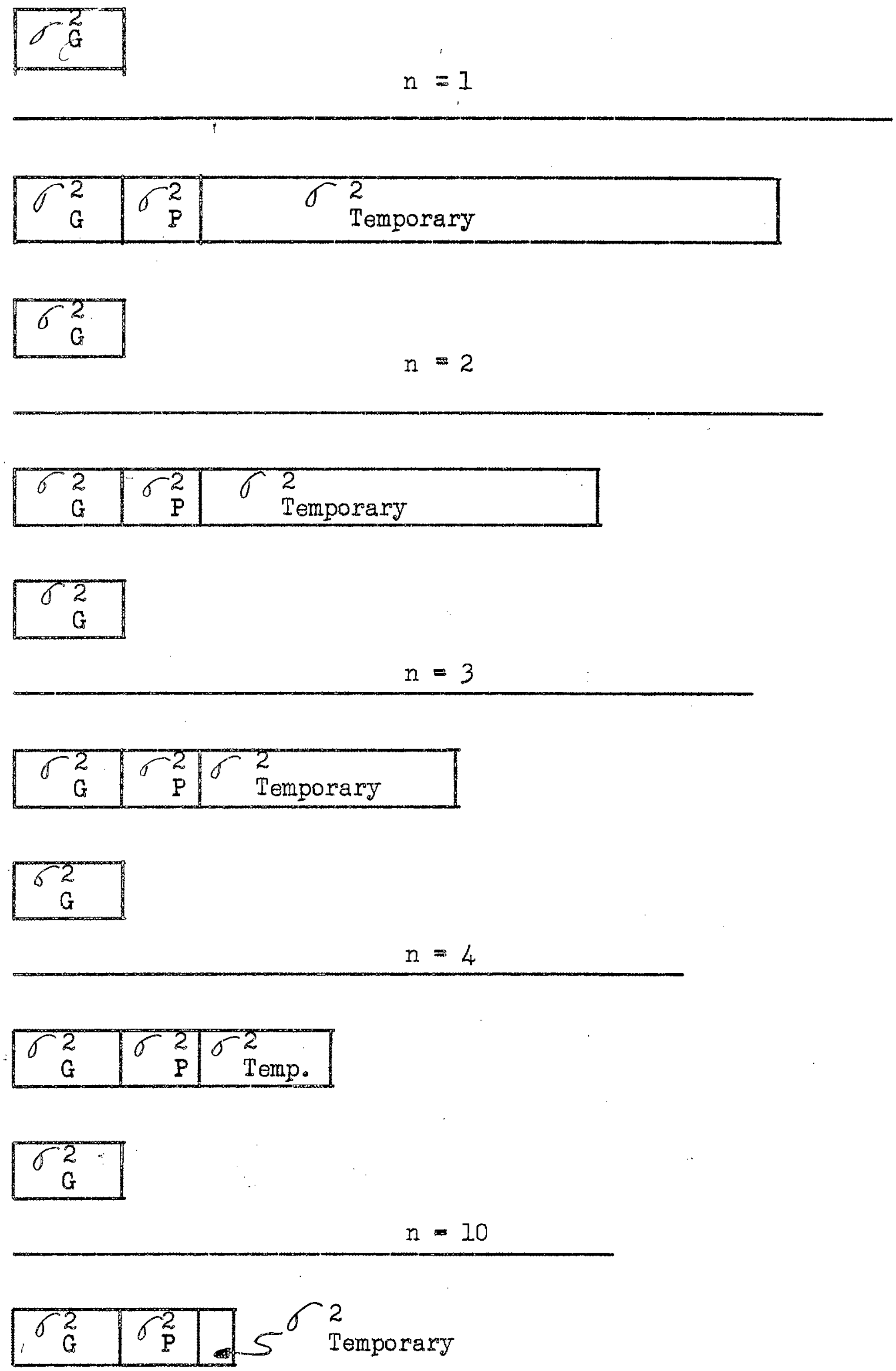

FIGURE 2. Diagram showing how the heritability of differences between averages increases as the number (n) of records in each average increases.

Figure 2 on the preceding page is drawn to scale for the case in which heritability of differences is .12 when n is 1 and repeatability of single records is .20. That means the case in which 80 percent of the variance between animals with one record each is caused by temporary environmental circumstances. σG^2 is the additively genetic variance between individuals. σP^2 is the variance due to permanent but nontransmissible differences between individuals. These include differences due to dominance deviations, epistatic deviations and to such effects of environment as are permanent for each animal but differ from one animal to another. As n increases, the variance due to temporary things falls to one nth of its value in single records (1).

TABLE XXIII

PROGRESS WHEN SELECTING BETWEEN ANIMALS WITH N RECORDS EACH AS A MULTIPLE OF THE PROGRESS WHICH COULD BE MADE BY SELECTING BETWEEN THEM WHEN THEY HAD ONLY ONE RECORD EACH (1).

	r								
	.1	.2	.3	.4	.5	.6	.7	.8	.9
2.....	1.35	1.29	1.24	1.20	1.15	1.12	1.08	1.05	1.03
3.....	1.58	1.46	1.37	1.29	1.22	1.17	1.12	1.07	1.04
4.....	1.75	1.58	1.45	1.35	1.26	1.20	1.14	1.08	1.04
6.....	2.00	1.73	1.55	1.41	1.31	1.22	1.15	1.10	1.04
10.....	2.29	1.89	1.64	1.47	1.35	1.25	1.17	1.10	1.05

[1]Lush, Jay L. 1945. Animal Breeding Plans. p. 174-175.

From this table it is readily seen that the averaging of many records is most useful for characteristics for which r is low. Considering the estimates of milk and fat production and most of the type components, the repeatability is high enough to place considerable confidence in the first record. The addition of more records would increase the accuracy of predicting future production and type ratings however. The greatest increase would occur by averaging in a second record. In the case of dairy character (0.20) each additional rating added to the average would greatly increase the accuracy.

The rate of improvement in traits of low heritability may often be increased by giving attention to the performance of close relatives as well as to the individual's own performance. In dairy data the use of the pedigree and the sire index has long been in practice. Lush (1955) pointed out that the progeny test is most needed for traits which cannot be expressed by one sex and are but slightly hereditary. He found that it required at least five offspring before the progeny test became a more accurate indicator of the parent's breeding value than the parent's own performance. In the case of dairy cattle where performance is sex limited, the progeny test is an important aid to selection particularly before the cow's own performance can be measured. Lush (1945) pointed out that the bases for estimating breeding value are pedigree, own performance and progeny test, and that as fast as some selection is practiced on one of them, the possibilities of further progress by additional selection on the same one diminishes and correspondingly increased attention should be paid to one of the other bases.

Legates and Lush (1954) undertook to derive an index for more accurate intra-herd selection for fat production by utilizing all the information on the individual cow and her close relatives. The statistics they used were (1) repeatability of fat records of the same cow (0.412), (2) correlation between fat records of maternal half sisters (0.073), (3) correlation between fat records of paternal half sisters (0.120) and (4) heritability of fat production (0.201). The index derived was $I = X_1 + 0.4X_2 + b_3X_3 + b_4X_4 + b_5X_5$ where X_1 and X_2 are the estimated real producing abilities of the cow and her dam respectively and X_3, X_4 and X_5 are the sums of the estimated real producing abilities of the cow's daughters, maternal sisters and paternal sisters; b_3, b_4 and b_5 were partial regression coefficients and values were given in a table. They calculated that the progress to be expected by use of the index for selections would generally be 1.10 to 1.15 times faster than by making selections on the cow's own performance.

The genetic gain which can be made by selecting for several traits simultaneously within a group of animals is the product of (1) the selection differential, (2) the multiple correlation between aggregate breeding value and the selection index and (3) genetic variability, according to Hazel (1943). He pointed out that the first of these may be very small due to the breeders carelessness and is limited by the rate of reproduction for each class of livestock, while the third is relatively beyond man's control. Therefore,the greatest opportunity of increasing the progress from selection is by insuring that the second is as large as possible.

The masking of genotypes by the confusing effects of environment, dominance and epistasis causes progress to be considerably less than it might be if exact genotypes could be known. In Hazel's study (1943) he reported that the indices constructed for swine would probably permit about 35 to 40 percent as much gain in selection as could be made with a perfect index in which the genotype of every animal was known.

The basic reason for a selection index is that variation between animals is much greater in net or total merit for _n_ characters than in any one of them. When a selection index is employed selection must be by truncation whereby all animals above a certain merit are retained and all animals below that level are culled or discarded.

Hazel and Lush (1943) pointed out that only one combination of selection intensities will allow maximum aggregate in any particular set of traits.

Harvey (1949) developed two selection indexes using Hazel's multiple regression technique in an attempt to determine maximum progress in both production and type in Jersey cattle. He included the heritability estimates, genetic correlations and phenotypic correlation in the indices and gave type one-third as much attention as fat production in one index and gave both characters equal attention in the second. Only information about the phenotypes of the dam and her daughter was considered in constructing these indexes. He reported that although selection on the basis of type alone should automatically bring about some improvement in production, it would require about 6 generations to obtain the improvement that selection on the basis of production would obtain in one generation. He presented regression coefficients for some frequently met combinations about a cow and her daughter and several of these combinations would yield progress about one-half as fast as if the exact Mendelian genotype of the cows were known.

In his data Harvey (1949) found the intra-herd phenotypic correlation between type and average fat production in the same individual to be 0.143 and the genetic correlation to be 0.181.

In the present study with Guernsey data there was no positive genetic correlation between type and production and the small values obtained were actually negative. This would indicate that the selection based on one of these characters would have no beneficial effect at all as to any progress gained in the other. Actually, there might even be a slight antagonistic effect in selection between the two. Since the negative values are small, however, it would seem more probable to say that there is no positive genetic correlation between type and production in Guernsey cattle from these data.

The breeder who places economic value on type and desires to make genetic gain in type and production simultaneously will have to give separate emphasis to both since they are not tied together genetically. The use of a selection index in this case should prove beneficial.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The main purpose of this study was to determine estimates of heritability, repeatability and the genetic correlations of milk and fat production and type characteristics for Guernsey cattle.

The data analyzed were from the files of the American Guernsey Cattle Club and contained 3202 Guernsey cows including 1981 daughter-dam pairs located in 239 herds in 39 different states. All cows had HIR records and were officially classified in the same herd.

All production records were adjusted to a mature equivalent basis, 305 days, twice-a-day milking, using the same conversion factors employed by the American Guernsey Cattle Club.

The average production of all cows used as dams and daughters was 8732 pounds milk, 4.88% butterfat and 426 pounds of butterfat. The dams average 8803 pounds of milk, 4.83% and 425 pounds of butterfat with an average of 3.41 records each. The daughters averaged 8688 pounds milk, 4.90%, 426 pounds butterfat and 2.39 records each.

The average over-all type rating score for the dams was 82.08% compared to 81.94% for the daughters.

Heritability estimates computed from the intra-herd, intra-sire regressions and correlations of daughter on dam and the repeatability estimates computed from an analysis of variance technique were as follows:

Characteristic	Repeatability Estimate	Heritability Estimate (Regression)	Heritability Estimate (Correlation)
Production			
Milk	0.47	0.26	0.28
Fat	0.41	0.30	0.28
Type			
General Appearance	0.40	0.24	0.24
Shoulders	0.38	0.20	0.22
Rump	0.52	0.28	0.28
Dairy Character	0.20	0.16	0.16
Body Capacity	0.33	0.28	0.28
Mammary System	0.41	0.24	0.24
Fore Udder	0.39	0.22	0.24
Rear Udder	0.34	0.26	0.26
Teat Placement	0.44	0.30	0.32
Over-all Rating	0.43	0.28	0.28

The heritability estimates for milk and fat production above were computed from averaged production records per cow. When reduced to a single record basis,the estimates were 0.18 and 0.19 for the milk and fat respectively.

From these data there appeared to be no genetic correlation of milk and fat production with type characteristics.

Milk production and fat production were genetically correlated 0.63 with each other.

The genetic correlation between over-all type rating and breakdown type components were as follows: General appearance 1.08, shoulders 0.40, rump 0.78, dairy character 0.80, body capacity 0.43, mammary system 0.87, fore udder 0.78, rear udder 0.73 and teat placement 0.82.

The genetic correlations of all possible combination of type and production characteristics were presented in table form.

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APPENDIX

APPENDIX A

LOCATION BY STATES OF THE 239 HERDS IN THE STUDY

State	State Number	Number of Herds in Study
Alabama	1	1
Arizona	2	4
California	4	7
Colorado	5	2
Connecticut	6	6
Delaware	7	1
Florida	9	1
Idaho	11	5
Illinois	12	10
Indiana	13	15
Iowa	14	11
Kansas	15	4
Kentucky	16	1
Maine	18	2
Maryland	19	6
Massachusetts	20	5
Michigan	21	15
Minnesota	22	11
Mississippi	23	1
Missouri	24	1
Nebraska	26	2
New Hampshire	28	2
New Jersey	29	7
Nex Mexico	30	3
New York	31	12
North Carolina	32	5
North Dakota	33	2
Ohio	34	23
Oklahoma	35	1
Oregon	36	7
Pennsylvania	37	16
Rhode Island	38	1
South Carolina	39	1
South Dakota	40	3
Utah	43	1
Vermont	44	5
Virginia	45	9
Washington	46	20
Wisconsin	48	10

Total states involved = 39

Total herds involved = 239

APPENDIX B

ALPHABETICAL LIST OF OWNERS OF THE 239 HERDS USED IN THIS STUDY

George G. Aaronson	Columbus, New Jersey
Charles P. Adkins	Saint Henry, Ohio
C. N. Adams	Mankato, Minnesota
F. S. Allen & Glenn W. Allen	Delavan, Illinois
Ray R. Allen	South Hero, Vermont
J. William Antilla	Longview, Washington
University of Arizona	Tucson, Arizona
Alfred W. Austin	Scottsdale, Arizona
Avondale Mills	Sylacauga, Alabama
Robert L. Baker	Bremen, Indiana
Stanley Baker	Lyndonville, New York
Lloyd Balderston III	Colora, Maryland
C. E. Bash & Company, Inc.	Huntington, Indiana
Bassett Estates Inc.	Pottersville, New Jersey
Harry C. & Gordon C. Bates	Clarkston, Michigan
Hazel H. Beach	London, Ohio
B. L. Beaudette	Birmingham, Michigan
Edward Becker	Dundas, Minnesota
Stanley C. Bengston	Sebastapol, California
W. H. Bertholf	Wichita, Kansas
W. J. Biever & Son	Schuylkill Haven, Pennsylvania
P. B. Blackwelder (Stanford & Blackwelder)	Mocksville, North Carolina
Raymond Bockbrader	Pemberville, Ohio
Richard Boeckman	Sherwood, Oregon

W. O. Boehle & Son	Lawrence, Kansas
Roy K. Boggs	New Plymouth, Idaho
J. Frank Bradley & Son	Franksville, Wisconsin
Clyde H. Breneman	Lancaster, Pennsylvania
John A. Breneman	Willow Street, Pennsylvania
Livings Brindle	Jamestown, Indiana
Wilbur C. Brown	Waterloo, Iowa
Mr. & Mrs. W. J. Bublitz	Olathe, Kansas
Albert Buchanan	Milford, Indiana
Laurance M. Buck	Baldwin, Maryland
S. McLeon Buckingham	Watertown, Connecticut
Ralph A. Burnham	Macomb, Illinois
Stuart E. Butterfield	Dolliver, Iowa
Sidney E. Butts	Morton, Washington
E. F. Calhoun	Grants Pass, Oregon
California State Poly College	San Luis Obispo, California
J. Thomas Carman	Glen Rock, Pennsylvania
Cedar Brook Farms Inc.	Bellville, Ohio
A A C B Cheney Trustees	Litchfield, Connecticut
William C. Child	Woodstock, Connecticut
Clemson Agriculture College	Clemson, South Carolina
Francis Clinton	Watkins, Minnesota
John A. Cohrs, Jr.	Tiskilwa, Illinois
Howard H. Colby	Romeo, Michigan
Colorado A & M College	Fort Collins, Colorado
John & Julia Corning	Kennebunk Port, Maine
Frank & Margaret A. Couzens (Betty Couzens Maloney & Madeleine C. Yaw)	Birmingham, Michigan

J. Ellis Croshaw, Jr.	Wrightstown, New Jersey
R. R. Crowgey	Wytheville, Pennsylvania
The Denison Engineering Company	Powell, Ohio
Boynton Dodge	Ellensburg, Washington
John M. Dunlop	Petersburg, Virginia
Leon O. Dunning	Delton, Michigan
Lawrence R. Dutcher	Port Byron, New York
Arthur P. Edison	Grand Rapids, Michigan
Hugh Ellsworth	Holt, Michigan
Herbert V. Estran	Bow, Washington
James W. Ewing, Jr.	Tucson, Arizona
Howard G. Farnsworth	Planada, California
W. E. Feind	Hazel, South Dakota
Arthur Fisher	Hilliards, Ohio
Carl Fortkamp	Coldwater, Ohio
Elmer F. Frahm	Frankenmuth, Michigan
Boyd Fullerton	New Brunswick, New Jersey
Howard Gallagher	Oeney, Illinois
W. M. Garst	Roanoke, Virginia
Giacomini Bros.	Fortuna, California
John J. Glessner	Ipswich, Massachusetts
Harry Goebel & Son	Andrews, Indiana
Homer Goss	Lewiston, Minnesota
Alfred & Muriel Graves & Henry & Karl Luitje	Hale, Michigan
Joseph J. Griesemer, Anthony T. Yorkman & Marguerite Yorkman	Billings, Missouri
Warren G. & Charlotte Grimes	Urbana, Ohio

C. E. Hacklander	Naperville, Illinois
H. J. Haga	Bristol, Virginia
F. A. Hall	Corunna, Indiana
Laurence D. Hansen	South Valley, New York
H. C. Hanson	Barnum, Minnesota
Earl E. Hardin	Bow, Washington
M. G. Harnden	Sedro Woolley, Washington
Gordon L. Harris	Royal Oak, Maryland
Woodrow Haugen	Barron, Wisconsin
Daniel H. Heller	Feura Bush, New York
Leroy H. Hersey	Edgewater, Maryland
E. D., R. E., Lloyd E., & T. M. Hershberger	Newton, Kansas
Walter Hickok	Ostrander, Ohio
Hillcrest Dairy, Inc.	Auburn, Massachusetts
W. D. Hoard & Sons Company	Fort Atkinson, Wisconsin
Herbert Hochmuth	La Valley, Wisconsin
Andrew J. Hoff	New Windsor, Maryland
Bert Holman	Baldwin, Wisconsin
Lyle Hunsberger	Grand Rapids, Michigan
University of Illinois	Urbana, Illinois
Iowa State College	Ames, Iowa
Ruth Jackson	Ashville, New York
W. L. Johnson, Jr.	Washington, Connecticut
Carl E. Kehret & Sons	Austin, Minnesota
J. Ray Keiser	Whitedeer, Pennsylvania
Kern City Union High School	Bakersfield, California
M. D. Keisling	Ft. Atkinson, Wisconsin

Clarence O. Knight	Guilford College, North Carolina
W. B. Knott	Dinwiddie, Virginia
Charles W. Kuhn	Basil, Ohio
F. H. Kuhn	Middleton, Idaho
Harry & Robert H. Lage	Davenport, Iowa
Ray Lange & Son	Garnavillo, Iowa
Don & Harriet Largent	Ceres, California
Harvey Laymon & George J. Lybarger	Mt. Vernon, Ohio
James A. Leamer, Jr.	Dunlo, Pennsylvania
Paul S. Logan & Sons	Lafayette, Indiana
L. L. Lombard & R. J. Hobson	Klamath Falls, Oregon
John E. Long	Monongahela, Pennsylvania
John E. Lovgreen	East Stanwood, Washington
Clyde E. & Donald Marsh	Middletown, Ohio
University of Massachusetts	Amherst, Massachusetts
G. A. McCulloch & R. J. Hobson	Amity, Oregon
W. T. McClelland & Son	Tucson, Arizona
George A. McKesson	Richmond, Virginia
H. P. McCullough	North Bennington, Vermont
Carl Meline	Burley, Idaho
Sam F. Meisenhelder	Dover, Pennsylvania
William J. McMonigle	Yelm, Washington
Mentor Farms	Volga, South Dakota
Allen D. Meyer	West Fargo, North Dakota
Meyer Bros.	Olympia, Washington
Michigan State University	East Lansing, Michigan
Mighigan State University Kellogg Farm	Hickory Corners, Michigan

Leo H. Miller & Metzger Bros.	South Whitley, Indiana
Milton Miller	Rockford, Illinois
University of Minnesota North Central Experiment Station	Grand Rapids, Minnesota
Mississippi State College	State College, Mississippi
A. R. Moody & Son	W. Brattleboro, Vermont
C. M. Morelli	Petaluma, California
Paul B. & Leon E. Morgan	Cresco, Iowa
R. C. B. & T. B. Morton	Prospect, Kentucky
Edward S. Moseley	West Newbury, Massachusetts
Helen R. C. Motley	Ontario, New York
Vernon D. Mudgett	Sterling Junction, Massachusetts
Richard L. Muehling	Cissna Park, Illinois
C. E. Munns & Sons	Elk River, Minnesota
Edgar S. Murray	Albuquerque, New Mexico
C. Faye Myers	Grand Blanc, Michigan
H. A. W. Myrin	Phoenixville, Pennsylvania
R. S. & S. P. Nanninga	Albuquerque, New Mexico
North Carolina State College of Agriculture	Raleigh, North Carolina
University of Nebraska	Lincoln, Nebraska
University of New Hampshire	Durham, New Hampshire
North Dakota Agriculture College	Fargo, North Dakota
Harold Oelker	Urbana, Ohio
Ohio State University	Columbus, Ohio
Oklahoma State University	Stillwater, Oklahoma
James P. Olson	Mount Vernon, Washington
Edgar Ophoven	Kimball, Minnesota

W. H. Ostermeier & Sons	Midland, Ohio
Arnold M. Pancratz	Dubuque, Iowa
C. Allen Patrick	Salem, New Jersey
Ethel Payne	Millerton, New York
G. Harold Peck	Schuylerville, New York
Thomas M. & Miss Laurel Peck	Geneva, Illinois
Pennsylvania State University	University Park, Pennsylvania
Brees & Perrin	DeKalb Junction, New York
R. H. & W. C. Perry	Ira, Vermont
Herman & Walter Pfeiffer	Arlington, Nebraska
Floyd R. Phillips	Rupert, Idaho
Elmer E. & Ike Pierson	Ravenna, Michigan
William L. Pleiness	Scottville, Michigan
Henry L. Pletcher	Nappanee, Indiana
Claude A. Potts	Lebanon, Indiana
L. W. Power	Burlington, Washington
Donald W. Pratt	Glidden, Iowa
Joe Pritzl	Fruitland, Idaho
Purdue University Agriculture Experiment Station	Lafayette, Indiana
O. R. Reed & Son	Delaware, Ohio
William Reed & L. J. Lancaster	Sequim, Washington
Harry Reese	Prescott, Iowa
University of Rhode Island	Kingston, Rhode Island
Mr. & Mrs. Earl H. Richart	Montesano, Washington
E. Jay & L. V. Rinehart	Galion, Ohio
Mr. & Mrs. Wilbert Roark	Boulder, Colorado
James B. & M. B. Robertson	Paoli, Pennsylvania

Charles E. Roberts & Harland & Keith Knight	Arena, Wisconsin
C. A. Robinson & Son	Sequim, Washington
Everett E. Robinson	Grant Pass or Wilderville, Oregon
Roeschley Bros.	Flanagan, Illinois
Edson E. Roush	Racine, Wisconsin
Fred Rudat, Jr.	Brownsmead, Oregon
Walter Schmid & Son	Sarasota, Florida
Julian L. Schwabacker	Bethlehem, Connecticut
Robert M. Scott	Bear Lake, Pennsylvania
Gustave Selander & Sons	Sherwood, Oregon
Zerna Sharp & Arthur Boicourt	Thorntown, Indiana
Earl H. Shearer & Sons	Centralia, Washington
V. K. Sherburne & Neil R. Govin	Rusk, Wisconsin
Eldon E. Sigrist	West Salem, Ohio
T. Edgar Sikes	Greensboro, North Carolina
Albert G. Simms	Albuquerque, New Mexico
Ross & Rosa M. Simon	Nova, Ohio
Herbert A. Snow	Park City, Utah
J. Herbert Snyder	Union Bridge, Maryland
Ward Snarr	Siler City, North Carolina
Joseph Solms & Sons	Marion, Indiana
South Dakota State College	Brookings, South Dakota
O. C. Spencer	, Washington
Roger Spies	Dover, Ohio
Douglas R. Stanton	Greenville, New York
Ira Stauffer	Lynden, Washington
H. O. Stouder	South Whitley, Indiana

Clarence E. Summers	Bow, Washington
Sunnyhill Farms, Inc.	Imperial, Pennsylvania
G. O. Swales	Johnson, Washington
S. P. Tague	Sequim, Washington
Estate H. B. Tuttle	Middlebury, Connecticut
Jesse E. Tuttle & Son	West York, Illinois
Upham Downs Farm	Middletown, Delaware
William L. Vaughan	Hallowell, Maine
Vermont Agriculture Experiment Station	Burlington, Vermont
Virginia Polytech Institute	Blacksburg, Virginia
Bernhard Wachholz & Sons	Stockton, Minnesota
Ralph H. Wagner	Barron, Wisconsin
W. B. Warner & Sons	Red Lion, Pennsylvania
State College of Washington	Pullman, Washington
Otis Weaver	Goshen, Indiana
Webb Bros.	Hamilton, Ohio
John F. Weeks	Laconia, New Hampshire
Ronald Wetherwax	Wyoming, New York
Harold B. Wilson	Caledonia, New York
Herman E. Winkler, Paul Hardy & John Dickerson	Lebanon, Indiana
Mr. & Mrs. John L. Winston	Gladstone, New York
Elmer J. Wirt & Son	Lewiston, Minnesota
University of Wisconsin	Madison, Wisconsin
Kermit L. Witmer	Dalmatia, Pennsylvania
S. S. Yates	Dorset, Vermont
Mr. & Mrs. W. L. Young	Franklin, Vermont
C. Edward & M. K. Zimmerman	Morristown, Pennsylvania
Henry Zumfelde	Wauseon, Ohio

APPENDIX C

INTRA-HERD, INTRA-SIRE VARIANCES AND COVARIANCES OF ALL TRAITS FOR DAMS AND DAUGHTERS

	(Dams)	Milk	Fat	General Appearance	Shoulders	Rump	Dairy Character	Body Capacity	Mammary System	Fore Udder	Rear Udder	Teat Placement	Overall Type
(Daughters)		1,951,458	3,454	.5340	.8490	.8946	.6014	.6599	.6667	.9374	.7544	.8844	.5571
Milk	1,631,887	2,440,610	7,690	-18.21	-11.80	39.45	-46.05	29.65	-46.31	-47.16	-23.42	-39.36	-31.92
Fat	3,793	6,627	521.0	-.4503	-.1741	1.924	-1.397	.4714	-1.241	-.8007	-.8918	-1.827	-.8660
General Appearance	.5177	-52.116	-2.770	.0639	.0102	.0612	.0442	.0476	.0517	.0490	.0490	.0653	.0612
Shoulders	.7054	-4.044	-.8041	.0463	.0844	.0197	.0150	.0333	.0279	.0320	.0238	.0252	.0483
Rump	.8544	-105.591	-4.428	.0701	.0354	.1252	.0551	.0340	.0660	.0741	.0694	.0422	.0687
Dairy Character	.5905	-30.929	-1.048	.0388	.0116	.0367	.0463	-.0054	.0122	.0027	.0075	.0197	.0238
Body Capacity	.6503	-19.786	-.2313	.0497	.0245	.0408	.0286	.0939	0	.0061	.0095	.0061	.0361
Mammary System	.6646	7.959	.4789	.0714	-.0116	.0680	.0395	.0150	.0816	.0748	.0830	.0762	.0626
Fore Udder	.7878	30.663	.0156	.0701	-.0054	.0599	.0286	.0184	.0905	.1020	.0605	.0898	.0687
Rear Udder	.7810	-23.472	-.4959	.0687	-.0129	.0653	.0503	.0218	.0694	.0497	.1014	.0483	.0605
Teat Placement	.7980	-4.165	-.0238	.0986	.0265	.0823	.0585	.0245	.0973	.0810	.0694	.1306	.0878
Overall Type	.5898	-10.027	-.872	.0918	.0177	.0871	.0605	.0374	.0776	.0707	.0694	.0796	.0789

VITA

Ernest Roy Berousek

Candidate for the Degree of

Doctor of Philosophy

Thesis: ESTIMATES OF HERITABILITY, REPEATABILITY AND GENETIC CORRELATIONS OF PRODUCTION AND TYPE OF GUERNSEY CATTLE

Major Field: Animal Breeding

Biographical:

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Education: Attended Camel Creek and Mustang Valley Rural Grade Schools near Oklahoma City; graduated from Stonewall Jackson Junior High School, Oklahoma City, 1932; graduated from Capitol Hill High School, Oklahoma City, 1935; received the Bachelor of Science degree from Oklahoma State University with a major in Dairy Production, in May, 1941; received the Master of Arts degree from the University of Missouri, with a major in Dairy Husbandry, in August, 1942; completed requirements for the Doctor of Philosophy degree in May, 1959.

Professional experience: Employed as herdsman and manager of large purebred Guernsey herds in Oklahoma and Illinois, 1942-45; Superintendent United States Dairy Experiment Station, Woodward, Oklahoma; 1944-45, Oklahoma State University, December 1946 to date.

Professional organizations: American Dairy Science Association; The American Genetic Association; American Association for the Advancement of Science; Oklahoma Academy of Science; Phi Sigma; Gamma Sigma Delta and Alpha Zeta.