GENETIC RELATIONSHIPS BETWEEN MILK, FAT, SNF, AND PROTEIN

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
William Wayne Wunder
1964

GENETIC RELATIONSHIPS BETWEEN MILK, FAT, SNF, AND PROTEIN

By

William Wayne Wunder

AN ABSTRACT OF A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Dairy

1964

Approved Lon D. McGilliard

ABSTRACT

GENETIC RELATIONSHIPS BETWEEN MILK, FAT, SNF, AND PROTEIN

by William W. Wunder

The reduced energy requirements of today's living have resulted in increased demand for the nonfat portions of milk and less demand for the fat. To change the composition of milk toward more SNF and less fat requires studying variation, environmental and genetic influences, and genetic and environmental interrelationships.

Milk, fat, and SNF from 6179 records by 3437 Holstein cows in 51 herds, 1188 records by 831 Guernsey cows in 15 herds, and 201 records by 145 Jersey cows in four herds were studied. Of these cows, 380 Holsteins with 646 records, 98 Guernseys with 181 records, and 88 Jerseys with 144 records were also tested for protein. SNF content was measured by Watson lactometer for Holsteins and Jerseys and by Golding plastic beads for Guernseys. Formol titration was used to determine protein content.

The coefficients of variation were larger for yields of fat, SNF, and protein than for the percentages of these traits. Among the percentages, percent fat had the largest coefficient of variation while SNF percent had the smallest.

Multiplicative factors were derived to adjust the records for differences in ages of cows at calving. SNF percent decreased more with age than did fat percent.

When the average SNF production for the lactation was computed for each month of calving over a two year period, there was interaction in the ranking of the months between years within the same age group and between age groups within the same year.

Rolling five-month herdmate groups were analyzed to determine the proper adjustment for numbers of herdmates. No genetic differences were found between adjusted herdmate averages.

Phenotypic correlations were from 0.75 to 0.99 among the yields and from 0.37 to 0.61 among the percentages. The correlations between the percent of a component and the yield of any other component or of milk were generally between 0.2 and -.3.

Repeatabilities from intracow correlations ranged from 0.63 to 0.84 for percentage of fat and SNF and from 0.40 to 0.54 for yield of milk, fat, and SNF. The repeatabilities for protein percent ranged from 0.26 to 0.66 while for yield of protein they ranged from 0.23 to 0.38.

From regression on dam within sire of 1067 Holstein daughters with SNF records and 125 Holstein daughters with SNF and protein records, heritabilities were: milk 0.17, fat 0.14, SNF 0.14, protein 0.06, fat percent 0.62, SNF percent 0.54, and protein percent 0.36. Genetic correlations among yields ranged from 0.48 between milk and protein to 1.0 between SNF and protein. Among the percentages of the components the values ranged from 0.4 to 0.75, while between the percent of a component and yield of milk or of any other component the correlations ranged from -.5 to 0.18. The corresponding values from paternal sister correlations were larger for heritabilities and generally larger for genetic correlations. Heritabilities and genetic correlations were also derived for Guernseys and Jerseys.

Selection for higher component percentages is an inefficient way to increase yields of the components because percentages of the components have the smallest coefficients of variation and the genetic correlations among percentages and yields are smaller than those among yields. When selection is on one trait, selection for milk results in the largest increase in SNF yield while causing minute decreases in SNF and protein percentages. SNF yield is preferred to protein as a selection criterion because of more gain in milk, SNF, and protein yield and no increase in fat percent. When the goal of selection can be specified, selection on combinations of traits should be as effective or more effective than selection on single traits.

GENETIC RELATIONSHIPS BETWEEN MILK, FAT, SNF, AND PROTEIN

By

William Wayne Wunder

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Dairy

1964

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to Dr. Lon D. McGilliard for his encouragement and friendly guidance during the investigation of the problem and his helpful suggestions during the writing of the thesis.

The encouragement of Dr. Clinton E. Meadows was also appreciated.

The help of Mr. A. J. Thelen and his associates of the DHIA-IBM tabulating center in machine procedures and Mr. Marion Spohn of the Computer Center staff in programming made the work much easier.

Most of all, I am grateful to my wife, Beth, for her patience, encouragement, and support.

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

In earlier times in the United States foodstuffs were in shorter supply, more physical labor was required in earning a living, and more walking was done. Fats were favored because they were an excellent source of energy, and butter and cream were the most prized among them. The portion of the population engaged in manual labor as a means of livelihood has decreased greatly since the turn of the century. With this has come a change in eating habits to less fats and fewer calories in the diet. Medical science has shown that the deposition of excess fat in the body from overeating can shorten the life span. As a result of these changes, foods with lower caloric values and higher protein content are now demanded by a large segment of the population. Among these foods are milks with high protein and SNF (solids-not-fat) content and little fat. To give added impetus to the change taking place, studies of milk flavor by Hillman et al. (1962) and Wahid-Ul-Hamid and Manus (1960) have shown milks with lower fat content and higher SNF content may be more acceptable in flavor to the consumer than whole milk.

Because milk is such an important part of the human diet, increased study and discussion of the possibilities and methods of altering the composition of milk toward more SNF and protein and less fat have taken place in recent years. To change the composition of milk toward higher SNF and protein content necessitates investigating several possible tools. Among these possible methods are changes in feeding, changes in breeding, and alteration of the composition at the milk processing plant. This study is concerned with the possibilities and methods of changing milk composition through breeding.

To use breeding as a method of changing milk composition requires measuring the hereditary variation in each constituent of milk and the genetic and phenotypic interrelationships between the constituents. The production record of a cow is considered to be the result of the working together of her genotype and the environmental and managerial factors in effect. Because all of these forces act together on the record, the true genetic value of the cow is never known. In order to estimate better the cow's genetic ability, as many of the environmental factors as possible need to be studied and their effects removed. Because the intensive study of milk composition from a genetic standpoint is relatively new, few data are available in the literature on correcting records for environmental effects, on hereditary variation in the traits, or on genetic correlations between the traits.

This study will attempt to determine: (1) the effects of age at calving and season of calving on the components of milk and how to adjust the records for these effects; (2) how to use the average of herdmates to adjust for the environmental and managerial level of the herd; (3) the amount of phenotypic variation in the traits; (4) the repeatability and heritability of the traits; (5) the phenotypic and genetic correlations between the traits; and (6) how this information might be used to increase yield of SNF and protein.

REVIEW OF LITERATURE

To alter the composition of milk requires studying variation among cows and breeds of cows, the effects of environment, genetic and environmental interrelationships between the components of milk, the nature of the genetic factors controlling milk composition, and how all these things best might be used to achieve the desired goal.

Differences Among Breeds

An early reference to variation between breeds is the summary of Turner (1936). Due to the paucity of numbers and the amount of variability within breeds, his figures may not depict accurately the breed averages. In a later review which was based on more animals for most of the breeds, Armstrong (1959) listed averages which showed lower SNF content for Guernseys and Holsteins and a somewhat higher fat content for Ayrshires and Jerseys than did Turner.

Recent investigations by Erb and Manus (1961) and the Ontario Department of Agriculture (1963) were extensive and are listed in Tables 1 and 2. The studies showed generally lower values than did Turner for SNF and protein content with the exception of protein content for Jerseys in the Ontario study. Wilcox et al. (1959) found 8.95 percent SNF for Guernseys and 8.48 percent SNF for Holsteins. Gaunt et al. (1962) found values close to those listed in Tables 1 and 2 for Ayrshires, Guernseys, Holsteins, and Jerseys. Their values for percent of fat, SNF, and protein were lower than those listed by Turner (1936). Combs et al. (1955) found slightly larger values than Tables 1 and 2 for all constituents in Guernseys, higher fat percent for Jerseys, and essentially the same values for all constituents in Holsteins.

Table 1. Differences between breeds in the composition of milk. Erb and Manus (1961)

Breed	Tests	Cows	Fat	SNF	Protein
Guernsey	2,548	450	4.82	9.06	3.44 (1203 tests)
Holstein	19,687	2,100	3.71	8.50	3.13 (9688 tests)
Jersey	4,057	700	5.35	9.45	3.84 (939 tests)

Table 2. Composition of milk by breeds. Ontario (1963)

Breed	No. lactations	Fat	SNF	Protein	Lactose
Guernsey	326	4.78	8.99	3.65	4.84
Holstein	331	3.76	8.48	3.23	4.74
Jersey	329	5.23	9.31	4.02	4.80
Ayrshire	296	3.86	8.64	3.37	4.77

Age of Cow

Authors who have studied the effects of age of the cow at freshening on composition of milk have noted a decrease in the percentage of fat, SNF, and protein with increasing age. However, they have not agreed on the magnitude and importance of the decrease. Johnson *et al.* (1961) found a gradual though irregular decrease in both fat and SNF content with increasing age for Holsteins and Jerseys in 243 records from 1935-1942 and 1953-1958. The figures studied were simple averages of the monthly results obtained during the first 305 days of lactation. The decline from the first lactation to the seventh or later lactations was 0.13 percent fat and 0.26 percent SNF for Holsteins and 0.36 percent fat and 0.21 percent SNF for Jerseys.

Declines of 0.45 percent SNF for Holsteins and 0.33 percent SNF for Guernseys from the first lactation to the seventh or later lactations were reported by Wilcox _et_ _al_. (1959). The lactation records were obtained over four years and included 310 Holstein records and 110 Guernsey records. Linear, quadratic, and cubic constants represented the effects of age on SNF content. Sargent and Legates (1964) reported linear and quadratic effects for age at freshening jointly accounted for 1.8 and 11.8 percent of the variance in fat and SNF percentages.

In a study involving 423 Dairy Shorthorn lactations in England, Bailey (1952) showed a decline of 0.45 percent SNF from the first to the sixth lactation and a decline of 0.26 percent fat from the first to the seventh or later lactations. Except for the seventh lactation the decline in SNF percent was linear while fat percent showed an irregular decline from the fourth through the seventh lactation.

Differences in age caused 13 percent of the total variance among lactation averages for SNF percent and three percent for protein percent in a study by von Krosigk _et_ _al_. (1960). A study using a larger number of cows, 814 Ayrshire lactation records obtained over a three and one-half year period, was made by Waite _et_ _al_. (1956). The results in Table 3 show definite downward trends in all constituents with increasing age of the cow. The decline in crude protein was less than for fat or SNF. Waite felt this was due to a slight rise in the non-casein nitrogen concentration in the milk of older cows which partly compensated for the fall in casein content. Robertson _et_ _al_. (1956) found the percentage of variation between lactations due to the influences of age on milk constituents to be: milk yield 27%, fat percentage 5%, SNF percentage 18%, and crude protein percentage 4%. The Ontario Progress Report (1963) stated that SNF percentage has a sharper decline with increasing age than does fat or protein percentage. The decline due to age for all constituents appeared more pronounced in the Guernseys and Jerseys than in the Ayrshires and Holsteins.

In considering the results of the studies on age of the cow, one must be cognizant that selection very likely was practiced on the populations that were analyzed. Some of the observed changes in age could be due to selection for total pounds of milk or fat. The review of the phenotypic correlations of milk with its constituents will show that culling the lowest milk producers from among the older cows could account for a decline in the percentage of the milk constituents.

Table 3. The effect of age of the cow on milk composition. Waite *et al.* (1956)

Lact. No.	No. of cows	Yield (gal.)	Fat %	SNF%	Crude protein %
1	187	730	4.11	9.01	3.36
2	138	792	4.06	8.92	3.35
3	108	846	4.03	8.82	3.28
4	102	907	4.02	8.84	3.30
5	75	879	3.90	8.72	3.26
6	65	887	3.91	8.74	3.30
7	44	961	3.94	8.67	3.25
8	45	885	3.82	8.65	3.23
9 or more	50	889	3.92	8.67	3.23

Season of Calving

The range of differences found by Waite et al. (1956) between lactations starting in different months was small compared with the standard deviation of lactation records. In a study including cows from 33 herds over a three and one-half year period, Robertson et al. (1956) found the correction for month of calving made trivial reductions in variance for all the traits. The actual reductions were: milk yield 1%, fat percentage 1%, SNF percentage 1%, and crude protein percentage 2%.

Yearly Differences

An analysis of variation of monthly SNF percentages for each cow covering a wide span of years showed significant differences among years for Holstein and Jersey cows in a study by Johnson et al. (1961). Differences for SNF percent among four years were reported by Wilcox et al. (1959).

Variation Among Cows

The amount of variation in a trait has an important bearing on how much that trait can be changed by selection. Generally, SNF percent and protein percent show less variation than does fat percent.

Robertson et al. (1956) in 814 records from 500 Ayrshire daughter-dam pairs found the following standard deviations for the dams: fat percent 0.33, SNF percent 0.27, and protein percent 0.17. The corresponding values for the daughters were: 0.37, 0.26, and 0.20.

The standard deviations of fat percentage determined by Gaunt et al. (1962) ranged from a low of 0.30 on Ayrshires to 0.51 on Jerseys. There was less variation in the protein and SNF percentages with the standard deviations ranging from 0.18 to 0.23 for protein and 0.25 to 0.31 for SNF. There were only 37 Brown Swiss lactations in this study while the number for the other breeds ranged from 129 to 150.

In an analysis of 50 Holstein lactations Slack *et al*. (1962) computed standard deviations for fat percent, SNF percent, and protein percent of 0.35, 0.36, and 0.21.

The standard deviation of protein percent of 0.20 reported by von Krosigk *et al*. (1960) is in good agreement with the values listed previously. Standard deviations for fat percent of 0.36 and 0.46 have also been reported by Lankamp (1959) and von Krosigk *et al*. (1960). These values fall within the range of the values reported previously as do the standard deviations of SNF of 0.28 and 0.22 reported by these same two authors. Combining the components of variance from the paper of Wilcox *et al*. (1959) yields 0.28 as the standard deviation of SNF percent for mixed Holsteins and Guernseys.

Repeatabilities

Gaunt *et al*. (1963) found repeatabilities of 0.67, 0.89, 0.81, and 0.88 for milk yield, fat percent, protein percent, and SNF percent. These are correlations between two consecutive lactations for 48 cows of mixed breeds. Differences between breeds would inflate the variance between cows and cause these correlations to be larger than would be the case if they had been computed within breeds. The repeatability of SNF percent for a lactation with the SNF percent of any other lactation was 0.61 in a study by Wilcox *et al*. (1959). Slightly lower repeatabilities for fat, protein, and SNF percents of 0.58, 0.41, and 0.52 were reported by von Krosigk *et al*. (1960). No repeatabilities for yields of SNF or protein were available in the literature.

Phenotypic Correlations

The phenotypic correlations between milk yield and the percentage of the major constituents are generally small or negative, while between the percentages of the major constituents they are usually 0.3 or greater. Studies on the phenotypic correlations between yields of the various components have been few in number.

The results of a study of the percentages of constituents involving 814 Ayrshire cows made by Robertson *et al*. (1956) are shown in Table 4. Correction for age was made on all of the productive traits.

Table 4. Intra-herd phenotypic correlations between milk and components. Robertson *et al*. (1956)

	Milk	% Fat	% SNF	% Protein	% Casein	
Milk		-.03	0.10	-.03	0.00	
% Fat	-.14		0.33	0.37	0.43	Dams
% SNF	-.18	0.40		0.77	0.84	
% Protein	-.26	0.42	0.81		0.92	
% Casein	-.20	0.43	0.87	0.93		

Daughters

Gaunt *et al*. (1962) studying the five dairy breeds reported the following ranges for phenotypic correlations: fat percent with protein percent 0.49 to 0.65, fat percent with SNF percent 0.53 to 0.73, fat percent with milk -.10 to -.25, protein percent with SNF percent 0.57 to 0.79, protein percent with milk -.10 to -.45, and SNF percent with milk -.11 to -.25.

In Holsteins Johnson (1957) reported phenotypic correlations of -.06 and -.08 for lactation milk yield with lactation fat percent and SNF percent, respectively, while the corresponding values from Jerseys were -.29 and -.11. Further disagreement is shown in the work of Kliesch et al. (1959) who found -.35 to be the phenotypic correlation between milk yield and percent fat. Phenotypic correlations between fat percent and SNF percent of 0.36, 0.38, 0.63, 0.84, and 0.54 have been reported by Johnson (1957), Slack et al. (1962), Rimm et al. (1962), and von Krosigk et al. (1960). The 0.79 and 0.92 also reported by Johnson (1957) indicate that pounds of fat and pounds of SNF for the lactation are closely correlated phenotypically in Holsteins and Jerseys.

Genetic Correlations

The genetic correlations between the percentages of milk constituents appear to be positive and 0.4 or larger while those between milk yield and the percentages of the constituents appear to be small and, in many instances, negative. The reports of genetic correlations are scarce and in some cases are based on few animals. The work of Robertson et al. (1956) based on 500 daughter-dam pairs of Ayrshires is probably the most complete. Their results are presented in Table 5. Johnson (1957) reported -.58 and -.29 as the genetic correlation between milk and percent fat in Holsteins and Jerseys, respectively, while O'Connor (1959) reported -.31. The genetic correlations of milk with SNF percent of 0.14, 0.39, and -.18 reported by Johnson (1957) and O'Connor (1959) again differ from those of Robertson et al. (1956). The 0.58 and 0.53 reported by von Krosigk et al. (1960) for daughter-dam and

Table 5. Genetic correlations between milk and components. Robertson <u>et</u> <u>al</u>. (1956)

	Milk	% Fat	% SNF	% Protein
Milk		-.01	-.02	0.22
% Fat			0.46	0.48
% SNF				0.94

paternal sister analyses and the 0.40 reported by O'Connor (1959) are in good agreement with those of Robertson <u>et</u> <u>al</u>. (1956) for the genetic correlation of fat percent with SNF percent. Johnson (1957) agrees less with values of 0.35 and 0.72. The genetic correlations of fat percent with protein percent of 0.78 and 0.62 were given by von Krosigk <u>et</u> <u>al</u>. (1960) and are somewhat larger than the value of Robertson <u>et</u> <u>al</u>. (1956). However, for the genetic correlation between SNF percent and protein percent, they are in good agreement with the values of 0.94 and 0.90 reported by von Krosigk <u>et</u> <u>al</u>. (1960).

Heritabilities

Several estimates of the heritabilities of milk constituents are listed in Table 6. Other than the values of Lankamp (1959) the estimates are in close agreement, considering differences in sample size, breeds, and locations.

Table 6. Heritabilities of milk constituents.

Breed*	% Fat	SNF	% SNF	% Protein	Source of data
A	0.32		0.53	0.48	Robertson *et al*. (1956)
A	0.52		0.65		O'Connor (1959)
G & H			0.57		Wilcox *et al*. (1959)
H	0.72		0.83	0.76	Lankamp (1959)
H	0.36	0.36	0.36		Johnson (1957)
J	0.28	0.34	0.34		Johnson (1957)
H	0.63		0.45		Sargent and Legates (1964)
...	0.52		0.53		von Krosigk *et al*. (1960)

* A, Ayrshire; G, Guernsey; H, Holstein; J, Jersey

Conclusions

More studies involving large numbers of animals are needed to ascertain more accurately the magnitude of the genetic and environmental factors affecting the SNF in cow's milk. In too many instances the results are in poor agreement or few estimates have been made.

SOURCE OF DATA

The 7565 SNF records from 13 counties in lower Michigan were 1188 Guernsey records from 15 herds, 6179 Holstein records from 51 herds, and 201 Jersey records from four herds. Two of the Jersey herds were inbred experimental herds owned by Michigan State University. During part of this study, these two herds were fed and milked as one herd. With few exceptions the Guernsey herds were tested for SNF by the Golding plastic bead method while the Watson lactometer was used for the Holsteins and Jerseys. Other than for two Guernsey, two Jersey, and 16 Holstein herds, the SNF testing was done in the field by DHIA supervisors. The training of the DHIA supervisors in the use of the Watson lactometer and the Golding plastic beads and the accuracy of these tests has been reported previously by Lamb *et al*. (1960, 1961).

Protein determinations were made for 144 Jersey records, 181 Guernsey records, and 646 Holstein records by the formol titration method. All protein testing was done under laboratory conditions and was on cows that were also being tested for SNF by the Watson lactometer. The Jersey and Guernsey records were from two herds each, while the Holstein records were from cows in seven herds.

The samples taken for SNF and protein testing were from the same milkings as the milk weights and samples for the DHIA test. The milk weights and butterfat tests from the cow's DHIA record were used to compute the percent SNF and pounds of SNF and protein. Totals for milk and butterfat and the butterfat percent for the lactation were taken from the cow's DHIA lactation record. Percentages of SNF and protein for the lactation were determined by dividing the yield of the component by the yield of milk for the lactation.

Where a monthly test was missed because of an abnormal condition of the cow, a lost or spilled sample, or a sample turning sour before it was tested, a weighted average of the previous month and the following month was used for the missing SNF or protein test. This weighted average was computed by dividing the total SNF or protein for these two months by the total milk for these same two months. If either of these tests was not available to compute this average, the test of the closest available month was used for the missing SNF or protein test.

Only lactation records in which five or more actual tests for SNF or protein were made were used in this study. Fifty-one percent of the records had nine or more actual tests. The percentages with eight, seven, six, or five actual tests were 15, 14, 11, and 9, respectively. Most of the records with less than nine tests were records in progress when the experimental testing began.

All records terminated by the cow going dry and meeting the requirements of five actual tests were used regardless of the number of days in milk. All records going beyond 305 days were cut off at 305 days.

The records used in this study followed calvings from August, 1958, to March, 1962.

METHODS AND RESULTS

Effects of Age at Calving

The review of literature noted that yields of the constituents increase to maturity while the percentages of the constituents decrease with increasing age of the cow. These changes due to age could have some effect on the phenotypic correlations between yield of a component and percent of that component or any other component. In daughter-dam comparisons variations in the age at calving usually occur between single records on the daughters and their dams. If the records are not corrected for age, some of the changes due to age could be interpreted as genetic effects which would bias the estimates of heritability and genetic correlation.

The changes with age at calving for Holstein cows are shown in Table 7 by the averages for yield of milk, fat, and SNF. Similar results for protein yield are also listed. Factors to adjust for age were constructed from ratios of the mean of the six to eight-year-old group to each of the other means. The factors for milk and fat were in close agreement with each other and with the factors of Kendrick (1955), while factors for yield of SNF indicated less change with age.

Results of a similar investigation of the percentages of fat, SNF, and protein are shown in Table 8. In Holsteins, fat and SNF show a gradual, steady decline in percent with increased age with an indication of a sharper decline, both absolutely and in proportion to the mean, occurring in percent SNF. The changes in percent and yield of fat and SNF with increasing age are in agreement with each other since the trait

Table 7. Changes in production with age at calving in Holsteins

A. Milk, fat, and SNF

Age (Yrs.)	Milk	Fat	SNF	No. records
< 2	9,571	354	837	54
$\geq 2, < 3$	11,042	407	966	821
$\geq 3, < 4$	11,779	433	1,020	707
$\geq 4, < 5$	13,099	481	1,122	523
$\geq 5, < 6$	13,457	493	1,149	398
$\geq 6, < 7$	13,799	499	1,166	299
$\geq 7, < 8$	13,664	495	1,152	215
$\geq 8, < 9$	12,858	458	1,079	129
$\geq 9, < 10$	13,179	477	1,115	77
≥ 10	13,608	484	1,135	83

B. Milk and Protein

Age (Yrs.)	Milk	Protein	No. records
< 2	12,730	453	14
$\geq 2, < 3$	14,200	473	187
$\geq 3, < 4$	14,100	462	150
$\geq 4, < 5$	14,440	465	103
$\geq 5, < 6$	13,550	451	72
$\geq 6, < 7$	14,070	466	44
$\geq 7, < 8$	14,630	477	31
$\geq 8, < 9$	13,800	457	19
≥ 9	15,960	508	26

Table 8. Changes in composition of milk with age at calving.

A. Holsteins

Age (Yrs.)	No. records	Fat %	SNF %	No. records	Protein %
<2	54	3.70	8.75	14	3.56
≥2, <3	821	3.69	8.75	187	3.33
≥3, <4	707	3.68	8.66	150	3.28
≥4, <5	523	3.67	8.57	103	3.22
≥5, <6	398	3.66	8.53	72	3.33
≥6, <7	299	3.62	8.45	44	3.31
≥7, <8	215	3.62	8.43	31	3.26
≥8, <9	129	3.56	8.39	19	3.31
≥9, <10	77	3.62	8.46	26*	3.18
≥10	83	3.56	8.34		

* ≥9 yrs.

B. Guernseys

Age (Yrs.)	No. records	Milk	Fat %	SNF %	Protein %
<2	1	10,280	4.86	8.95	3.89
≥2, <3	45	9,760	4.87	9.27	3.72
≥3, <4	44	9,290	5.07	9.36	3.88
≥4, <5	37	9,260	4.98	9.26	3.64
≥5, <6	23	9,210	4.73	9.16	3.59
≥6, <7	17	9,110	4.59	8.95	3.58
≥7, <8	7	9,800	4.33	8.88	3.62
≥8, <9	6	10,110	4.24	8.77	3.46
≥10	1	7,480	3.88	8.29	3.48

C. Jerseys

Age (Yrs.)	No. records	Milk	Fat %	SNF %	Protein %
<2	3	8,190	5.50	9.45	4.32
≥2, <3	65	8,410	5.52	9.55	3.93
≥3, <4	33	8,270	5.50	9.55	3.89
≥4, <5	16	9,230	5.66	9.59	4.21
≥5, <6	11	8,790	5.22	9.45	4.10
≥6, <7	6	9,670	5.31	9.55	4.19
≥7, <8	4	10,100	5.17	9.56	4.09
8	1	10,890	4.96	9.18	4.32
>10	5	9,030	4.58	9.35	4.01

showing the smallest decrease in percent has the largest increase in yield. Protein percent shows an irregular pattern which is probably due to the fewness of numbers. Guernseys and Jerseys also show irregularity of change in all components which, again, is probably due to the size of the sample. Waite et al. (1956) found a steady decline in percentage of fat, SNF, and protein with increasing age. Fat percent showed a relatively greater decline than percent SNF or protein. Conversely, the Ontario Progress Report (1963) stated the decline in percentage with increasing age was sharper for SNF than for fat or protein. Other studies, Bailey (1952), Johnson et al. (1961), and Wilcox et al. (1959), showed an unsteady decline in percentages with aging.

Because the factors for SNF yield were similar to those for yield of fat and milk, the factors of Kendrick (1955) were chosen to adjust the yield of milk, fat, SNF, and protein for differences in age of cow at calving.

Age correction factors for percentages of fat, SNF, and protein derived from the Holstein data are shown in Table 9. The factors are close to those that can be derived from the data of Waite et al. (1956) and Putman et al. (1944). Although the data give evidence that the decline in SNF percentage is sharper than the decline for fat or protein percent, more data would be needed to ascertain these differences accurately. Therefore, the factors in Table 9 were used to make adjustments for age in percent SNF and protein in the three breeds. These factors were also suitable for adjusting the fat percent for age, but this adjustment was not made.

Table 9. Age correction factors for percentages of fat, SNF, and protein. Derived from Holstein data in Table 8.

Age (months)	Correction Factor
< 36	0.96
36 to 47	0.97
48 to 59	0.98
60 to 71	0.99
72 to 97	1.00
≥ 98	1.01

The appropriateness of adjustments for age depends upon the causes of the decline in the percent of the constituents with age. If the smaller percentages in the older cows are the result of selection for higher milk yield, which is negatively correlated with the percentages of the constituents, then age adjustment is in error. If this decline is a function of the aging process, then correcting for age should increase estimates of heritability and genetic correlations among the percentages of these constituents.

Breed Averages and Standard Deviations

Averages and standard deviations for every trait in each breed are listed in Table 10. The means are representative of well-managed herds except that the proportions of SNF and protein are slightly lower because of the adjustment for age.

Standard deviations for yield of milk and fat are similar to the generally accepted ones. Holsteins had the largest standard deviations for yields of milk and its components while those from Guernseys and

Table 10. Averages and standard deviations within herds of milk and components. (305 - 2x - ME)

Trait	Mean	Std. Dev.	Coef. of Variation	No. Records	Herds
Guernsey					
Milk	10,382	1665	16	1190	15
Fat	502	81	16	1190	15
SNF	949	163	17	1190	15
% Fat	4.84	.43	9	1190	15
% SNF	8.92	.52	6	1190	15
Prot.	348	60	17	181	2
% Prot.	3.73	.23	6	181	2
Holstein					
Milk	13,657	2288	17	6179	51
Fat	499	84	17	6179	51
SNF	1,178	197	17	6179	51
% Fat	3.66	.30	8	6179	51
% SNF	8.44	.29	3	6179	51
Prot.	467	108	23	646	7
% Prot.	3.37	.22	7	646	7
Jersey					
Milk	8,803	1598	18	201	4
Fat	470	81	17	201	4
SNF	835	149	18	201	4
% Fat	5.38	.51	9	201	4
% SNF	9.24	.26	3	201	4
Prot.	345	64	19	144	2
% Prot.	4.03	.25	6	144	2

Jerseys were similar to each other in size. With the exception of protein yield in Holsteins, the coefficients of variation for yields were of like magnitude, both within and between breeds.

The coefficient of variation for fat percent was larger than those for percent of SNF or protein in all three of the breeds. Percent protein had a larger coefficient of variation than did percent SNF in Holsteins and Jerseys, while in the Guernseys these two coefficients were the same. Little difference exists between breeds in the coefficient of variation of fat percent and protein percent, but for percent SNF the Guernseys have the largest coefficient of variation.

Variation of fat percent in Holsteins was low, the variation in Guernsey SNF percent was high, and the variation for protein percent in each breed was high as compared with the studies of Gaunt _et al_. (1962), Robertson _et al_. (1956), Slack _et al_. (1962), von Krosigk _et al_. (1960), and Wilcox _et al_. (1959).

Season of Calving and Yield of SNF

A study of the Holstein data was undertaken to determine if differences in production of SNF due to season of calving existed and whether an adjustment for such differences would be appropriate. Two consecutive 12 month periods, December 1958 to November 1959 and December 1959 to November 1960, were studied. Actual test day production of SNF for each cow was adjusted for the average test day production of the herd for the 24 month period to remove differences between herds. Production for the first test day was missing when the cow was not tested within 42 days after calving. Other causes of missing test days were spilled samples, spoiled samples, unidentified samples, sick cows, termination of the record by the cow going dry before the tenth test day, and lactations in progress when the project was initiated.

Cows under 36 months of age at calving were a much larger part of all cows calving during the base milk period than they were of those calving during the rest of the year. For the first year, cows less than 36 months of age at calving accounted for 3 percent of the total cows calving in May and 48 percent of the total cows for July. Because of this unequal distribution of ages, the cows were divided into three groups by age at calving. The ages used were: less than 36 months, 37 to 47 months, and 48 months or over. These groups were further separated into those that had a complete complement of tests, 10 test days, and those that had an incomplete complement of tests, less than 10 test days.

The data were analyzed by the Method of Unweighted Means (Snedecor, 1956) with 12 seasons of calving and 10 months of lactation. Classification by year, age, and number of test days resulted in 12 different groups, each of which was analyzed separately. The statistical model used was

$$y_{ijk} = u + s_i + m_j + sm_{ij} + e_{ijk}$$

where y_{ijk} is the deviation of production on test day from the average of the herd for the k^{th} cow in the j^{th} month of lactation begun in the i^{th} month. u is the mean of deviations from herd averages for all test days for that age, year, and completeness group, s_i is the effect due to calving in the i^{th} month, m_j is an effect due to the j^{th} month of lactation, and e_{ijk} is an effect peculiar to the k^{th} cow in the j^{th} month of lactation begun in the i^{th} month. It was assumed that s_i, m_j, and sm_{ij} were random variables, uncorrelated, with zero expectation and variances σ^2_S, σ^2_M, and σ^2_{SM}. The e_{ijk} are assumed to be independent, normally distributed, with mean of zero and variance σ^2.

The analysis of variance from one group is presented in Table 11. These results are typical of those for all 12 groups.

Table 11. Analysis of variance in SNF yield by season of calving and month of lactation. (Cows less than 36 months at calving with 10 test days and calving between Dec. '58 and Nov. '59)

Source of variation	d.f.	M. Sq.	Individual Basis
Subtotal	119	.51	
Season of Calving	11	.53	31.80
Month of Lactation	9	4.69	1159.25
Interaction	99	.12	.75
Intra-cell	2350	.36	.36

In the other analyses, the mean squares on an individual basis for month of lactation were from 20 to 100 times as large as those for season of calving, while the ratios of mean squares for season of calving to intra-cell mean squares were at least 20 and as large as 80. Ten of the 12 groups had significant, $p \leq .05$, interaction terms. The two groups that did not were from the second 12 month period and were cows 36 to 47 months of age at calving with 10 tests and cows less than 36 months at calving with less than 10 tests.

Seasonal calving created great disparity in the number of cows that calved each month. Each year between 50 and 54 percent of the cows calved during the months of August through November.

When the average test day production for the lactation was computed for each month of calving, there were differences in the ranking of the months between years in the same age group and between age groups in the same year. The months ranked differently when the cows with 10 test days were compared with cows that had less than 10 test days. In those analyses of cows with less than 10 tests, the number of cows with production on the different test days varied widely with the numbers for the tenth month being especially small. There was no precise way of testing for differences between means by month of calving because of the unequal numbers of cows calving in each month.

Ignoring interactions and unequal numbers and grouping the means by month of calving yielded the results shown in Tables 12, 13, and 14. In each of the 12 groups the average for each month of calving was corrected for the average of the age group to which it belonged to remove differences in production due to the age of the cow. All averages in Table 12 are averages weighted by the number of cows while those in Tables 13 and 14 are unweighted. The number of cows represented in Table 13 is approximately 150 percent of the number in Table 12. In both Table 12 and 13 there is a difference in the ranking of the months between the two years. Table 14 shows the combined results of Tables 12 and 13 and gives an estimate of the effect of each month of calving on the lactation total. As a group, the cows calving during May through September averaged 62 lb. less of SNF per lactation than did cows calving in the other months of the year.

To what extent cows might be selected to calve in the different months of the year is unknown. If selection does exist, then it is inaccurate to ascribe all the differences between the average production of cows that calve in different months to the environmental factors that might be involved. It would be possible that, among cows milking in their second or later lactations, cows calving in June through October were less selected because of a need for a large volume of base milk and

Table 12. Deviation of SNF production per day within herds and ages by month of calving. (Cows with 10 test days)

Calving Month	Daily Average	Calving Month	Daily Average	Combined Average	No. of Cows
Dec. '58	.13	Dec. '59	.10	.11	125
Jan.	.13	Jan.	.14	.13	117
Feb.	.00	Feb.	.03	.02	90
Mar.	.11	Mar.	.20	.18	72
Apr.	.08	Apr.	.11	.08	85
May	-.06	May	-.17	-.11	61
June	-.21	June	-.07	-.14	91
July	-.01	July	-.02	-.01	251
Aug.	-.11	Aug.	-.07	-.10	316
Sept.	-.18	Sept.	.00	-.11	216
Oct.	.12	Oct.	-.09	.08	132
Nov. '59	.13	Nov. '60	-.09	.09	116

Table 13. Deviation of SNF production per day within herds and ages by month of calving. (Cows with less than 10 test days)

Calving Month	Daily Average	Calving Month	Daily Average	Combined Average
Dec. '58	.22	Dec. '59	.06	.14
Jan.	.12	Jan.	.02	.07
Feb.	.21	Feb.	.02	.12
Mar.	.06	Mar.	.03	.05
Apr.	.13	Apr.	.02	.07
May	-.14	May	-.07	-.10
June	-.03	June	-.15	-.09
July	-.32	July	-.04	-.18
Aug.	-.11	Aug.	-.08	-.10
Sept.	-.21	Sept.	.00	-.10
Oct.	.00	Oct.	.09	.05
Nov. '59	.07	Nov. '60	.09	.08

Table 14. Deviation of SNF production per day within herds and ages by month of calving. (All cows combined)

Calving Month	Daily Average	305 Day Deviation
Dec.	.12	38 lb.
Jan.	.12	38 lb.
Feb.	.08	24 lb.
Mar.	.11	35 lb.
Apr.	.08	24 lb.
May	-.10	-32 lb.
June	-.11	-35 lb.
July	-.11	-33 lb.
Aug.	-.10	-31 lb.
Sept.	-.10	-32 lb.
Oct.	.06	19 lb.
Nov.	.09	27 lb.

cows calving during the rest of the year are culled more severely. By this reasoning, the cows under 36 months of age at calving should be a relatively unselected group because few of them will have made a previous record. This group of cows is a much smaller sample than the older cows or cows of all ages grouped together, and the possibility of chance creating differences in the real producing ability between cows calving in different months increases. Of the cows analyzed that were under 36 months of age at calving, no trend could be found to indicate that calving in certain months results in lower or higher production. Because of the interactions and uncertainties, no high or low seasons were established.

Adjusting Herdmate Averages

An increasingly frequent practice is to express production records as deviations from the average of the records of herdmates. Since herdmates have calved at a similar time of the year in the same herd and, in most cases, been exposed to many of the same environmental conditions, the average of the herdmates should estimate well the environmental level at which the record was made. However, herdmate groups that differ genetically from the average or heterogeneous environmental conditions within herds may limit the accuracy and usefulness of this estimate.

In this study the herdmates of a cow included all of the cows in the herd other than paternal sisters, that calved in the same month and year as the cow or in the preceding or following two months. This system of grouping the herdmates was chosen because consistent seasonal effects were not found, part of the environmental changes with time would be accounted for, and using five months includes larger numbers of herdmates than using fewer months. Paternal sisters calving in the same month and year have identical herdmate groups, while paternal sisters calving in adjacent months would, on the average, have 80 percent of their herdmates in common. This overlapping of the herdmate groups may result in a reduction of the genetic differences and the variance between herdmate groups.

Table 15 summarizes the analysis of herdmate groups. The model used was $y_{ij} = u + h_i + c_{ij}$ where y_{ij} is the lactation record of the j^{th} cow in the i^{th} herdmate group. u is the breed average, h_i is the deviation of the i^{th} herdmate group from the breed average, and c_{ij} is the amount the j^{th} cow differs from the average of the i^{th} herdmate group. The h_i and c_{ij} are assumed to be random variables, uncorrelated, and to have zero means and variances σ^2_H and σ^2_C. Components of variance were determined by Method I (Henderson, 1953). The correlation between herdmates is

$$r = \frac{\sigma^2_H}{\sigma^2_H + \sigma^2_C}$$

The regression of a cow on her herdmate average is $b = \dfrac{\sigma^2_H}{\sigma^2_H + \dfrac{\sigma^2_C}{n}}$

where n is the number of herdmates. The predicted average of future herdmates from n present herdmates is $u + b(\bar{y}_{i.} - u)$, where $\bar{y}_{i.}$ is the average of the n herdmates. Hereafter, this predicted average will be called the adjusted herdmate average. Using the adjusted herdmate

Table 15. Components of variance for milk and milk constituents from analysis of herdmate groups. (Yields in 10 lb.)

Trait	Between ($\hat{\sigma}^2_H$)	Within ($\hat{\sigma}^2_C$)	$\frac{\hat{\sigma}^2_C}{\hat{\sigma}^2_H}$
<u>Guernsey</u>			
Milk	5,656	27,738	4.9
Fat	15	66	4.4
SNF	37	265	7.1
% Fat	.0138	.1842	13
% SNF	.0089	.2654	29
Prot.	5	37	7.5
% Prot.	.0114	.0527	4.6
<u>Holstein</u>			
Milk	27,123	52,352	1.9
Fat	41	71	1.7
SNF	229	390	1.7
% Fat	.0225	.0930	4.1
% SNF	.0153	.0847	5.5
Prot.	45	116	2.6
% Prot.	.0145	.0484	3.3
<u>Jersey</u>			
Milk	750	25,547	34
Fat	1	66	125
SNF	5	222	47
% Fat	.0220	.2631	12
% SNF	.0047	.0652	14
Prot.	3	40	12
% Prot.	.0146	.0633	4.4

average should overcome some of the sampling error caused by small numbers of cows in the herdmate groups.

For ease in computation the adjusted herdmate average was computed by

$$\frac{n\,\bar{y}_{i.} + \frac{\hat{\sigma}^2_C}{\hat{\sigma}^2_H}\,\hat{u}}{n + \frac{\hat{\sigma}^2_C}{\hat{\sigma}^2_H}}$$

since $\hat{b} = \frac{n}{n + \frac{1 - r}{r}}$

In Holsteins and Guernseys, the component of variation among groups of herdmates was generally larger in proportion to the component within group for yield of the traits than for the percentages of the traits.

The components of variation among herdmate groups from the Guernsey and Jersey breeds were smaller fractions of the total than previously reported for milk and fat yield by Legates and Lush (1954), Lush and Straus (1942), Plum (1935), Pirchner and Lush (1959), Specht and McGilliard (1960), and Burdick and McGilliard (1963). Because groups of herdmates may have several cows in common with other groups of herdmates and most herds contributed many groups of herdmates, the component between groups of herdmates is likely to be smaller than the variation between herds. Most of the Jersey cows were in two herds owned by the University. While they were handled as two separate breeding herds, they were under the same manager and during part of the study were housed, fed, and milked together. Guernseys might have had a larger herdmate component had there been more than 15 herds involved. These 15 herds had also been selected to participate in a sire testing program. This forced added environmental and genetic similarity.

The percent of total variation accounted for by the herdmate component in yield of milk and fat in Holsteins is in agreement with previous work.

A method commonly used to compute the adjusted herdmate average for yield of milk or fat is $\frac{n \bar{y}_{i.} + \hat{u}}{n + 1}$ which is based on the assumption that $\frac{\sigma^2_C}{\sigma^2_H} = 1.0$. This investigation and those of Burdick and McGilliard (1963), Legates and Lush (1954), Lush and Straus (1942), Plum (1935), Pirchner and Lush (1959), and Specht and McGilliard (1960) indicate the value of $\frac{\hat{\sigma}^2_C}{\hat{\sigma}^2_H}$ is closer to 2.0 than to 1.0.

Protein percent in all three breeds and fat percent and SNF percent in Holsteins had 15 percent or more of the total variation due to groups of herdmates. Eight percent or less of the total variation in Guernsey and Jersey fat percent and SNF percent was due to the herdmate component. Burdick and McGilliard (1963) found herds accounted for 11 percent of the total variation in fat percent in Holsteins and 10 percent in Guernseys. Reasons for the differences between these results and those of Burdick are unexplained other than for those reasons given for yield of milk and fat and sampling errors.

Regression of Cow on Adjusted Herdmate Averages

Robertson and Rendel (1954) proposed that the intrasire regression of AI daughters on the average of the herd to which they belong be used to estimate genetic differences between herds. Henderson *et al.* (1954) have proposed the intrasire regression of daughter on herdmates or contemporary herd averages as an appropriate correction of each record for the effects of the herd in which it was made. The United States Department of Agriculture is using this correction for the daughters of sires in its sire summaries. Estimates of this regression have been 0.6 or higher in reports by Henderson *et al.* (1954), Henderson and Carter (1957), Pirchner and Lush (1959), and Johansson (1960) with the recent estimates near 0.9, Van Vleck (1964).

The intrasire regressions of the cow on her adjusted herdmate average are summarized in Table 16. Most of the regression coefficients are 0.96 or larger. The unusual values for percent fat and SNF in Guernseys, percent SNF in Holsteins, and yield of fat and SNF in Jerseys occurred when the $\hat{\sigma}^2_C/\hat{\sigma}^2_H$ used to adjust the herdmate average was especially large. In Guernseys negative covariances in percent fat and SNF resulted and variances of the adjusted herdmate averages increased, while for percent SNF in Holsteins and yield of fat and SNF in Jerseys the variance of the adjusted herdmate average was reduced to the extent that the resulting regression values had little meaning. The regressions from a much larger sample for Holsteins should be estimated more reliably. Since these regressions are essentially 1.0 for all but percent SNF, a value for b of 1.0 was used to adjust the cow's performance for differences in herdmates in all traits in all breeds. Essentially, this indicates no genetic differences between adjusted herdmate averages.

Table 16. Intrasire regression of cow record on adjusted herdmate average.

Trait	Covariance	Variance	$\hat{b}$
Guernsey			
Milk	5,283	4,464	1.17
Fat	16	15	1.08
SNF	34	26	1.31
% Fat	-.0002	.4424	-0.00
% SNF	-.0230	6.6098	-0.00
Prot.	3	3	1.03
% Prot.	.0090	.0085	1.06
Holstein			
Milk	22,616	22,982	.98
Fat	36	36	1.00
SNF	191	195	.98
% Fat	.0173	.0173	1.00
% SNF	.0032	.0010	3.27
Prot.	43	34	1.28
% Prot.	.0101	.0106	.96
Jersey			
Milk	262	210	1.25
Fat	-.1110	.0130	-8.49
SNF	.43	1.01	.42
% Fat	.0139	.0103	1.35
% SNF	.0028	.0020	1.42
Prot.	1.9	1.4	1.37
% Prot.	.0140	.0095	1.47

Each record was measured from the adjusted herdmate average by $d_{ij} = y_{ij} - \hat{b}(\bar{y}'_{i.} - \hat{u})$ proposed by Henderson et al. (1954). In this method d_{ij} is the adjusted record of the cow expressed as a deviation from the regressed adjusted herdmate average, y_{ij} is the cow's record, $\hat{b}$ is the regression of the cow on the adjusted herdmate average (1.0 in all cases), $\bar{y}'_{i.}$ is the appropriate adjusted herdmate average considering the sire of the cow, the herd, and the calving date, and $\hat{u}$ is the breed average. These adjusted records were used in all following analyses.

Phenotypic Correlations

Product moment correlation was used to estimate phenotypic correlations among milk, fat, SNF, protein, percent fat, percent SNF, and percent protein within Guernseys, Holsteins, and Jerseys.

These phenotypic correlations are presented in Tables 17 and 18. Yield of milk had a large positive correlation with yield of the three components while it had a small positive to small negative correlation with the percentages of the three constituents. Correlations between yields of the constituents were also large and positive. Positive correlations between the percentages of the various constituents were of moderate size.

The correlation between milk and yield of fat in Holsteins is larger than the 0.75 reported by Johnson (1957), while the correlation of milk and yield of SNF in Holsteins and the correlations for milk with yield of fat or SNF in Jerseys are essentially the same as his. Correlations between milk and percent of the components in Holsteins and

Guernseys have the same sign and magnitude as those for Ayrshires (Robertson _et_ _al_., 1956) and for Holsteins (Johnson, 1957). The Jersey correlations for these same traits fit closely the Jersey results reported by Johnson (1957).

In all three breeds the correlations of fat yield with SNF yield is larger than the 0.79 reported by Johnson (1957) for Holsteins. The correlations between fat percent and SNF percent fall within the range of 0.37 to 0.62 reported by Johnson (1957), Robertson _et_ _al_. (1956), Slack _et_ _al_. (1962), and von Krosigk _et_ _al_. (1960).

For each of the three breeds the correlations between fat percent and protein percent lie close to the values of 0.42 and 0.51 reported by Kliesch _et_ _al_. (1959) and Robertson _et_ _al_. (1956), but are smaller than the 0.63 and 0.62 reported by Slack _et_ _al_. (1962) and von Krosigk _et_ _al_. (1960).

The correlations between SNF percent and protein percent are close to each other but are smaller than those which lie in the range of 0.69 to 0.81 previously reported by Slack _et_ _al_. (1962), Robertson _et_ _al_. (1956), and von Krosigk _et_ _al_. (1960).

The results do not support consistently the suggestion of Tabler and Touchberry (1959) that cows of the higher testing breeds have a larger positive correlation between fat percent and fat yield than do cows of the lower testing breeds. Neither did the Guernseys and Jerseys always have a larger positive correlation between yield and percent of SNF or protein than the Holsteins.

Table 17. Phenotypic correlations among milk, fat, and SNF.

1188 Guernsey Records

	Fat	SNF	% Fat	% SNF
Milk	0.84	0.98	-.20	-.12
Fat		0.87	0.35	0.12
SNF			-.10	0.05
% Fat				0.44

6179 Holstein Records

	Fat	SNF	% Fat	% SNF
Milk	0.88	0.98	-.23	-.14
Fat		0.90	0.25	0.10
SNF			-.14	0.03
% Fat				0.48

199 Jersey Records

	Fat	SNF	% Fat	% SNF
Milk	0.88	0.99	-.30	-.04
Fat		0.91	0.18	0.17
SNF			-.21	0.10
% Fat				0.43

Table 18. Phenotypic correlations among milk, fat, SNF, and protein.

181 Guernsey Records

	Fat	SNF	Prot.	% Fat	% SNF	% Prot.
Milk	0.79	0.98	0.83	-.27	-.15	-.34
Fat		0.86	0.79	0.35	0.22	-.03
SNF			0.87	-.13	0.03	-.23
Prot.				-.04	0.09	0.17
% Fat					0.61	0.49
% SNF						0.57

646 Holstein Records

	Fat	SNF	Prot.	% Fat	% SNF	% Prot.
Milk	0.86	0.93	0.81	-.25	-.11	-.27
Fat		0.88	0.75	0.25	0.09	-.08
SNF			0.82	-.17	0.05	-.20
Prot.				-.10	0.04	0.04
% Fat					0.41	0.39
% SNF						0.52

144 Jersey Records

	Fat	SNF	Prot.	% Fat	% SNF	% Prot.
Milk	0.90	0.99	0.91	-.27	0.01	-.24
Fat		0.92	0.90	0.17	0.18	-.06
SNF			0.93	-.19	0.16	-.17
Prot.				-.07	0.18	0.13
% Fat					0.37	0.42
% SNF						0.50

Repeatabilities

Intracow correlations were used to estimate the repeatabilities of milk and the six constituents in each of the breeds. The model used was $d_{ij} = u' + c_i + e_{ij}$ where d_{ij} is the adjusted record of the j^{th} lactation of the i^{th} cow in the breed, u' is the breed average of the adjusted records, c_i is the amount all records of the i^{th} cow differ from average because of genetic and permanent environmental influences, and e_{ij} is the temporary environment peculiar to the j^{th} record of the i^{th} cow. Any nonpermanent genetic effects are included in e_{ij}. The elements c_i and e_{ij} are random, uncorrelated variables with expectations of zero and variances σ^2_C and σ^2_E. Repeatability is $\frac{\sigma^2_C}{\sigma^2_C + \sigma^2_E}$

Variance components were determined by equating mean squares to expected mean squares according to Henderson (1953).

The repeatabilities are listed in Table 19. Adjusted lactation records had repeatabilities of 0.4 to 0.5 for yield of each trait except protein and 0.6 or larger for percent of fat or SNF. The correlations for fat percent and SNF percent lie midway in the range of values reported previously by Gaunt et al. (1963), von Krosigk et al. (1960), and Wilcox et al. (1959), while the repeatability of protein percent is much lower. Gaunt et al. (1963) reported 0.81 and von Krosigk et al. (1960) reported 0.41 as the repeatability of protein percent. In their studies protein percent had a slightly lower repeatability than did percent of fat or SNF.

Since the variation in protein percent in this study is five per-

Table 19. Repeatabilities of milk and milk constituents. (Yields are expressed in 10 lb.)

Trait	$\hat{\sigma}^2_C$	$\hat{\sigma}^2_E$	Repeatability	No. Cows	No. Records
Guernsey					
Milk	15,422	12,994	0.54	831	1188
Fat	37	34	0.52	831	1188
SNF	130	109	0.54	831	1188
Prot.	9	22	0.29	98	181
% Fat	.150	.054	0.73	831	1188
% SNF	.047	.028	0.63	831	1188
% Prot.	.019	.034	0.26	98	181
Holstein					
Milk	29,094	30,108	0.49	3437	6179
Fat	36	44	0.45	3437	6179
SNF	204	229	0.47	3437	6179
Prot.	20	69	0.23	380	646
% Fat	.076	.025	0.76	3437	6179
% SNF	.051	.025	0.67	3437	6179
% Prot.	.020	.036	0.36	380	646
Jersey					
Milk	13,840	14,858	0.48	143	199
Fat	31	46	0.40	143	199
SNF	106	148	0.42	143	199
Prot.	17	27	0.38	88	144
% Fat	.218	.041	0.84	143	199
% SNF	.057	.030	0.66	143	199
% Prot.	.052	.027	0.66	88	144

cent or more greater than the amount of variation previously reported, it is possible that changes in laboratory personnel, aged milk samples, and varying voltage for the titrimeter have increased the variation in protein percent and yield of protein in this study. On the other hand, Jerseys had the most variation of the three breeds for protein percent and had repeatabilities for percent and yield of protein close to the values from the other constituents. Since testing in all breeds was done by the same person and equipment, differences between breeds in repeatabilities of protein yield and percent may be real.

Genetic Correlations

Genetic correlations among milk and its components need to be known to predict more accurately the genetic change in all traits from selection on any one trait or combination of traits. These correlations are necessary for the construction of a selection index which will give the proper weight for each trait in order to attain maximum genetic progress. Genetic correlations measure the relationships between the genes controlling multiple traits. Phenotypic correlations measure only the outward expression of the traits and thereby include environmental as well as genetic correlations.

Genetic correlations are obtained by correlating the phenotypic expressions of one trait in a group of animals with the phenotypic expressions of a different trait in related animals. In this study estimates were made from relationships between daughters and dams and between paternal sisters. Estimating genetic correlations by the intrasire regression of daughter on dam followed the method developed by Hazel (1943) and used some modifications suggested by Touchberry (1951). The paternal sib analyses followed the procedures outlined by Hazel et al. (1943). In both methods the record used was the first record available for the animal and was a deviation from the adjusted herdmate average.

Genetic correlations are presented in Tables 20 through 30. Blank cells in the upper halves of the tables are due to negative components of variance between sires for a trait in paternal sisters or negative covariances between the same trait in daughters and dams. These negative terms mean that paternal sisters are less alike and daughters resemble dams less for the same trait than unrelated animals. Possible causes are sampling errors and the subjection of related animals to environments so unlike that their phenotypes are less alike than are those of unrelated animals in that population. When negative components occur, the genetic correlation is meaningless because the denominator of the fraction is imaginary.

Differences occurred in the estimates obtained by the two methods, regression of cow on dam and correlations between paternal sisters. More animals were used in the analysis of paternal sisters. In most cases the estimates from paternal sibs were larger than the estimates from the daughter-dam pairs. The larger numbers of Holstein data lower the chance that sampling errors are producing the differences in the genetic correlations between the two methods. There are many cows in the analysis of paternal sisters which are not in the daughter-dam analysis, and this group may include sire groups that have larger genetic correlations among some of the traits or that have been exposed to environmental conditions that are being interpreted as genetic correlations. Since daughters and dams are not contemporaries, there is less chance for environmental correlations to be interpreted as being genetic.

In all three breeds milk is closely correlated genetically with yields of SNF, fat, and protein with the largest correlation being between milk and yield of SNF. The genetic correlation between milk and yield of any of the three components was 0.48 or larger. The most frequent values were near 0.9. The data provided no conclusive evidence to discern whether milk is correlated more with yield of fat or with yield of protein.

Yields of fat, SNF, and protein are closely correlated for all three breeds. Fat yield had a genetic correlation with SNF yield in the range of 0.67 to 0.89 in Holsteins, about 0.8 in Guernseys, and 0.85 to 0.98 in the Jersey paternal sisters. In the study by Johnson (1957) the correlation was 0.99 for both Holsteins and Jerseys. A perfect correlation existed between fat yield and protein yield in the Holstein data, while for Guernseys and Jerseys the values were 0.60 and 0.87, respectively. SNF yield was more closely correlated with the protein yield than with fat yield in Holsteins, but the opposite was true in Guernseys and Jerseys.

Milk was independent to negatively correlated with the percentages of the three components. In Holsteins, milk seemed to have the most antagonistic relationship with fat percent, while in Guernseys and Jerseys the most antagonism was between milk and protein percent. In previous work by Johnson (1957), O'Connor (1959), and Robertson *et al.* (1956) the correlations between milk and percentages of fat and SNF had ranges of -.01 to -.58 and .39 to -.18, respectively. The correlation between milk and percent of crude protein was 0.22 in the study by Robertson et al. (1956).

Table 20. Heritabilities and genetic correlations. 1067 Holstein daughter-dam pairs. 251 sire groups.

	Milk	Fat	SNF	% Fat	% SNF
Milk	0.17	0.57	0.95	-0.50	-0.37
Fat		0.14	0.67	0.41	0.02
SNF			0.14	-0.32	-0.01
% Fat				0.62	0.68
% SNF					0.54

Table 21. Heritabilities and genetic correlations. 125 Holstein daughter-dam pairs. 34 sire groups.

	Milk	Fat	SNF	Prot.	% Fat	% SNF	% Prot.
Milk	0.19	0.86	0.98	0.48	0.00	0.00	-0.04
Fat		0.23	0.88	1.00	0.03	0.02	0.18
SNF			0.20	1.00	0.01	0.01	0.00
Prot.				0.06	0.10	1.00	0.23
% Fat					0.19	0.40	0.69
% SNF						0.14	0.75
% Prot.							0.36

Table 22. Heritabilities and genetic correlations. 657 Holstein sires. 2888 cows.

	Milk	Fat	SNF	% Fat	% SNF
Milk	0.56	0.86	0.97	-0.29	-0.12
Fat		0.52	0.89	0.12	0.15
SNF			0.51	-0.19	0.00
% Fat				0.65	0.54
% SNF					0.51

Table 23. Heritabilities and genetic correlations. 76 Holstein sires. 320 cows.

	Milk	Fat	SNF	Prot.	% Fat	% SNF	% Prot.
Milk	0.05			1.00	-1.00	-1.00	-0.53
Fat		*					
SNF			*				
Prot.				0.15	-1.00	-0.27	0.11
% Fat					0.46	0.01	0.18
% SNF						0.62	0.76
% Prot.							0.58

* Negative component

Table 24. Heritabilities and genetic correlations. Regression of daughter on dam within sire and herd. Non-deviated ME records. 231 Guernsey daughter-dam pairs. 120 sire-herd groups.

	Milk	Fat	SNF	% Fat	% SNF
Milk	0.23	0.80	0.99	-0.11	-0.00
Fat		0.37	0.82	0.46	0.00
SNF			0.22	-0.01	0.00
% Fat				0.63	0.15
% SNF					0.32

Table 25. Heritabilities and genetic correlations. 13 Guernsey daughter-dam pairs. 7 sire groups.

	Milk	Fat	SNF	Prot.	% Fat	% SNF	% Prot.
Milk	0.34	0.96	0.98	0.94	0.00		0.16
Fat		0.59	0.96	0.57	0.06		-1.00
SNF			0.42	0.90	0.04		0.00
Prot.				0.52	0.02		0.47
% Fat					0.44		-1.00
% SNF						*	
% Prot.							0.08

* Negative covariance

Table 26. Heritabilities and genetic correlations. 198 Guernsey sires. 793 cows.

	Milk	Fat	SNF	% Fat	% SNF
Milk	0.58	0.79	0.96	-0.02	-0.14
Fat		0.71	0.84	0.58	0.16
SNF			0.65	0.14	-0.03
% Fat				0.90	0.42
% SNF					0.63

Table 27. Heritabilities and genetic correlations. 17 Guernsey sires. 69 cows.

	Milk	Fat	SNF	Prot.	% Fat	% SNF	% Prot.
Milk	0.81	0.68	0.93	0.88	0.00	-0.19	-0.28
Fat		1.00	0.89	0.70	0.23	0.15	0.56
SNF			0.77	0.80	0.37	0.16	-0.00
Prot.				0.90	0.14	-0.11	-0.00
% Fat					1.00	0.87	1.00
% SNF						1.00	0.83
% Prot.							0.54

Table 28. Heritabilities and genetic correlations. 33 Jersey daughter-dam pairs. 9 sire groups.

	Milk	Fat	SNF	Prot.	% Fat	% SNF	% Prot.
Milk	*						
Fat		*					
SNF			*				
Prot.				*			
% Fat					0.18		0.10
% SNF						*	
% Prot.							0.34

* Negative covariance

Table 29. Heritabilities and genetic correlations. 34 Jersey sires. 145 cows.

	Milk	Fat	SNF	% Fat	% SNF
Milk	0.81	0.81	0.99	-0.51	0.10
Fat		0.75	0.85	0.06	0.42
SNF			0.92	-0.47	-0.05
% Fat				1.00	0.22
% SNF					0.03

Table 30. Heritabilities and genetic correlations. 16 Jersey sires. 88 cows.

	Milk	Fat	SNF	Prot.	% Fat	% SNF	% Prot.
Milk	1.00	0.95	0.99	0.98	0.28		-0.20
Fat		1.00	0.98	0.87	0.56		-0.72
SNF			1.00	0.94	0.38		-0.43
Prot.				1.00	0.13		-0.06
% Fat					0.68		-1.00
% SNF						*	
% Prot.							0.15

* Negative component

In Holsteins, fat percent had a larger correlation with protein percent than with SNF percent, while in Guernseys and Jerseys the opposite was true. Robertson _et_ _al_. (1956) and von Krosigk _et_ _al_. (1960) also found fat percent to be slightly more correlated with protein percent than with SNF percent. As would be expected from the part-whole relationship, a large correlation exists between SNF percent and protein percent.

These values were 0.75 and 0.76 from the Holstein daughter-dam pairs and paternal sisters and 0.83 from the Guernsey paternal sisters. Other studies by Robertson _et al_. (1956) and von Krosigk _et al_. (1960) list 0.94 and 0.90 for this correlation.

In the estimates of genetic correlations from the Holstein data, the points of greatest disagreement between the daughter-dam results and the paternal sib results that could be estimated were for yield of protein with milk, percent fat, and percent SNF, and for percent protein with milk and percent of fat. The correlations between yield of protein and the percentages of fat and SNF did not agree in sign of the correlation. No estimates of these two correlations were available in the literature.

Heritabilities

Heritabilities are useful in predicting the probable response of a trait to selection. Intrasire regression of daughter on dam and intrasire correlation of paternal sisters were used to estimate heritabilities. Except for the 231 Guernsey pairs of daughters and dams, whose results are shown in Table 24, all of the records used were deviations from adjusted averages of herdmates.

Heritabilities from the two methods are listed on the diagonals in Tables 20 through 30. Estimates from the groups of paternal sisters were consistently larger than those from the daughter-dam pairs. This difference was largest for heritabilities of yields.

The heritabilities from Guernsey daughters and dams listed in Table 24 are from an intrasire, intraherd analysis in which absolute ME records were used. When the records in Table 24 were measured from the adjusted herdmate average, the heritabilities were essentially zero. The weighting factors used to adjust the Guernsey herdmate averages were too large and probably contributed to the unusual estimates.

The Jersey data were few, had a large weighting factor for adjusting the herdmate averages, and were mainly from intensely inbred experimental herds. In view of these limitations, the estimates for Jerseys have little application.

Heritabilities for yields were appreciably lower than heritabilities for percentages. With the exception of protein, the heritabilities for yields within a breed were of the same magnitude; the same was true for the percentages.

Heritabilities for yields of milk, fat, and SNF in Holsteins were smaller than the commonly accepted range of 0.2 to 0.3 for yield of milk and fat. Estimates of heritability for yield of milk and SNF in Guernseys were within this range, while the estimate for fat yield was larger. Protein yield had a smaller heritability than yield of milk, fat, or SNF in Holsteins by both methods of estimation, but in the Guernseys the opposite situation existed.

The percentages of fat and SNF had heritabilities of 0.5 to 0.6 in Holsteins with approximately 0.4 for percent of protein. In Guernseys the values for percent of fat and SNF were 0.32 and 0.37, and again percent of protein had a smaller heritability. Heritabilities reported previously have ranged from 0.32 to 0.72 for fat percent, 0.36 to 0.83 for SNF percent, and were 0.48 and 0.76 for percent of protein in studies by Johnson (1957), Lankamp (1959), O'Connor (1959), Robertson *et al.* (1956), von Krosigk *et al.* (1960), and Wilcox *et al.* (1959). The most frequent heritability values for both fat percent and SNF percent were near 0.5.

The small estimates of heritability for yield and percent of protein in Holsteins are difficult to explain unless they result from the same condition that caused the low values of repeatability. The pairs of daughters and dams with protein records in the Guernseys are too few to give a reliable estimate. Heritabilities listed for yield of milk, fat, and SNF in the Holsteins are representative because the values changed little when the original ME records were analyzed intrasire and intraherd.

CONCLUSIONS AND APPLICATIONS

Many of the environmental and genetic factors studied have applications in the breeding and management of dairy cattle to produce more SNF and protein at lower cost.

Applications to Dairy Cattle Breeding

The repeatabilities for all traits except yield and percentage of protein are 0.4 or larger for records which are adjusted for age and for herdmates. Since repeatability is a measure of the tendency for repeated records of cows to be the same amount above or below the herd average, large positive values indicate that cows will tend to produce the same, relative to the herd average, from year to year. In the same manner a repeatability near zero means that one record each on a group of cows gives little indication of what they may do in following lactations. Thus, repeatability can be used to estimate the probable producing ability of a cow for each trait by $\frac{nr}{1 + (n-1)r}$ (average deviation from herdmates) where n is the number of records and r is repeatability. From this formula it can be seen that repeated records will be needed the most for traits with low repeatability such as yield and percentage of protein.

The large repeatabilities for fat and SNF percentages indicate little change in the percentage of these two constituents from lactation to lactation. This information could be used to decrease the cost of production testing by applying percentages of SNF and protein adjusted for age in first lactation to the milk yields of following lactations.

An important factor in the success of any dairy herd is high production per cow. To aid in getting high production the cows need to be ranked according to probable producing ability and the lowest ranking cows replaced with animals of high potential production. Phenotypic correlations ranging from 0.87 to 0.99 were found among yields of milk, fat, and SNF, while the correlations among yields of milk, fat, and protein ranged from 0.75 to 0.91. These correlations indicate there would be little difference in the rankings of the cows in a herd on the basis of milk, fat, SNF, or protein yield. By using their milk and fat yield records dairymen can have a herd high in SNF and protein production and be ready for markets based on these constituents without the additional expense of SNF or protein testing.

The conclusions above assume that the price differentials paid for changes in SNF or protein percent will, like those presently paid for fat percent, reflect the market value of the resulting yield of SNF or protein. Should price differential premiums become large enough to make it more profitable to breed for higher test than for higher yield, testing the individual cows for percent of SNF or protein, or both, could become important. For this to occur, consumer demand would have to be for milks of higher SNF and protein content than the existing cow population could supply and fortification to these higher levels with skim milk powder would have to be unacceptable from the standpoint of flavor or expense.

Breeders of registered dairy cattle who have a large income from the sale of breeding stock and the AI bull studs may find that testing for SNF or protein will give their product enough additional sales value to make the testing a good investment.

The coefficients of variation are larger for milk and yields of the components of milk than for the percentages. Phenotypic and genetic correlations have shown closer relationships among the yields of milk and its components than among the percentages. The standard deviations and phenotypic correlations can be used to indicate what changes culling on different traits will make between the average of the selected group and the average of the group before selection. Predictions of genetic change in the herd or population can be made using the estimates of the heritabilities and genetic correlations.

Michigan DHIA records for the years 1961 through 1963 show an involuntary loss of 12 percent of the milking herd per year in a report by Johnson and Thelen (1963). Rendel and Robertson (1950) estimated that for each cow in the milking herd there were 0.35 to 0.40 mature heifers produced per year. Based on these figures a 20 percent culling rate should be attainable in an average DHIA herd. The average generation interval is the same as the average age of the cow herd, which was estimated by Specht and McGilliard (1960) to be 4.4 years in Michigan DHIA cows.

Table 31 shows the difference between the average of the selected group and the average of the group before selection when only the top 80 percent of the herd are kept for each of the productive traits. The phenotypic correlations and standard deviations used in estimating these changes were taken from the Holstein data in this study.

Table 31. Differences between the averages of the selected group and the average of the group before selection for trait Y after culling 20 percent of the herd on trait X.

Trait X	Trait Y						
	Pounds				Percent		
	Milk	Fat	SNF	Prot.	Fat	SNF	Prot.
Milk	801	26	68	31	-.024	-.014	-.021
Fat	705	29	62	28	.026	.010	-.006
SNF	785	26	69	31	-.015	.003	-.015
Prot.	649	22	57	38	-.010	.004	.003
% Fat	-184	7	-10	-4	.105	.049	.030
% SNF	-112	3	2	2	.050	.102	.004
% Prot.	-216	-2	-14	2	.041	.053	.077

The immediate effects on the herd average from culling on these seven traits reflect the large phenotypic correlations between yields and the smaller correlations between percentages and yields. Culling on the yield of any component is effective in increasing the yield of all components. Yields are, in general, changed very little from selecting on the basis of percentages.

Table 32 shows the expected genetic change per generation from selecting for different productive traits, while Table 33 shows the change in these traits per year based on a 4.5 year generation interval. The heritabilities and genetic correlations used to compute the results in Table 32 and 33 are those from the Holstein results.

The projected genetic results predict that selecting for yield of any single trait increases the yield of all the traits. With the

Table 32. Expected genetic change per generation in trait Y after selecting the top 80 percent of the population on trait X.

Trait X	Trait Y						
	Pounds				Percent		
	Milk	Fat	SNF	Prot.	Fat	SNF	Prot.
Milk	136	2.6	10.2	1.8	-.017	-.011	-.001
Fat	70	4.2	6.5	3.4	.013	.001	.003
SNF	117	2.7	9.7	3.4	-.010	.004	.000
Prot.	39	2.7	6.3	2.3	.002	.018	.003
% Fat	-130	3.5	-6.5	0.7	.065	.023	.025
% SNF	-90	0.2	2.7	6.7	.025	.055	.025
% Prot.	-8	1.2	0.0	1.3	.035	.033	.028

Table 33. Expected genetic change per year in trait Y after selection on trait X. 4.5 year generation interval and selection of the top 80 percent for trait X.

Trait X	Trait Y						
	Pounds				Percent		
	Milk	Fat	SNF	Prot.	Fat	SNF	Prot.
Milk	30	0.6	2.3	0.4	-.004	-.002	-.000
Fat	16	0.9	1.4	0.8	.003	.000	.001
SNF	26	0.6	2.2	0.8	-.002	.001	.000
Prot.	9	0.6	1.4	0.5	.000	.004	.001
% Fat	-29	0.8	-1.4	0.2	.014	.005	.006
% SNF	-20	0.0	0.6	1.5	.006	.012	.006
% Prot.	-2	0.3	0.0	0.3	.008	.007	.006

exception of protein yield, the largest increase in any one trait results when that is the trait being selected. Selection for a higher percent of a component is an inefficient way to increase yields of the components except for SNF percent and protein yield.

Selecting for yield of milk will increase the yields of milk, fat, SNF, and protein while it decreases the percentages of fat and SNF slightly. The resulting reduction in protein percent is minute.

Selection on fat yield shows a good increase in yields of fat and protein and moderate increases in the yields of milk and SNF. Fat percent is increased slightly while protein percent and SNF percent show negligible increases.

When SNF yield is the selection criterion, good increases in yields of milk, SNF, and protein should result as well as a moderate increase in yield of fat. The percentage of fat is decreased, protein percent is unchanged, and SNF percent is increased slightly from selecting on SNF yield.

Protein yield as the basis of selection results in relatively moderate increases in yields of fat, SNF, and protein and a small increase in milk yield. It also should give a small increase in percent of SNF and very slight increases in percentages of fat and protein.

While selection on percent of fat increases the percentages of all three constituents, it decreases the yields of milk and SNF and results in little increase in protein yield. SNF percent as the selection criterion is an excellent tool for increasing yield of protein and the percentages of SNF and protein. It also decreases milk yield, gives a slight increase to fat yield, and results in a small increase in SNF yield and the percent of fat. Selection on protein percent should give a good increase in protein percent, moderate increases in fat percent and SNF percent, small increases in yields of fat and protein, no change in yield of SNF, and a very slight decrease in the yield of milk.

If the goal of selection is to produce as many pounds of SNF and protein as possible by selection on a single trait, then selection on yield of SNF would be advisable. Selection based on SNF yield will result in good increases genetically in yield of milk, SNF, and protein. It decreases fat percent slightly, gives a small increase to SNF percent, but does nothing for protein percent. For those who are willing to spend a little more time and money in selection, combinations of the traits in a selection index will increase the gains in a single trait or produce a more correctly balanced gain in all the traits.

When the goal of selection is to increase the percentages of SNF and protein as much as possible, the SNF percent is the best single criterion for selection. Selecting on this trait gives the maximum increase in SNF percent, near maximum increase in protein percent, and has the added advantage of increasing the fat percent the least. However, the increases in yields of milk and its constituents are not as high as when selection is based on the yield of one of them. Selection on either protein percent or fat percent will give essentially the same increase in protein percent, a smaller increase in SNF percent, and a larger increase in fat percent.

The genetic and environmental correlations show that many genetic and environmental relationships exist among the milk components. For example, having only the milk yield of the cows in the herd gives some information about what their yield of fat, SNF, or protein might be relative to each other. The most efficient use of all the relationships within and between traits found in this study would be made by a selection index designed to maximize the gain in any one component or an economically correct combination of all the components. Familiarity with milk pricing is needed to determine the economic weights for the combination index.

Areas in Need of Further Research

Age of the cow at calving was shown to have an effect on the yields and percentages of SNF and protein. To make age adjustments more accurately and at shorter age intervals, a much larger number of records need to be studied. All breeds need to be represented to determine differences among breeds. Increased incidence of mastitis with age also needs to be investigated for the effects it might have on yield and composition.

The effect of season of calving on SNF yield for the lactation appeared to be small. However, the study of season of calving was hampered by interaction effects and was inconclusive. Further investigations with a larger sample and more refined statistical methods are needed before a precise appraisal of this source of variation can be made for the yields and percentages of SNF and protein.

Few researchers have studied variation in the yield of SNF or protein. Estimates from large samples in several widely scattered locations are needed to confirm these results or to show that variation is not uniform from population to population or locality to locality. Results from the study of variation in the percentages of fat, SNF, and protein were close to the results of other studies.

Wide diversity was found among the breeds for the percent of variation in the traits due to the herdmate groups. Within the Holsteins variations in yields of SNF and protein were similar to those for yield of fat, while the variations for percentages of SNF and protein were close to that for percent of fat. This similarity was not found in the Guernseys and Jerseys. Analysis of more data is needed to determine what part of these differences is actually due to breeds and what part is due to sampling.

The peculiarities of regressing a cow's record on her rolling five-month adjusted herdmate average as opposed to a fixed season adjusted herdmate average requires further investigation. The rolling five-month seasons should show some reduction in variation in comparison with non-overlapping seasons. Further study is needed to determine if genetic differences might exist between adjusted rolling five-month herdmate averages for milk and milk components.

Genetic-environmental interactions have not been studied to ascertain if certain genotypes or families interact with certain environmental conditions to increase or decrease the yield or percent of the constituents. If such conditions exist, they might be useful in altering yields or percentages.

Additional estimates of genetic correlations, particularly those involving yield of protein, are needed. This study was unable to determine even the sign of the correlations between yield of protein and the percentages of fat and SNF.

Differences in heritabilities and genetic correlations were noted between the estimates from daughter-dam regression and intrasire correlation. The largest differences between the two methods occurred for heritabilities of yields. The component of variation between herdmate groups was much smaller in relation to the component from within herdmate groups for the percentages than for the yields. This, plus the larger estimates for heritabilities of the percentages than for yields by both methods of estimation, suggests that environmental influences are greater for yields than for percentages. Since environment seems to have a greater influence on yields, it may be easier to include environmental effects in the intrasire correlations for yields than for percentages. Multiplication by four would enlarge these errors and account for a larger difference between the two methods of estimation in the heritabilities of yields than of percentages. Further study in the removal of environmental effects by measuring from adjusted herdmate averages or other methods is needed. If there is a directionally consistent bias in the heritability estimates obtained by the two methods, it may be that multiplication of the daughter-dam regression by some number other than two and/or the intrasire correlation by a number other than four will result in more accurate estimates. Additional research is needed to explore the merit of possible changes.

Most of the genetic correlations obtained from the paternal sisters are larger than those obtained from daughter-dam pairs. Because the paternal sisters are more likely to be contemporaries, it is possible that correlated environmental factors within sire groups are inflating the between-sire covariance components. Additional study may develop tools for removing these environmental correlations and increasing the accuracy of genetic correlations from paternal sisters.

With the results of this study and several others that are underway, selection programs can be formulated to move toward the desired goal. The next question to be answered is, "What is the goal?" Studies on milk flavor have been made by Hillman et al. (1962) and Wahid-Ul-Hamid and Manus (1960). In both studies, milks with lower fat and higher SNF content were preferred to whole milk. Although neither study made mention of the practicality of the method, they both made use of good quality non-fat dry milk to standardize the SNF to the new higher levels. Because selection for higher percentages of the constituents results in a lower yield of the constituents than would selection for yield of the constituents, it might be possible to select for increased yield of SNF and protein, add the cost of standardizing the SNF and protein to the desired level at the milk plant, and still be able to sell the milk to the consumer at a lower price than if selection had been practiced for higher percentages of SNF and protein. This plan would also have the advantage of offering the consumers milks with many levels of fat and SNF content. Studies need to be made to define specifically what contents of milk are desired and whether selection for milk of this content or standardization at the milk plant combined with selection for highest yield is the most economical way of producing this milk.

SUMMARY

Milk, fat, and SNF from 6179 records by 3437 Holstein cows in 51 herds, 1188 records by 831 Guernsey cows in 15 herds, and 201 records by 145 Jersey cows in four herds were studied. Of these cows, 380 Holsteins with 646 records, 98 Guernseys with 181 records, and 88 Jerseys with 144 records were also tested for protein. SNF content was measured by Watson lactometer for Holsteins and Jerseys and by Golding plastic beads for Guernseys. Formol titration was used to determine protein content.

The coefficients of variation were larger for yields of fat, SNF, and protein than for the percentages of these traits. Among the percentages, percent fat had the largest coefficient of variation while SNF percent had the smallest.

Multiplicative factors were derived to adjust the records for differences in ages of cows at calving. SNF percent decreased more with age than did fat percent.

When the average SNF production for the lactation was computed for each month of calving over a two year period, there was interaction in the ranking of the months between years within the same age group and between age groups within the same year.

Rolling five-month herdmate groups were analyzed to determine the proper adjustment to make for numbers of herdmates. No genetic differences were found between adjusted herdmate averages.

Phenotypic correlations were from 0.75 to 0.99 among the yields and from 0.37 to 0.61 among the percentages. The correlations between the percent of a component and the yield of any other component or of milk were generally between 0.2 and -.3.

Intracow correlation was used to determine repeatabilities which ranged from 0.63 to 0.84 for percentage of fat and SNF and from 0.40 to 0.54 for yield of milk, fat, and SNF. The repeatabilities for protein percent ranged from 0.26 to 0.66 while for yield of protein they ranged from 0.23 to 0.38.

From regression on dam within sire of 1067 Holstein daughters with SNF records and 125 Holstein daughters with SNF and protein records, heritabilities were: milk 0.17, fat 0.14, SNF 0.14, protein 0.06, fat percent 0.62, SNF percent 0.54, and protein percent 0.36. Genetic correlations among yields ranged from 0.48 between milk and protein to 1.0 between SNF and protein. Among the percentages of the components the values ranged from 0.4 to 0.75, while between the percent of a component and yield of milk or of any other component the correlations ranged from -.5 to 0.18. The corresponding values from paternal sister correlations were larger for heritabilities and generally larger for genetic correlations. Heritabilities and genetic correlations were also derived for Guernseys and Jerseys.

Genetic gains were estimated for a 20 percent culling rate on each trait. Selection for higher component percentages is an inefficient way to increase yields of the components because percentages of the components have the smallest coefficients of variation and the genetic correlations among percentages and yields are smaller than those among yields. Milk selection results in the greatest increase in SNF yield while causing minute decreases in SNF and protein percentages. SNF yield is preferred to protein yield as a selection criterion because of more gain in milk, SNF, and protein yield and no increase in fat percent.

LITERATURE CITED

Armstrong, T. V. 1959. Variation in the gross composition of milk as related to the breed of the cow: A review and critical evaluation of literature of the United States and Canada. J. Dairy Sci., 42:1.

Bailey, G. L. 1952. Studies on variation in the solids-not-fat content of milk. I. Variation in lactation yield, milk-fat percentage, and solids-not-fat percentage, that are due to the age of the cow. J. Dairy Research 19:89.

Burdick, J. M. II, and L. D. McGilliard. 1963. Interactions between sires in artificial insemination and management of dairy herds. J. Dairy Sci., 46:452.

Combs, T. N., P. M. Reaves and G. C. Graf. 1955. The fat and solids-not-fat content of milk of individual cows. J. Dairy Sci., 38:620.

Erb, R. E. and L. J. Manus. 1961. Importance of milk solids-not-fat and protein and simple methods for testing and recording in DHIA. Mimeo. prepared for distribution at "Livestock Days" at Colorado State Univ. Feb.

Gaunt, S. N., A. R. Corwin, H. C. Gilmore, E. H. Birdsong and S. Russell. 1962. Protein, solids-not-fat, and fat variations in lactation milk records. J. Dairy Sci., 45:687.

Gaunt, S. N., J. Moore and A. R. Corwin. 1963. Repeatability of monthly and bi-monthly lactation records of milk, protein, solids-not-fat, milk fat and total solids for five breeds of cattle. J. Dairy Sci., 46:1173.

Hazel, L. N. 1943. The genetic basis for constructing selection indexes. Genetics 28:476.

Hazel, L. N., M. L. Baker and C. F. Reinmuller. 1943. Genetic and environmental correlations between growth rates of pigs at different ages. J. Animal Sci., 2:118.

Henderson, C. R. 1953. Estimates of variance and covariance components. Biometrics 9:226.

Henderson, C. R., H. W. Carter and J. T. Godfrey. 1954. Use of the contemporary herd average in appraising progeny tests of dairy bulls. J. Animal Sci., 13:959.

Henderson, C. R. and H. W. Carter. 1957. Improvement of progeny tests by adjusting for herd, year, and season of freshening. J. Dairy Sci., 40:638.

Hillman, J. S., J. W. Stull and R. C. Angus. 1962. Consumer preference and acceptance of milk varying in fat and solids-not-fat. Arizona Agr. Expt. Sta. Tech. Bull. 153.

Johansson, I. 1960. Progeny testing methods in Europe. J. Dairy Sci., 43:706.

Johnson, K. R. 1957. Heritability, genetic and phenotypic correlations of certain constituents of cow's milk. J. Dairy Sci., 40:723.

Johnson, K. R., D. L. Fourt, R. A. Hibbs and R. H. Ross. 1961. Effect of some environmental factors on the milk fat and solids-not-fat content of cow's milk. J. Dairy Sci., 44:658.

Johnson, L. A. and A. J. Thelen. 1963. Michigan Dairy Herd Improvement Records Annual Summary. Cooperative Extension Service, Michigan State University Dairy Department.

Kendrick, J. F. 1955. Standardizing DHIA records in proving sires. United States Dept. of Agr. ARS-52-1. Jan.

Kliesch, J., U. Neuhaus and P. Horst. 1959. Untersuchungen über die Schwankungen des Eiweiss- und Fettgehaltes im Verlauf der Laktation und über die Beziehungen zwischen Eiweissgehalt, Fettgehalt und Milchmenge. Züchtungskunde 31:18.

Lamb, R. C., L. D. McGilliard and J. R. Brunner. 1960. Accuracy of the lactometric field test for measuring solids-not-fat content of milk. J. Dairy Sci., 43:491.

Lamb, R. C., L. D. McGilliard and J. R. Brunner. 1961. Accuracy of the plastic bead method of measuring solids-not-fat of milk under field conditions. J. Dairy Sci., 44:856.

Lankamp, H. 1959. Erblichkeitsgrad und Vererbung verschiedener Milchbestandtiele. Tierzüchter 11(15):387.

Legates, J. E. and J. L. Lush. 1954. A selection index for fat production in dairy cattle utilizing the fat yields of the cow and her close relatives. J. Dairy Sci., 37:744.

Lush, J. L. and F. S. Straus. 1942. The heritability of butterfat production in dairy cattle. J. Dairy Sci., 25:975.

O'Connor, L. K. 1959. The inheritance of milk quality. XVth Intern. Dairy Congr. (London) Vol. 1:158.

Ontario Department of Agriculture and Canada Department of Agriculture. 1963. Ontario Milk Composition Study, Progress Report. December.

Pirchner, F. and J. L. Lush. 1959. Genetic and environmental portions of variation among herds in butterfat production. J. Dairy Sci., 42:115.

Plum, M. 1935. Causes of differences in butterfat production in dairy cattle. J. Dairy Sci., 18:811.

Putman, D. N., G. A. Bowling and C. T. Conklin. 1944. The recognition of the influence of age on butterfat percentage when calculating mature equivalents. J. Dairy Sci., 27:903.

Rendel, J. M. and A. Robertson. 1950. Estimation of genetic gain in milk yield by selection in a closed herd of dairy cattle. J. Genetics 50:1.

Rimm, A. A., R. E. Mather and W. P. Apgar. 1962. The nature of the solids-not-fat curve during lactation. J. Dairy Sci., 45:144.

Robertson, A. and J. M. Rendel. 1954. The performance of heifers got by artificial insemination. J. Agr. Sci., 44:184.

Robertson, A., R. Waite and J. C. D. White. 1956. Variation in the chemical composition of milk with reference to the solids-not-fat. II. The effect of heredity. J. Dairy Research 23:82.

Sargent, F. D. and J. E. Legates. 1964. Genetic and environmental influence on fat and solids-not-fat in milk. J. Dairy Sci., 47:340.

Slack, N. H., R. E. Mather and K. O. Pfau. 1962. Some interrelationships between the percentages of SNF, protein, and fat in Holstein milk. J. Dairy Sci., 45:144.

Snedecor, G. W. 1956. Statistical Methods. 5th Ed. Iowa State College Press, Ames, Iowa.

Specht, L. W. and L. D. McGilliard. 1960. Rates of improvement by progeny testing in dairy herds of various sizes. J. Dairy Sci., 43:63.

Tabler, K. A. and R. W. Touchberry. 1959. Selection indices for milk and fat yield of Holstein-Friesian dairy cattle. J. Dairy Sci., 42:123.

Touchberry, R. W. 1951. Genetic correlations between five body measurements, weight, type and production in the same individual among Holstein cows. J. Dairy Sci., 34:242.

Turner, W. C. 1936. Factors affecting the composition of milk. Missouri Agr. Expt. Sta. Bull. 365.

Van Vleck, L. D. 1964. Genetic parameters of five-month lactation records. J. Dairy Sci., 47:421.

Von Krosigk, C. M., J. O. Young, and G. A. Richardson. 1960. Genetic influences on the composition of cow's milk. J. Dairy Sci., 43:877.

Wahid-Ul-Hamid, S. S. and L. J. Manus. 1960. Effect of changing the fat and nonfat solids of milk. J. Dairy Sci., 43:1430.

Waite, R., J. C. D. White and A. Robertson. 1956. Variations in the chemical composition of milk with reference to the SNF. I. The effect of stage of lactation, season of year, and age of cow. J. Dairy Research 23:65.

Wilcox, C. J., K. O. Pfau, R. E. Mather and J. W. Bartlett. 1959. Genetic and environmental influences upon solids-not-fat content of cow's milk. J. Dairy Sci., 42:1132.