GENETIC AND ENVIRONMENTAL FACTORS AFFECTING THE RED DANISH CATTLE IN MICHIGAN

Thesis for the Degree of Ph. D.

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Lester Joseph Cranek, Sr.

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This is to certify that the

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Lester J. Cranek

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N. P. Ralston
Major professor

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N.J.

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By

Lester Joseph Cranek, Sr.

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
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Department of Dairy

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Approved N. P. Ralston
(Major Professor)

LESTER JOSEPH CRANEK, SR. ABSTRACT

Analyses were made of all normal lactation records in the American Red Danish cattle population in Michigan prior to August, 1951, to determine the effect on production characteristics of Red Danis sires when mated to cows of the various dairy breeds in a grading-up program. The progeny of forty-one herd sires were represented within the sire progeny groups there were available 693 dams daughter comparisons. All lactation records of 270 days' duration or more were standardized to 305 day, 2X, mature equivalent basis by means of D.H.I.A. factors.

A significant increase in milk and butterfat production of the Red Danish cross progeny over the foundation breeds was found. The mean milk and butterfat production for the foundation breeds and their graded-up progeny was 8,536 and 9,116 pounds of milk, and 354 and 372 pounds of butterfat, respectively. There was no evidence of heterosis among the various breeds and crossbred animals. This increase was not attributed to an upward time trend in production. Estimates of repeatability of production records for the foundation breeds on an all herds and an intraherd basis were 0.54 and 0.36 milk production, and 0.66 and 0.37 for butterfat production, respectively. Those found for the Red Danish

progeny on an all herds and an intraherd basis were 0.52 and 0.26 for milk production, and 0.67 and 0.28 for butterfat production, respectively.

The effect of mild inbreeding was analyzed by the intrasire regression of production on inbreeding. A nonsignificant decline of 23 pounds of milk and 0.3 pound of butterfat per 1-percent increase in inbreeding was observed. The analysis showed that some sires withstand inbreeding, whereas others did not. The gets of inbred sires were no more uniform milk and butterfat production than those of noninbred sires.

Two lethal defects, paralyzed hindquarters and mummification (a type of ankylosis), were found to be transmitted by the Red Danish sires. The observed frequency, of 2.2 and 1.4 percent for the paralyzed and mummified conditions, respectively, fitted the Mendelian inheritance ratio as simple recessive autosomal characters. The frequency of the heterozygous carriers in the population for the paralyzed and mummified conditions appears to be 25 and 11 percent, respectively. There appeared to be an increase of calf mortality and female sterility with each successive cross of Red Danish sires.

LESTER JOSEPH CRANEK, SR. ABSTRACT

The performance of herds sires as indicated by progeny and dam-daughter comparisons is presented for thirty-one sires having at least five dam-daughter pairs. Twenty-four sires increased production. When divided into sire family groups, it was found all families were alike in transmitting ability, as calculated by the "Equal-Parent Index," which these data fitted.

The influence of three nonhereditary factors, time trend and yearly environmental changes, month of calving, and length of calving interval on milk and butterfat production. Of the total observed variance for milk production, 2 and 3 percent was attributed to the month of calving and the length of calving interval, respectively, while 2.4, 3.2, and 6.7 percent of the total observed variance for butterfat production was attributed to the month of calving, length of calving interval, and year-to-year changes, respectively.

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GENERAL INTRODUCTION

An intense search for superior animals by the United States Department of Agriculture in the 1930's led to the importation of two bulls and twenty cows of the Red Danish Milkrace breed from Denmark. In order to more thoroughly evaluate the genetic composition of the animals of this importation, it became necessary to test a high percentage of the males. Cooperating dairymen in Michigan were enlisted to prove these bulls under the supervision of Mr. A. C. Baltzer of Michigan State College.

The characteristics of these Red Dane progeny were such that they satisfied an apparent desire of these cooperating dairymen to the extent that on January 16, 1948, the American Red Danish Cattle Association was formed. An open herdbook was established, and third- and fourth-generation females and males, respectively, would become eligible for registration, providing the foundation cows; and all succeeding females, were production tested. Anyone breeding Red Danish cattle for the purpose of final registration of the third and succeeding generations must comply with the birth-reporting and production-testing regulations.

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The establishment of a new breed at this stage in our knowledge of animal breeding offers an entirely new approach to the rapid development of a breed that will possess significant economic characteristics. Such an assertion seems warranted in view of the vast accumulation of breeding knowledge. Little time has elapsed to allow unsound fads and fancies and unintelligent promotional activities and the development of policies to restrict the use of fundamental information on the inheritance of the desirable traits. If the American Red Danish Cattle Association will adhere to the fundamental objectives outlined in their program and keep abreast of current breeding information, they can avoid many of the pitfalls which have delayed progress in some of our other breeds.

This investigation was initiated to establish the trend of the essential characteristics in the development of the American Red Danish cattle up to the present. The data presented in this study should materially aid in breed progress, as it was designed to determine the repeatability and heritability of production characters, to find the superior breeding animals, to observe the frequency of undesirable defects, and to emphasize some of the major environmental factors responsible for phenotypic variation.

Brief History of the American Red Danish Cattle

Development of the Red Danish Milkrace in Denmark

The early history of the Red Danish Milkrace is veiled in obscurity, as is equally true with the history of the other dairy breeds of the world.

The cattle found in Denmark at the end of the period 1778 were of no distinct color, except those in the northern part of Jutland, which were mostly black, or white and black. In the southern and eastern part of Denmark, in which regions the Red Danish dairy breed was to later develop, the cattle consisted of an admixture of color and type. These cattle were of small to average size, were horned and generally spotted in color, red and white, yellow, or brindle, and a little tendency to showing black. It is certain that the native cattle of the western part of Jutland were of a more dual-purpose type and presented a more fixed type at the beginning of the nineteenth century than did the cattle of any other part of Denmark (Anthony, 1951).

From 1800 to 1840, several types of cattle were brought to the islands of Funen, Sealand, and Lolland-Falster. This infusion of cattle consisted of Sleswig and Holstein cattle, some Jutland

cattle, traces of Ayrshire, Swiss and Tyrol blendings, and some Angler cattle. The Sleswig cattle (Ballum and north Sleswig) predominated, and the red color was the most predominant. This movement occurred because of large quantities of surplus feeds from the distilleries and breweries on the islands of Funen and Sealand. The city of Copenhagen also grew to such a size that an outside beef and milk supply was needed. Since transportation facilities were poor, cattle were walked across the country from the sections in southern Jutland, Sleswig-Holstein, and the west coast in the Ballum section, and many Angler cows were brought in from Angel in southeastern Sleswig.

As these cattle moved across the islands, many were traded and sold to the farmers en route. Many of the young calves born en route were left behind because they were unable to keep pace with the drove. As these animals were milked and developed, the Danish farmers realized that these animals were superior to their own native cattle. Consequently, the Danish farmers were dissatisfied with their poor native cattle, and thus introduced this superior outside blood into their breeding herds. The Red Danish dairy breed, therefore, had its development from 1845 to 1885 by breeding

the native cattle to three closely related breeds--the Ballum, North Sleswig, and Angler cattle.

The Ballum cattle came from along the west coast of Sleswig on the rich grass marshlands of that section. They were characterized as a dual-purpose breed, with the weight for a full-grown cow being 1,000 to 1,200 pounds. The color was nearly always a dark red.

The Angler cattle are native to the peninsula of Angel, which juts out into the Baltic Sea from the east coast of Sleswig-Holstein. The Angler cattle were a rather small, delicate breed, and milky. The weight of a full-grown cow was from 550 to 775 pounds. Their general color was a light red or medium red, frequently with white markings on the belly. A red spotted color was sometimes found.

The North Sleswig breed originated in an area lying between, and somewhat north of, the areas of the Ballum and Angler breeds. The size of the breed was a blending of the Ballum and Angler breeds, with the Ballum cattle having the greatest influence. The Sleswig retained, in part, the milking qualities of the Angler, and yet had a tendency to be beefy, similar to the Ballum. The color, in general, was dark red with nearly black heads and legs.

The first recognition of the breed as the Red Danish occurred at the Fourteenth Farmers Assembly (dairy show), Svendborg, Funen, 1878, where, for the first time, there appeared an entry class "Red Danish Cattle of Pure Race." Prior to that time, the cattle were either called Angler or "Red Funen Milk Cattle." The latter of the two early names was rather popular, and actually did not recede until the first Provincial Herd Book was published in 1885 on Sealand, when the name "Red Danish Milkrace" was used as the official designation of all red cattle, which, in a few years, was quite generally accepted all over Denmark.

A special impetus was given to the Red Danish breed due to the agricultural crisis of the years around 1880. The Danish grain farmer could not compete with American- and European-grown grains. The price of butter remained high, and a shift was made to dairying. A movement was made to organize cow-testing associations to help select the best cows and bulls. Consequently, these associations--the first starting in 1895--spread all over Denmark and the world. Today Denmark still remains as the leader in cow and progeny testing for herd development.

Importation to the United States

During the 1930's the United States Department of Agriculture conducted an extensive search for plants and animals superior in their production and genetic quality, hoping to introduce them into the United States agricultural system. Since Denmark had the highest average production per cow in the world, importation of the Red Danish Milkrace would be desirable for future study. The average cow in Denmark produced about 100 pounds more butterfat per year than the average cow in the United States. The cows entered in the Danish herd book during 1931 had produced an average of 559 pounds of butterfat, some of them being milked three times a day (Reed and Fohrman, 1946). In 1935, Dean E. L. Anthony of Michigan State College was appointed by the USDA to go to Denmark to select animals for a foundation herd to be used in the United States for study of their production characteristics and transmitting qualities.

An importation of two bulls and twenty cows was made. The animals came from the Islands Funen and Zealand. The cattle from Funen were selected from two herds in the southern part, while those from Zealand were from two farms in the central part and one in the southernmost tip (Anthony, 1952). This herd

eventually was located at the Beltsville Research Center, and has been supervised by specialists of the Dairy Bureau of the USDA. A program was instituted to study the genetic worth of the Red Danish Milkrace.

Entrance Into Michigan

By 1939, there was a surplus of young bulls produced from this herd. In cooperative arrangement with the Dairy Bureau Industry of the USDA and the Extension Service of Michigan State College, bulls from the Beltsville herd were placed with several cooperating dairy farmers in Michigan. According to Baltzer (1952), the project was for the purpose of proving these Red Danish Milkrace bulls in order to make available young proved sires for use in the experimental herd at Beltsville.

The program provided that:

1. All cooperating herds would be under production testing in the DHIA.

2. The entire herd would be subscribed to the Red Danish sire project.

3. All females would be kept for at least one lactation record.

4. Replacement of original foundation cows would be made as rapidly as possible with the cross females.

5. All bull calves produced through the project would be castrated.

6. The herds would maintain a Bangs and T.B. health program.

Development of the Red Danish Cattle in Michigan

On January 25, 1939, a meeting was held in Sanilac County, Michigan, by ten local dairymen to form a Red Dane bull association for introduction of the Red Dane bulls to be used in the project. These dairymen subscribed their herds, consisting of 248 cows of the various dairy breeds, to the program. Four of the farmers were appointed bullkeepers for this bull association. On February 17, 1939, four Red Danish bulls arrived at Marlette, Sanilac County, Michigan, to mark the first entrance of Red Danish cattle into Michigan

Interest in this project grew among dairymen in other sections of the state. In June, 1939, a Red Dane bull association was formed in Alcona County, Michigan, with twelve breeders subscribing

their herds consisting of 213 cows. Oscoda County dairy farmers formed a Red Dane bull association of four bull blocks consisting of thirty herds and 230 cows, in November, 1941.

With the advent of artificial insemination, numerous dairymen professed interest in securing artificial service from Red Danish bulls. In the spring of 1945, Red Dane bulls were placed in artificial service. During the period 1945 to 1948, two hundred ten breeders subscribed 2,233 cows of the various dairy breeds to be bred artificially to Red Dane bulls. The dairymen that subscribed their herds to the artificial service agreed to abide by the rules described earlier, just as did the breeders using Red Dane bulls by natural service. In July, 1945, twenty-nine breeders from Ogemaw County, subscribing 386 cows to artificial Red Dane service, formed a Red Dane Association; followed by thirty breeders in June, 1946, from Calhoun County, subscribing 285 cows; twenty-one breeders in June, 1946, from Isabella County, subscribing 230 cows; forty-nine breeders in July, 1946, from Iosco County, signing 372 cows; twenty-five breeders in October, 1946, from Tuscola County, entering 250 cows; fourteen breeders in December, 1946, from Barry County, subscribing 140 cows; twenty-six breeders in February, 1948, entering 370 cows; twelve breeders in April, 1948,

from Newaygo County entered 200 cows; and a natural-service group from Lapeer County entered in 1946. Along with this increase of breeders from the above-mentioned counties, the number of breeders in the natural-service blocks also increased.

Of the first 2,956 foundation cows entered in this program, 32.8 percent were Guernsey, 29.0 percent were Holstein, 25.6 percent were Shorthorn kept for dairy purposes, 9.2 percent were Jersey, 2.7 percent were Brown Swiss, 0.10 percent were Ayrshire, and 0.60 percent were of mixed ancestry. The breed of these cows was identified by the DHIA supervisor. If a cow exhibited enough breed characteristics of any one breed, it was classified as such. All of these cows were grade animals.

Origin of the American Red Danish Cattle Association

As early as January, 1943, local Red Dane county association meetings were held and members discussed the possibility of eventual registration of their cattle. In September, 1943, a joint meeting of the Red Dane county associations from Alcona, Oscoda, and Sanilac Counties met to develop standard practices and uniform rules of conduct, and also to discuss and make recommendations for eventual registration. Many meetings were held, and finally

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on January 16, 1948, the American Red Danish Cattle Association was formed. The purpose of this breed association is to promote the breed of Red Danish cattle and to keep proper records of ancestry, production of foundation cows, and of the Red Danish descendants. An open herd book is to be maintained, providing for the registration of third-cross females and fourth-cross males, provided they meet the requirements set forth by the organization (see Appendix, Exhibit A).

GENERAL OBJECTIVES

The objectives of this investigation are:

1. To study the effect of three successive crosses of Purebred Red Danish sires on the average milk and butterfat production, butterfat percentage, and the repeatability and heritability of these characters.

2. To study the contributions of the various Red Danish sires on milk, butterfat, and butterfat percentage based on progeny performances and dam-daughter comparisons.

3. To determine the effect of mild inbreeding as practiced in this population on the yield of milk and butterfat and the occurrence of lethal defects.

4. To study the milk and butterfat records for variation due to major environmental factors peculiar to this particular population.

GENERAL INVESTIGATIONAL PROCEDURE

Source of Data

Since it was compulsory that all cows entered in this program of grading up to Red Danish bulls be DHIA tested, the herd books of the cooperating farmers contain, on all cows, all production records made under this program. In addition to herd testing, an annual calving report was submitted to A. C. Baltzer, Extension Dairyman of Michigan State College, in charge of the project. This report contained the ear tag number of the calf, and the number of the calf's sire. The report included all calves born from September 1 to August 31 of the succeeding year.

With the incorporation of the American Red Dane Cattle Association in 1948 by the breeders in this project, a survey was made in which each breeder listed essential data that was compiled into record form by the association. The files of the association contained all data necessary to identify each animal entered in the program, birth date, sire, dam, progeny and owner. Production data have been kept by the association since 1949.

Collection of Data

For compilation of data relative to this study, a worksheet designed to include all the desired information for each subject was designed (Fig. 1).

The American Red Danish Cattle Association cooperated in providing the following data: the breed or generation of the subject, coded as follows: 01, Guernsey; 02, Holstein; 03, Milking Shorthorn; 04, Jersey; 05, Brown Swiss; 06, Ayrshire; 07, Hereford; 08, Angus; 09, Red Poll; 10, mixed breed; 11, first cross Red Dane; 12, second cross Red Dane; 13, third cross Red Dane; 14, fourth cross Red Dane; 15, fifth cross Red Dane; and 16, sixth cross Red Dane; and the eartag number of the subject, date of birth, color by code: 1, red; 2, black; 3, red and white; 4, black and white; and 5, roan; name of herd owner, tattoo number of the sire, and eartag number of the dam.

As the Red Dane office completed groups of two thousand individual cow worksheets, they were returned in numerical order according to eartag number to the investigator for additional processing. Each ear tag number was entered into a herd book and assigned a code number, the first code number being number 0001, and the succeeding ones being assigned ascending numbers until all were

Figure 1

Cow Worksheet Used in Collecting the Data For This Study

GENERATION							SUBJECT							SIRE			DAM		
F	P	I	A				EAR TAG NO.	REG. NO.	C. NO.	BIRTH DATE	COL.	I. B. C.	H. O. C.	NUMBER	C. NO.	I. B. C.	EAR TAG NO.	C. NO.	I. B. C.
			13	14	15	16													

1	2			3		4	5	6	7	8	9	10	11	12	13	14	15	16	
LAC.	FRES'NG. DATE			FRES'NG. AGE		CALV.	X'S.	365 DA'S. OR LESS	ACT. PRODUCTION 365 DA'S. OR LESS		DISP. OF	REMARKS OF EACH	CALF DESCRIP'T.; EACH FRESH'NG						REMARKS
														BORN				SIRE	
NO.	YR.	MO.	DA.	YR.	MO.	INT.	M'd.	NO. DA'S. MILKED	LB'S. MILK	LB'S. FAT	COW	LACT.	SEX	ALIVE	DEAD	DEFECT	COLOR	NO.	

coded. These code numbers were then entered in the appropriate space on each cow worksheet. The worksheets were then sorted into herd-owner groups. An alphabetical list of the herd owners was made and each was assigned a code number. This number was placed in the respective space on the worksheet. Each herd group was then processed individually for these following data. The worksheets were sorted into ascending year of birth which placed all animals born the same year into the same group. The birth reports for that herd were used to identify the generation and color of each animal which the Red Dane office was unable to supply on about 35 and 95 percent of the worksheets, respectively. The groups for each herd were then sorted by the number of the sire. Consequently, all worksheets having the same sire number came into the same group. A code number for the sire was then entered in the appropriate blanks for each sire group. A list of Red Danish sires used in this project had been made previously by the investigator and coded. To assign the same code numbers to the dams as they had when they were subjects, the worksheets were sorted into ascending order by eartag numbers, since the code number and eartag number are of direct numerical relationship. With the worksheets in this order, it was a relatively easy matter to find rapidly the worksheet of a dam

when used as a subject. Then the code number assigned to the ear-tag number as a subject was transferred to the appropriate blank when she became a dam on a worksheet. If a subject in any one particular herd group had a dam that was located in another herd group, the code number was obtained from the herdbook. All dams appeared as subjects within the same herd group at least 95 percent of the time.

The worksheets for each herd group were then placed into large manila envelopes along with a set of instructions to help the breeder in completing the desired information (see Appendix, Exhibit B). The name and county address of the owner were placed on the outside of each packet. These packets were then grouped together into county groups and sent out to the county agent for each respective county. In some cases the breeders in each county in this program were called in for an instructional meeting of how to properly complete the worksheets; in other instances the county agents visited each breeder and explained the mechanics individually. Figure 1 illustrates the information desired from the breeders. The breeders entered data only beneath the heavy line. Codes were used by the breeders in five instances in completing the worksheet: disposal of the subject, remarks about each lactation, sex of calf,

defects exhibited by calf, and color of calf. Sections 9, 10, 11, 14, and 15 of Figure 2 explain the various codes used for the coding performed by the breeder.

The packets of worksheets when completed by the breeders were either returned to the county agents for return to the investigator or mailed directly to him by the breeders. As the worksheet packets were returned from the breeders, they were inspected for accuracy and completeness.

Placing of Data on IBM Cards

Punching of Data from Worksheets

Some of these data from the worksheets were then punched by key-punch operators into IBM punch cards, designated as Individual Lactation Card No. 1 (Fig. 2), according to the following plan:

Columns Punched	Data Taken from Worksheet
1-2	Generation Number
3-6	Code Number of Subject
7	Color Code of Subject
11-13	Code Number of Owner of Subject
14-17	Code Number of Sire of Subject

Figure 2

IBM Cards 1 and 2

#1 INDIVIDUAL LACTATION CARD

Columns	Field
1-2	GENERATION
3-6	SUBJECT NUMBER
7	COLOR
8-10	I.B.C.
11-13	HERD OWNER
14-17	SIRE NUMBER
18-20	I.B.C. OF SIRE
21-24	DAM NUMBER
25-27	I.B.C. OF DAM
28-29	LACTATION NUMBER
30-33	FRESHENING DATE
34-37	FRESHENING AGE
38-39	CALVING INTERVAL
40	TIMES MILKED
41-43	LENGTH LACTATION
44-48	LB'S. OF MILK
49-51	LB'S. OF FAT
52-54	FACTOR 52.53-54
55-59	52. 53-54 X 44-48 = 55-59 2X 305 M.E. MILK
60-62	49-51 X 52. 53-54 = 60-62 2X 305 M.E. FAT
63-65	60-62 ÷ 55-59 = 63.64-65 (% ANS.)
66-67	DISPOSAL
68-69	REMARKS (EACH LACT.)
70	SEX 1-MALE 2-FEMALE
71	BORN 1-ALIVE 2-DEAD
72-73	DEFECT
74	COLOR
75-78	SIRE NUMBER
79	CODE FOR FRESH'NG. DATE
80	

#2 SUMMARY CARD FROM INDIVIDUAL LACTATION CARD

Columns	Field
1-2	GENERATION
3-6	COW NUMBER (CONTROL)
7-27	TRANSFER COLUMNS 7-27 FROM IND. LACT. CARD
28-29	CARD COUNT (NUMBER)
30-35	55-59 (SUM) 2X 305 M.E. MILK
36-39	60-62 (SUM) 2X 305 M.E. FAT
40-44	30-35 ÷ 28-29
45-47	36-39 ÷ 28-29
48-50	45-47 ÷ 40-44 = 48.49-50 (%)
51-54	63. 64-65 (SUM)
55-61	XY OF I. B. C. X MILK PRODUCTION: 40-44 X 8-10 I.B.C. OF SUBJECT
62-68	XY OF I. B. C. X MILK PRODUCTION: 40-44 X 18-20 I.B.C. OF SIRE
69-74	XY OF I. B. C. X MILK PRODUCTION: 40-44 X 25-27 I.B.C. OF DAM
75-80	

21-24	Code Number of Dam of Subject
28-29	Lactation Number
30-33	Freshening Date--Year, Month, Day
34-37	Freshening Age--Year, Month
38-39	Calving Interval--Months
40	Times Milked Daily
41-43	Length of Lactation
44-48	Pounds of Milk
49 51	Pounds of Fat
68-69	Coded Remarks of Each Lactation
70	Sex of Calf
71-72	Defects of Calf
73	Color of Calf
74-77	Sire Number of Calf

To facilitate key punching, a mask was improvised which hooded everything but the information desired from the worksheets. A card was punched for each lactation listed for a subject. This included all columns from 1 to 77 as listed in the flow chart. Zeros were punched in columns where information for those respective columns were lacking. All cards were punched "verified" by another operator.

Punching of Inbreeding Coefficients

This was accomplished in a rather complicated manner. Without it, however, the task of calculating and entering the coefficients of inbreeding would have been prohibitive for the number involved in this study.

The inbreeding coefficients of the Red Danish bulls had been calculated and printed on the usual long, folded sheet of paper as will be described subsequently under calculations of inbreeding coefficients. A deck of cards--hereafter referred to as "sire-master inbreeding deck"--were punched and verified from this list. The code number and inbreeding coefficient of the sire were punched in Columns 14 to 17, and 18 to 20, respectively, one card per sire.

The inbreeding coefficients of a subject--due to the amount of relationship existing between sires--had been calculated as will be described subsequently under calculations of inbreeding coefficients. A deck of cards--hereafter referred to as "subject-master inbreeding deck"--were punched from the "subject" worksheets. A card containing generation number in Columns 1 to 2, subject number in Columns 3 to 6, subject's inbreeding coefficient in Columns 8 to 10, subject's sire's number in Columns 14 to 17, and subject's dam's number in Columns 21 to 24 was punched for each subject

having an inbreeding coefficient. The "subject-master inbreeding deck" was then sorted behind the "sire-master inbreeding deck" on Columns 14 to 17. This placed all the cards of daughters of a particular sire behind his card. The inbreeding coefficients in the "sire-master inbreeding deck" were transferred to the respective columns in the "subject-master inbreeding deck"--Columns 18 to 20--by gang-punching.

The inbreeding coefficients of the subjects were partial to the extent of needing to be multiplied by the factor $\sqrt{(1 + F_s)(1 + F_d)}$, where F_s is the inbreeding coefficient of the sire and F_d is the inbreeding coefficient of the dam, as described under calculations of inbreeding coefficients. To accomplish this correction it was necessary to sort the "subject-master inbreeding deck" on Columns 1 to 2. This placed the second, third, and fourth generation cards in respective decks. The second generation was the first generation to have inbreeding coefficients; the correction that needed to be made was the factor $\sqrt{1 + F_s}$, since the dams were not inbred. The second generation's "subject-master inbreeding deck" cards were sorted on Columns 18 to 20--sire's inbreeding coefficient--behind a deck of cards, hereafter called "sire inbreeding correction deck," containing the factor

needed to correct for each degree of inbreeding in Columns 18 to 20. The "sire inbreeding correction deck" had been made from a table of factors developed by the investigator which was, in substance, all combinations of $\sqrt{(1 + F_s)(1 + F_d)}$. Each "subject-master inbreeding deck" card fell behind the "sire inbreeding correction deck" card having the same amount of inbreeding in Columns 18 to 20. The correction factor was then gang-punched in Columns 28 to 30 of the "subject-master inbreeding deck." The "subject-master inbreeding deck" was then processed through the 602 Calculator. Columns 8 to 10--containing the subjects' partial inbreeding coefficient--were multiplied by Columns 28 to 30--containing the correction factor, and the sum--the "whole" inbreeding coefficient --was punched in Columns 31 to 33.

The third-generation Red Danish females have as dams the same females appearing as subjects in the second generation. Therefore, it was only a procedure of collation to transfer the inbreeding coefficients from the cards of the second generation's "subject-master inbreeding deck" to the columns designated for the dam's inbreeding coefficient, Columns 25 to 27. The second generation's "subject-master inbreeding deck" was ordered on Columns 3 to 6, and the third generation's "subject-master inbreeding deck" was

ordered on Columns 21 to 24. When the subject's number appearing in Columns 3 to 6 of the second-generation deck was the same as the dam number in Columns 21 to 24--a second-generation subject being a dam in the third generation, the inbreeding coefficient appearing in Columns 30 to 32 of the second-generation deck was transferred to Columns 25 to 27 of the third-generation deck. The set of third-generation ''subject-master inbreeding deck'' cards contained, with respect to inbreeding coefficients, a partial inbreeding coefficient of the subject in Columns 8 to 10--the sire's inbreeding coefficient in Columns 18 to 20 and the dam's inbreeding coefficient in Columns 25 to 27. The procedure to adjust the inbreeding coefficient of the subject from a partial factor to a whole factor was essentially the same as followed with the second generation's ''subject-master inbreeding deck'' cards. The procedure differed slightly, however, since in the third generation, it was possible for the dams to have an inbreeding coefficient whereas in the second generation they did not. This necessitated a slightly different correction factor from that obtained in the expression $\sqrt{(1 + F_s)(1 + F_d)}$. A ''sire-dam inbreeding correction deck'' was punched from the table of correction factors computed by the investigator. The third generation's ''subject-master inbreeding deck'' was sorted on Columns 18

ordered on Columns 21 to 24. When the subject's number appearing in Columns 3 to 6 of the second-generation deck was the same as the dam number in Columns 21 to 24--a second-generation subject being a dam in the third generation, the inbreeding coefficient appearing in Columns 30 to 32 of the second-generation deck was transferred to Columns 25 to 27 of the third-generation deck. The set of third-generation "subject-master inbreeding deck" cards contained, with respect to inbreeding coefficients, a partial inbreeding coefficient of the subject in Columns 8 to 10--the sire's inbreeding coefficient in Columns 18 to 20 and the dam's inbreeding coefficient in Columns 25 to 27. The procedure to adjust the inbreeding coefficient of the subject from a partial factor to a whole factor was essentially the same as followed with the second generation's "subject-master inbreeding deck" cards. The procedure differed slightly, however, since in the third generation, it was possible for the dams to have an inbreeding coefficient whereas in the second generation they did not. This necessitated a slightly different correction factor from that obtained in the expression $\sqrt{(1 + F_s)(1 + F_d)}$. A "sire-dam inbreeding correction deck" was punched from the table of correction factors computed by the investigator. The third generation's "subject-master inbreeding deck" was sorted on Columns 18

to 20, behind the "sire-dam inbreeding correction deck." Then each deck resulting from the sort on Columns 18 to 20 was sorted on Columns 25 to 27. This placed all "subject-master inbreeding deck" cards behind the "sire-dam inbreeding correction deck" card containing the factor needed for multiplication to correct the partial inbreeding coefficient of the subject.

The procedure for ensuing generations was identical with that of the third generation.

The subject lactation cards and the "subject-master inbreeding deck" cards were then ordered on Columns 3 to 6. By collation, the inbreeding coefficients appearing in Columns 14 to 17, 25 to 27, and 30 to 32 of the "subject-master inbreeding deck" cards were transferred to Columns 14 to 17, 25 to 27, and 8 to 10, respectively, of the subject lactation cards. The subject lactation cards then contained the inbreeding coefficients of the subject, sire and dam in Columns 8 to 10, 14 to 17, and 25 to 27, respectively.

Standardization of Records for Age and Length of Records

The data utilized here are the production records of milk, butterfat and butterfat percentage, and ages and dates that concerned each record. All records of a cow--of 270 to 365 in

length--up to and including her tenth lactation were used. The amount of information derived regarding a cow's productive ability rises at a decreasing rate with additional records, particularly after the third record. Records at very advanced ages usually contain a considerable amount of error due to permanent environmental changes such as damage to mammary tissue (Berry, 1945). Berry and Lush (1939) and Lush et al. (1941) discussed the question of omission of records from a cow's average and concluded that the omission of a record known to be made under abnormal circumstances might increase the value of the average. In this study, all records were used, except those followed by abortion 154 days after breeding, or where the record carried notation of an illness or accident deemed serious enough, by the investigator, to affect production. Such records were identified by a code number and sorted out with an IBM sorter, so that omission of a record was impersonal and not affected by its size of production figures. The lifetime average was used as the measure of each cow's producing ability. Berry and Lush (1939) and Berry (1945) proposed a method of correcting for incomplete repeatability where unequal numbers of records are used for the average production of a cow. This method places such averages on a comparable basis and gives

greater weight to deviations from the herd average, where the deviation is based on larger numbers of records. However, Laben and Herman (1950) used this method, as well as the lifetime average of a cow, for comparing dams and daughters and estimating heritability of milk and fat yield and found no increased correlation when using the corrected lactation numbers formula. After weighing all of the facts and theories, it was deemed best to use the lifetime average production figures in the statistical analysis of these data.

Lactation records from 270 to 365 days' length were standardized up or down to a 305-day basis, according to correction factors developed by Dickerson (1941). Corrections for age at freshening were made by application of age correction factors developed by Kendrick (1942). The two factors for age and length of lactation were multiplied together for all possible combinations of age and length of record to secure a single correction factor for easier calculation with the 602 Calculator. Each of these combined factors was then punched in individual master cards, Columns 52 to 54, each master being identified by a breed code number the same as used to indicate breed or generation of the subject. All masters were X'd in Column 74. The mixed breed correction factors were used for all Danish crosses. The following procedure was used to

insert the correction factor required to convert each lactation record to a 2X 305-day mature equivalent record into the Individual Lactation Card No. 1 (Fig. 2).

1. All individual lactation cards were sorted on Column 1. All cards falling in the 1 pocket were either mixed-breed foundation cows or Danish crosses. These were retained together, since the same correction factors were used for both groups. The cards falling on the 0 pocket were then sorted on Column 2. This sort separated these cards into breed decks; these decks were then combined into groups by the order of Ayrshire, Guernsey, and Jersey; Brown Swiss, Milking Shorthorn and Red Poll; and Holstein, respectively, since the correction factors used were computed in that order. This was done by combining all cards falling into the 1, 4, and 6 pockets for the Ayrshire, Jersey, and Guernsey group, combining all cards falling into the 3, 5, and 9 pockets for the Brown Swiss, Milking Shorthorn, and Red Poll group, and keeping the cards falling in the 2 pocket separate as the Holstein group.

2. Each of the above decks were sorted separately to freshening age--Columns 34 to 37--and to length of lactation--Columns 41 to 43--behind the master cards containing the correction factors for the specific group. This procedure placed all lactation cards

needing a specific correction factor for age at freshening and length of lactation behind the master card containing this factor. The cards were then gang-punched, the correction factor transferring from Columns 52 to 54 of the master card to Columns 52 to 54 of the individual lactation cards.

3. The master cards were then separated from all decks by sorting for X in Column 78.

4. The individual lactation cards were then processed through the 602 Calculator by the following calculations:

a. Columns 44-48 X 52.-54 into 55-59 = 305 2X M.E. milk production.

b. Columns 49-51 X 52.-54 into 60-62 = 305 2X M.E. butterfat production.

c. Columns 60-62. ÷ 55-59 into 63-64 = Percentage of butterfat.

(The periods indicate decimal points.)

Calculation of Average Lifetime Production

In order to place all records of a cow on an average lifetime production basis, it was necessary to make another card designated as Summary Card No. 2 (Fig. 2). The data used to make this

card were obtained from Card No. 1, the individual lactation card. Each cow had one card. The procedures were as follows:

1. All individual lactation cards were sorted on Columns 3 to 6.

2. The cards were in order by subject number, with all individual lactation cards of a particular subject in sequence.

3. The tabulator was utilized to make a summary card. When the subject number changed a summary card was punched for each subject showing:

   a. Columns 1-24 = Group transfer of same data from Card No. 1.

   b. Columns 28-29 = A card count which indicated number of lactations being summarized.

   c. Columns 30-35 = Total lifetime 305 2X M.E. milk production, a summation of individual lactations from Card No. 1, Columns 55-59.

   d. Columns 36-39 = Total lifetime 305 2X M.E. butterfat production, a summation of individual butterfat yields from Card No. 1, Columns 60-62.

4. The 602 Calculator was then utilized in order to obtain the average lifetime production of milk and butterfat and calculation

of the butterfat percentage from the total 305 2X M.E. production of milk and butterfat found in Columns 30 to 35 and 36 to 39, respectively. The calculations were as follows:

a. Columns 30-35 ÷ 28-29 into 40-44 = average lifetime milk production.

b. Columns 36-39 ÷ 28-29 into 45-47 = average lifetime butterfat production.

c. Columns 45-47 ÷ 40-44 into 48.49-50 = average lifetime percent of butterfat.

5. Since Card No. 2 had unused columns, these columns were utilized for the calculation of regression of milk production on inbreeding. These calculations gave the cross-product terms for inbreeding X milk production and were as follows, when X = inbreeding coefficients, Y = production:

a. Columns 40-44 X 8-9.10 into 55-61 = XY of subject.

b. Columns 40-44 X 18-19.20 into 62-68 = XY of sire.

c. Columns 40-44 X 25-26.27 into 69-74 = XY of dam.

Calculation of Total Sums of Squares

It was desirous to calculate the total sums of squares for milk and butterfat production, since these statistics are required for calculation of the analysis of variance, intraclass correlation, standard deviation, "t" test, and analysis of covariance using intrasire dam-daughter regression, dam-daughter regressions, dam-daughter correlations, paternal half-sib correlations, and regression of production on inbreeding.

A card, Repeatability Total Sum of Squares Card No. 3, was made in order to perform the calculations (Fig. 3). Each cow had as many cards as she had lactations. The procedures were as follows:

1. All data used in this card were transferred from Card No. 1 in the following sequence:

   a. Columns 1-2 into 1-2 = Generation of subject.

   b. Columns 3-6 into 3-6 = Code number of subject.

   c. Columns 11-13 into 7-9 = Herd owner number.

   d. Columns 14-17 into 10-13 = Sire number of subject.

   e. Columns 21-24 into 14-17 = Dam number of subject.

   f. Columns 55-59 into 18-22 = 305 day 2X M.E. milk production.

Figure 3

IBM Cards 3 and 4

Columns	Field
1-2	GENERATION 1-2 INTO 1-2
3-6	COW NUMBER 3-6 INTO 3-6
7-9	HERD OWNER 11-13 INTO 7-9
10-13	SIRE NUMBER 14-17 INTO 10-13
14-17	DAM NUMBER 21-24 INTO 14-17
18-22	2X 305 M.E. MILK 55-59 INTO 18-22
23-34	LB'S. MILK^2 18-22^2
35-37	2X 305 M.E. FAT 60-62 INTO 35-37
38-43	LB'S. FAT^2 35-37^2
44-46	PERCENT FAT 63.64-65 INTO 44.45-46
47-49	PERCENT FAT^2 44.45-46^2
50-53	FRESHENING DATE 30-33
54-55	CALVING INTERVAL 38-39
56-80	

#4 REPEATABILITY BETWEEN Σ^2 (TRANSFERRED FROM CARD #2)

Columns	Field
1-2	GENERATION 1-2 INTO 1-2
3-6	COW NUMBER 3-6 INTO 3-6
7-10	SIRE NUMBER 14-17 INTO 7-10
11-14	DAM NUMBER 21-24 INTO 11-14
15-16	COW COUNT (NUMBER) 28-29 INTO 15-16
17-22	2X 305 M.E. MILK (TOTAL) 30-35 INTO 17-22
23-34	TOTAL LB'S. MILK^2 17-22^2
35-44	BETWEEN Σ^2 MILK 23-34 ÷ 15-16
45-48	2X 305 M.E. FAT (TOTAL) 36-39 INTO 45-48
49-56	TOTAL LB'S. FAT^2 45-48^2
57-63	BETWEEN Σ^2 FAT 49-56 ÷ 15-16
64-66	HERD OWNER 11-13 INTO 64-66
67-70	51-52. 53-54 INTO 67-68.69-70
71-76	67-68.69-70^2 INTO 71-74.75-76
77-80	71-76 ÷ 15-16 = 77-79.80

g. Columns 60-62 into 35-37 = 305 day 2X M.E. butterfat production.

h. Columns 63.64, 79 into 44.45, 46 = Percent of butterfat.

i. Columns 30-33 into 50-53 = Date of freshening.

j. Columns 38-39 into 54-55 = Length of previous calving interval.

2. The following 602 calculations were performed with the data:

a. Columns $18\text{-}22^2$ into 23-34 = X^2 for milk production.

b. Columns $35\text{-}37^2$ into 38-43 = X^2 for butterfat production.

c. Columns 44.45, 46^2 into 47-48.49 = X^2 for percentage of butterfat.

Calculation of the Between Sums of Squares

The between sums of squares were necessary for each of alyses used to analyze these data. Therefore, these statistics calculated by making another calculation card, Repeatability en Sum of Squares Card No. 4 (Fig. 3). This card served nish all between sums of squares needed and not just the

ility analysis--as the name implies. This was merely an
ation of the card for working purposes.

Each cow had one card and the procedures necessary for
ulation of this card were as follows:

. All data used in this card were transferred from Card
the following order:

a. Columns 1-2 into 1-2 = Generation of subject.

b. Columns 3-6 into 3-6 = Code number of subject.

c. Columns 14-17 into 7-10 = Sire number of subject.

d. Columns 21-24 into 11-14 = Dam number of subject.

e. Columns 28-29 into 15-16 = Card count (number of lactations).

f. Columns 30-35 into 17-22 = Total 305 2X M.E. milk production.

g. Columns 36-39 into 45-48 = Total 305 2X M.E. fat production.

h. Columns 11-13 into 64-66 = Herd owner of subject.

i. Columns 51-52.53-54 into 67, 68.69-70 = Total percent butterfat.

2. The following 602 calculations were performed with the
lata:

a. Columns $17\text{-}22^2$ into 23-34 = $S(X)^2$ for milk production.

b. Columns 23-34 ÷ 15-16 into 35-44 = $[S(X)^2]/n$ for milk production.

c. Columns $45\text{-}48^2$ into 49-56 = $S(X)^2$ for butterfat production.

d. Columns 49-56 ÷ 1516 into 57-64 = resulted in $[S(X)^2]/N$ for butterfat production.

e. Columns 67, 68.-69, 70^2 into 71, 74 .75, 76 = $S(X)^2$ for butterfat percentage.

f. Columns 71-76 ÷ 15-16 into 77-78-80 = $[S(X)^2]/n$ for butterfat percentage.

Calculation of Regression of
Production on Inbreeding

The data needed for this analysis were calculated on a card ed as Regression of Production in Inbreeding Card No. 5). The data needed for the calculations were transferred he Summary Card No. 2, since average lifetime production s were used. One part of the statistic was calculated on lo. 2, as calculating space was not available on Card No. 5.

Figure 4

IBM Cards 5 and 6

Card columns	Field
1-2	GENERATION 1-2 INTO 1-2
3-6	SUBJECT NUMBER 3-6 INTO 3-6
7-9	I.B.C. OF SUBJECT 8-10 INTO 7-9
10-12	I.B.C. OF SIRE 18-20 INTO 10-12
13-15	I.B.C. OF DAM 25-27 INTO 13-15
16-20	AVE. MILK PROD. 40-44 INTO 16-20
21-23	AVE. FAT PROD. 45-47 INTO 21-23
24-29	I.B.C. OF SUBJECT^2 $7\text{-}9^2$
30-35	I.B.C. OF SIRE^2 $10\text{-}12^2$
36-41	I.B.C. OF DAM^2 $13\text{-}15^2$
42-47	XY OF I.B.C. X FAT PROD.: I.B.C. X FAT (SUBJ.) 7-9 X 21-23
48-53	XY OF I.B.C. X FAT PROD.: I.B.C. X FAT (SIRE) 10-12 X 21-23
54-59	XY OF I.B.C. X FAT PROD.: I.B.C. X FAT (DAM) 13-15 X 21-23
60-68	AVE. MILK PROD.^{2} $16\text{-}20^2$
69-74	AVE. FAT PROD.^{2} $21\text{-}23^2$
75-80	SIRE NUMBER

#6 SIRE EVALUATION AND HERITABILITY STUDY

Card columns	Group	Source	Field
1-2	DAUGHTER'S DATA	FROM CARD #2	GENERATION 1-2 INTO 1-2
3-6	DAUGHTER'S DATA	FROM CARD #2	COW NUMBER 3-6 INTO 3-6
7-10	DAUGHTER'S DATA	FROM CARD #2	SIRE NUMBER 14-17 INTO 7-10
11-14	DAUGHTER'S DATA	FROM CARD #2	DAM NUMBER 21-24 INTO 11-14
15-19	DAUGHTER'S DATA	FROM CARD #2	MILK PROD. DAUS. AVE. 40-44 INTO 15-19
20-22	DAUGHTER'S DATA	FROM CARD #2	FAT PROD. DAUS. AVE. 45-47 INTO 20-22
23-31	DAUGHTER'S DATA	FROM CARD #5	MILK PROD.^{2} (AVE.) 60-68 INTO 23-31
32-37	DAUGHTER'S DATA	FROM CARD #5	FAT PROD^2 (AVE.) 69-74 INTO 32-37
38-45			XY OF FAT DAUS. X DAMS 20-22 X 53-55
46-47	DAM'S DATA	FROM CARD #2	CARD COUNT 28-29 INTO 46-47
48-52	DAM'S DATA	FROM CARD #2	MILK PROD. DAM'S AVE. 40-44 INTO 48-52
53-55	DAM'S DATA	FROM CARD #2	FAT PROD. DAM'S AVE 45-47 INTO 53-55
56-64	DAM'S DATA	FROM CARD #5	MILK PROD.^{2} (AVE.) 60-68 INTO 56-64
65-70	DAM'S DATA	FROM CARD #5	FAT PROD^2 (AVE.) 69-74 INTO 65-70
71-80			XY OF MILK DAUS. X DAMS 15-19 X 48-52

The procedure of card make-up and calculations was as

:

1. All data used in this card were transferred from Sum-
Card No. 2 in the following order:

a. Columns 1-2 into 1-2 = Generation of subject.

b. Columns 3-6 into 3-6 = Code number of subject.

c. Columns 8-10 into 7-9 = Inbreeding coefficient of subject.

d. Columns 18-20 into 10-12 = Inbreeding coefficient of sire.

e. Columns 25-27 into 13-15 = Inbreeding coefficient of dam.

f. Columns 40-44 into 16-20 = Average lifetime milk production.

g. Columns 45-47 into 21-23 = Average lifetime butterfat production.

h. Columns 14-17 into 75-78 = Sire's number.

2. The following calculations were made with the 602 Cal-
to obtain the X^2, Y^2, and the cross-product terms of in-
g times butterfat production, where X = inbreeding, Y =
ion.

a. Columns 7-9^2 into 24-29 = X^2 of subject.

b. Columns 10-12^2 into 30-35 = X^2 of sire.

c. Columns 13-15^2 into 36-41 = X^2 of dam.

d. Columns 7-9 X 21-24 into 42-46.47 = XY of subject.

e. Columns 10-12 X 21-23 into 48-51.52 = XY of sire.

f. Columns 13-15 X 21-23 into 53-56.57 = XY of dam.

g. Columns 16-20^2 into 58-66 = Y^2 of subject's milk production.

h. Columns 21-23^2 into 67-71 = Y^2 of subject's butterfat production.

Calculations of Sire Evaluation and Estimates of Heritability

The data involved in this card, the Sire Evaluation and ability Card No. 6 (Fig. 4), were transferred from two cards, No. 2 and Card No. 5.

1. The following data were transferred:

   a. Columns 1-2 into 1-2 = Generation of subject.

   b. Columns 3-6 into 3-6 = Code number of subject.

   c. Columns 14-17 into 7-10 = Sire's number.

   d. Columns 21-24 into 11-14 = Dam's number.

e. Columns 40-44 into 15-19 = Subject's average lifetime milk production.

f. Columns 45-47 into 20-21 = Subject's average lifetime butterfat production.

g. Columns 28-29 into 46-47 = Number of lactations of subject.

2. The cards from Step 1 were then sorted to Columns 11
which placed them in order by dam number. They were then
d against Card No. 2, which was sorted to Columns 3 to 6.
atched a subject of Card No. 2 with her daughter's Card No.
: following information from Card No. 2 was then transferred
natching Card No. 5 (Columns 3 to 6 of Card No. 2 matching
s 11 to 14 of Card No. 6):

a. Columns 40-44 into 48-52 = Dam's average lifetime milk production.

b. Columns 45-47 into 53-55 = Dam's average lifetime butterfat production.

3. The cards were then separated and Card No. 6 from
and 2 was sorted to Columns 3 to 6 and matched with Card
orted to Columns 3 to 6. The following information was
red from Card No. 5 to its matching Card No. 6 (Columns
natching 3 to 6):

a. Columns 57-65 into 23-31 = Subject's average milk production squared.

b. Columns 67-71 into 32-37 = Subject's average butterfat production squared.

4. The cards were then separated and Card No. 6 from s 1, 2, and 3 was sorted to Columns 11 to 14, which placed ı in order by dam number. Card No. 5 was sorted to Cols 3 to 6 and the two cards matched. The following data were sferred from Card No. 5 to its matching Card No. 6 (Columns o 14 matching 3 to 6):

a. Columns 58-66 into 56-64 = Dam's average milk production squared.

b. Columns 67-71 into 65-70 = Dam's average butterfat production squared.

5. Card No. 6 from Steps 1, 2, 3, and 5 was then processed ıgh the 602 Calculator for the following, where X equals dam's uction and Y equals daughter's production:

a. Columns 20-22 X 53-55 into 38-45 = XY of daughter-dam milk production.

b. Columns 15-19 X 48-52 into 71-80 = XY of daughter-dam butterfat production.

Methods Used in Deriving Coefficients of Inbreeding

Bulls

A six-generation pedigree was constructed for all Red Danish ls used in the project. This necessitated the coding of many anils since the pedigrees of the foundation stock were filled in with nes only and it was desirous to have numbers for IBM calculans.

The measure used to calculate the intensity of inbreeding the one developed by Wright (1922) as follows: $F_x = \Sigma[(1/2)n +$ $+ 1(1 + F_a)]$ where F_x is the inbreeding coefficient of animal x; nd n' are the number of generations from sire and dam, respecely, to the common ancestor, and F_a is the inbreeding of the estor itself. However, in the calculations of these data, a ghtly different written formula was used, although the numerical ults were identical with those of Wright's original formula. As ised for IBM technique by Hazel and Lush (1950), the formula is re conveniently written here as $F_x = 2\Sigma[(1/2)n + n'(1 + F_a)]$ ere n and n' are defined as the numbers of generations from subt x through its sire and dam, respectively, to a common ancestor. change in definition of n and n' is, in this case, solely a

nvenience which permits the same cards to be used for computing :her the inbreeding of x or the relationship of x to some other imal.

As previously stated, the coefficients of inbreeding were cal-lated for these data by the IBM procedure described in detail by ızel and Lush (1950). However, this procedure was improved in .e instance, and a further procedure was added to eliminate all .ndwork. This last operation by machine reduces chances of er-›rs in at least five instances--reading, posting, copying, factoring, ıd reposting--when large numbers are involved, such as finding e coefficients of inbreeding and relationships of eighty-seven ani-als as in these data, with 14,847 paths of relationship.

The procedure as outlined by Hazel and Lush reads in one stance as follows: "The cards are machine sorted into hereditary :oups ordered numerically by ancestor number, or alphabetically / ancestor name if ancestors are not numbered. The subgroups ıder each ancestor are ordered by ancestor's offspring. Within ıch subgroup the cards are in order by subject number." This rocedure was changed in the calculations of these data in the fol-›wing ways. The cards were machine sorted in inverse order into ereditary groups ordered numerically by subject number, in this

se no names being used. The subgroups under each subject were dered by ancestor's offspring. Within each subgroup the cards re ordered by ancestor's number.

In Hazel's and Lush's procedure a two-way table is set up and n + n' values are written in the table as they occur on the hered- list. After completing this table, the coefficients for each com- nation of subjects are reduced by combining powers of one-half to ir smallest terms and are then converted to inbreeding coeffi- nts and genic covariances and posted in another two-way table.

In calculating the inbreeding coefficients and genic covariance these data it was decided that to work with two 87 by 87 two- y tables and posting and combining approximately 15,000 n + n' lues would resolve into too many errors and be beyond the scope this study in regards to clerical work involved. Therefore it s decided to formulate a procedure to eliminate these two tables, d, as an end result, have the inbreeding coefficients and genic variances tabulated on the usual long, folded sheet of paper. The ethod evolved consisted of the following steps.

1. Using the hereditary list, a card was punched for each bject and its related subject showing the generation numbers + n') of common ancestor to subject and related subject. By

: other method these generation numbers (n + n') would have
en posted in a two-way table in the cell where the paths of the
bject and related subject cross. When punching these relationship
rds, the smaller subject number should be kept in the left-hand
ld. An example is shown in Figure 5. The sample card illus-
ated in the upper section of Figure 5 is taken from the hereditary
oup listed in the lower section. All subsequent cards were punched
the same manner.

2. There are two possible methods for punching the relation-
ip cards: key-punching and selective reproducing and gang-punch-
g. Due to the wide variations of the number of listings in the
rious hereditary groups, the most efficient method can only be
termined after a preliminary check of the listings of the hered-
ary groups.

In rather extensive hereditary groups and with numerous
cestor offspring subgroups within an ancestor group, the best
ethod would probably be that of key-punching. Although this is
e least desirable method of the two, it does, however, cancel four
the five chances of errors possible in using the two-way tables.
the cards are punch-verified, the chances of reading error is
lso eliminated.

Figure 5

Example of Relationship Card

Columns			
1-4	5-8	9	10
bject	Related Subject	Generations from Subject to Common Ancestor	Generations from Related Subjects to Common Ancestor
504	1505	2	5

bject	Ancestor's Offspring	Ancestor	Side of Pedigree	Generation
504*	2000	1001*	1	2
505	2000	1001	1	5
504*	2023	1001	1	4
505	2023	1001	2	5
507	2021	1001	1	3
509	2021	1001	2	5

* No relationship cards were punched for a subject re-
ed to itself when the common ancestor was on the same side
the pedigree. The above example in the hereditary list illus-
tes this in the case of matching 1504 with 1504 because the
mmon ancestor is on the same side--side 1 or paternal side.
e side does not enter into the matching of different subject num-
rs. For example, 1504 would match with 1507 even though the
e remains as 1. This means they are related through the top
e of the pedigree.

The other method used in this study consisted of taking the riginal deck of hereditary cards, sorting the group to ascending rder on the columns containing the subject number (1 to 4 for lustration), and then working from the hereditary group list. The rst card that appears on the list was taken as a master. The ards to be matched with this card were divided into two groups--hose which contain subject numbers smaller than the master and hose which contain subject numbers greater than the master card. he group with the smaller subject numbers were reproduced into ew cards--Columns 1 to 4 to Columns 1 to 4--also reproducing he generation number. Then the subject number from the master ard was gang-punched into the new cards in the appropriate col-mns. The generation number was also gang-punched from the naster card. The group of cards with the subject numbers larger han the master card was processed the same way with the exception f reversing the fields in the new cards so that the smaller subject umber of the master card remained on the left.

3. After the relationship deck had been completed, the cards vere sorted into decks containing the same total of the two genera-ion numbers appearing in each card. This was done by the fol-owing procedure. The cards were sorted on one of the columns

containing a generation number. The sort results in six decks, 0 through 5 when working with 5 generation pedigrees. These decks were kept separate and each deck was sorted on the other column containing the second generation number. All decks except the 0 deck broke down into 6 decks, the 0 deck into 5. The cards of the second sort were handled in the following manner:

a. Since the column sorted contained only numbers from 0 to 5 (because of using 5 generation pedigrees in this project), at each sort cards fell only into the 0 to 5 pockets.

b. The cards from the 0 deck sort were dropped in storage pockets 1, 2, 3, 4, and 5; cards from the 1 deck sort were dropped in storage pockets 1, 2, 3, 4, 5, and 6; the cards from the 2 deck sort were dropped in storage pockets 2, 3, 4, 5, 6, and 7; cards from the 3 deck sort were dropped in storage pockets 3, 4, 5, 6, 7, and 8; cards from the 4 deck sort were dropped in storage pockets 4, 5, 6, 7, 8, and 9; and the cards from the 5 deck sort were dropped in pockets 5, 6, 7, 8, 9, and 10.

c. All cards in storage pocket 1 had a generation total of $(1/2)^1$; cards in storage pocket 2 had a generation total of $(1/2)^2$ and so on, for cards in pockets 3, 4, 5, 6, 7, 8, 9, and 10.

4. A master card with a coefficient corresponding to the generation total was placed with each stack of cards from the storage pockets and this coefficient was gang-punched into the selected columns.

5. The relationship cards were then sorted to ascending order by sorting on subject number and related subject number using the two as one number.

6. This sort was then tabulated with minor control on subject relation number. The printed list will have the coefficient of relationships of any one animal with all other animals in the study and the coefficient of relationship to itself. An example is given in Figure 6.

Females

The measure most commonly used to calculate inbreeding coefficients has been referred to on pages 47 and 48. Lush (1949) presented a method whereby the genic covariance between sire and

Figure 6

Relationship List

Subject	Related Subject	Relationship
1507	1507	.1250*
1507	1508	2650
1507	1509	3356
1507	1510	5625
1508	1508	0625*
1508	1509	1462
1508	1510	1325
1508	1511	2121
1508	1512	1913

* This relationship of an animal to itself multiplied by 2 will give the correct F_x for any particular animal. The proof for this was given on pages 47 and 48.

dam of subject X is used. In this method $F_x = [Rs_d/2] \times \sqrt{(1 + F_s)(1 + F_d)}$, where F_x is the same as in Wright's equation, Rs_d is the relationship between sire and dam, and $\sqrt{(1 + F_s)(1 + F_d)}$ is the square root of one plus the sire's inbreeding coefficient times one plus the dam's inbreeding coefficient. F_x may likewise be determined by the summation of certain fractions of the genic covariance between the sire and all of the sires appearing in the bottom half of the pedigree. The equation for this method may be conveniently written as $F_x = RsMgsi/4 + RsMgsj/8 + RsMgsk/16$, depending on number of generation used, times $\sqrt{(1 + F_s)(1 + F_d)}$, where RsMgsi/4 is the one-fourth of the genic covariance of sire and maternal grandsire, RsMgsj/8 is one-eighth of the genic covariance of sire and maternal great grandsire, RsMgsk/16 is one-sixteenth the genic covariance of sire and maternal great, great, grandsire, and $\sqrt{(1 + F_s)(1 + F_d)}$ is the same as defined earlier.

Since the genic covariance of all Red Danish bulls used in this project had been calculated and printed on the usual long, folded sheet of paper, it was decided to use the last described method for the calculation of the inbreeding coefficients of the female crosses.

The females in this study were the progeny of a succession of four generations of Red Danish sires bred to the various dairy breeds and to the subsequent resulting cross females. Therefore the first generation females were not inbred due to the out-cross of Red Dane to an unrelated breed. The second generation females, however, were inbred if the sire and dam's sire, both Red Danish, were related. The calculation equation for the inbreeding of this cross can be written as $F_x = RsMgsi/4 \times \sqrt{(1 + F_s)(1 + F_d)}$. In the third generation, there were two Red Danish sires in the bottom half of the pedigree, consequently the equation for calculating these inbreeding coefficients was $F_x = [RsMgsi/4 + RsMgsj/8] \times \sqrt{(1 + F_s)(1 + F_d)}$. Since in the fourth generation female pedigrees, three Red Danish sires appeared in the bottom half of the pedigree, the equation for the inbreeding coefficients was $F_x = [RsMgsi/4 + RsMgsj/8] \times \sqrt{(1 + F_s)(1 + F_d)}$.

The part of the equation due to the genic covariance of the sires in question was obtained from the genic covariance listing of Red Danish sire, previously explained. It was a matter of determining the sire and the sires on maternal side of pedigree for the various crosses and by referring to the genic covariance listing and dividing the product listed as the relationship between the sires in

question by the proper divisor. These relationships could also be multiplied by the proper fraction, 0.25, 0.125, or 0.0625, as the case may be, for easier calculation. For the second, third, and fourth generation animals, it was conveniently done by using the accumulation multiplier and calculating a final product which was the part of the inbreeding coefficient due to the relationship between sire and dam.

Unless the sire and the dam are highly inbred, the term under the square root sign will not differ much from 1.0; it would be approximately correct to say that the inbreeding of the offspring is one-half of the relationship between its parents. However, in this study the term under the square root sign was calculated and multiplied times the term due to the relationship between the parents. To facilitate the addition of the part of the inbreeding coefficient due to the term under the square root sign, a table of calculated values was constructed and a "sire and dam correction inbreeding deck" of IBM cards was punched from the table to enable addition of the term by IBM processes. This is described under punching of inbreeding coefficients.

AVERAGE MILK AND BUTTERFAT PRODUCTION, REPEATABILITY, AND HERITABILITY OF COWS RESULTING FROM THREE SUCCESSIVE CROSSES OF PUREBRED RED DANISH SIRES

Review of Literature

Grading-Up Effect

Introduction

Observations by breeders have long established that crossbreeding corrected the deleterious results often found in inbreeding, in which the undesirable recessive genes come together in the homozygous phase. Observations have also indicated that mating animals less closely related than that occurring in random breeding produces offspring with increased size and production as compared to inbred or purebred animals. In 1914 it was suggested that this increase be called heterosis (Shull, 1948). The American Society of Animal Production Committee on Investigations (1940) accepted heterosis as being synonymous with hybrid vigor from the standpoint of its usage in animal breeding. They define heterosis as the superiority that is exhibited by the progeny over the better parent. This applies

to the progeny from crossing of strains, lines, varieties, breeds, and species.

A brief, recent review of the different degrees of crossbreeding animals is given by Gilmore (1952). In general these experiments with subgenera, species and breed-crossings indicate that higher production can be obtained in fewer generations than with selection within the breed. However, the results to date indicate that just as great performance can be obtained with continued selection within the breed. A longer time is required, however, and culling must be judicious and continuous. Reed (1951) reported that the first ten Red Sindhi-Jersey heifers tested at Beltsville averaged 8,717 pounds of milk and 515.6 pounds of butterfat actual production milked three times daily, mostly 365 days in length. A total of 139 crossbred females of various ages were on hand at the end of June, 1951. Of the total number, one hundred fourteen are 50 percent Sindhi, fifteen are 75 percent Sindhi, and ten are 25 percent Sindhi, the rest of their breeding being Jersey, Brown Swiss, or Holstein. The ultimate objective of that breeding project is to develop heat-resistant strains of milking cows for the south.

The purpose of this study was to determine the effect of three successive crosses of Red Danish bulls on average milk

and butterfat production and butterfat percentage, when crossed with the various dairy breeds. An attempt was also made to observe if any heterosis had occurred in the first crossbred generation.

Crossbreeding the Dairy Breeds

The success of Mendelism, after its rediscovery in 1900, in explaining satisfactorily the mechanism of the inheritance of the more distinct physical differences between animals led to the setting up of several crossbreeding experiments in dairy cattle. Wriedt (1930) reported what is perhaps the earliest crossing between two dairy breeds--begun in Denmark in 1906 in a herd containing purebred Red Danish Milkrace and purebred Jersey cattle. Jersey bulls were used on both Red Danish Milkrace and Jersey cows. The object of the experiment was partly to analyze the genetic control of production characteristics, particularly that of butterfat percentage.

The investigations comprised a total of 1,175 cows. Included were the Red Danish Milkrace dams, their purebred daughters, the purebred daughters from the Jersey bulls used in crossing back, and all the crossbred cows of various degrees of crossbreeding. Table I shows the results of this experiment reported for 70-day

TABLE I

(From Wriedt, 1930).

Breed	Milk Yield in First 70 Days (lbs.)	Fat Content (%)	Fat Yield in First 70 Days (lbs.)
Red Danish Milkrace (175)	1,694	3.40	67
F_1 (71)	1,574	4.39	80
Purebred Jersey (116)	1,350	5.57	87

yields of milk and fat content in the first lactation. The number of animals involved in each group makes the data very meaningful. The Jersey purebreds used for comparison to the Jersey parental breed were daughters of the bulls that sired the F_1 and the Red Danish Milkrace are the dams of the F_1. The means of the parental breeds are 1,522 pounds of milk, 4.48 percent butterfat content, and 77 pounds butterfat yield, respectively, for the seventy days observed. The F_1 yield is very close to the means of the parental breeds for all these characters. Reciprocal crosses showed no consistent differences.

The author concluded that one genetic factor was responsible for the difference between the two breeds, basing such conclusion on the butterfat percentage in the milk of Jersey and Red Danish cattle and 108 F_1 hybrids, 42 backcrosses to Red Dane bulls, and 49 backcrosses to Jersey bulls. The gene for high fat content had an equal effect whether it was united with a gene for high or for low fat content. There were also indications that some Jersey bulls carried a modifying gene for increased fat percentage.

In 1911, crossings between two dairy breeds were begun by T. J. Bowlker in Massachusetts--a private breeder mating Guernseys and Holsteins reciprocally. Castle (1919) reported that the object of this experiment was to obtain females with capacity to produce as much milk as the Holsteins and have the high test of the Guernseys. In 1919 the entire project was turned over to the University of Illinois. At this time, twenty-three F_1 Guernsey X Holstein and eight of the reciprocal cross had finished records. The fat production for these two groups was 265 pounds and 287 pounds, respectively, as compared to 261 pounds for twenty-four purebred Holstein dams and an estimated 231 pounds for eight purebred Guernsey dams (the national average for the breed at this time). While the production of fat for the crossbreds is greater

for each group than for either parent, the significance of the differences has not been determined. Gilmore (1952) analyzed these available data in terms of Fat Corrected Milk and found the calculated amounts to be intermediate between females. Although additional reports were published concerning this experiment--Yapp (1929, 1930, 1931), the data contained therein were inconclusive and unsuitable for comparisons between crosses and parental breeds.

Schmidt (1948) made a study of the crossing of Black Pied Lowland cows (Friesian) and Jersey bulls. The F_1 generation suggested strongly that hybrid vigor (heterosis) actually was found in this cross. However, there was some suggestion that the Friesian cows selected for this experiment had a rather low butterfat percentage. Table II shows the production values for the F_1 cross as compared to the parental breeds. The Friesian cows were the dams of the F_1 crossbreds and the Jerseys were a group of unrelated cows under the same management. The four Jersey bulls that sired the F_1 crosses were selected from high butterfat percentage dams. The F_1 cross lies between the parental breeds in both milk yield and butterfat percentage, but sufficiently above the mean in both cases to be considerably above that of either parent breed for fat yield. Although these results approach the definition of

TABLE II

(From Schmidt, 1948)

Breed	305-Day Yield First Lactation (lbs.)	Fat Content (%)	Protein (%)	Lactose (%)	Fat Yield (lbs.)
Friesian (12)	6,527	3.12	3.11	4.50	237
F_1 (12)	6,166	5.05	3.37	4.66	362
Jersey (19)	4,555	5.65	3.36	4.60	293

heterosis, as defined by the American Society of Animal Production Committee on Investigations (1942), the number of animals was so small that it could well be due to that of random chance.

The Bureau of Dairy Industry at Beltsville, Maryland, initiated the most extensive experiments to date in crossing dairy breeds. Reed (1945) reported that four dairy breeds were included in the experiment--Holsteins, Jerseys, Guernseys, and Red Danes. All the foundation animals, both males and females, were of known producing and transmitting ability, and it was felt that blending this proved stock would bring forth any hybrid vigor that might result from crossing breeds.

The major plan of the experiment differs from the usual pattern of crossbreeding, in that it calls for continuous introduction of new genes through the use of proved sires of the respective breeds. The females resulting from the mating of two breeds --Holstein and Jersey for example--were mated to the Red Dane sire for the three-breed crosses. The resulting three-breed females in this case were then mated to either a Jersey or Holstein proved sire in the second round of the three breeds involved. Preliminary reports by Reed (1946, 1947, 1948, 1949, 1950), La Master et al. (1950), and Fohrman (1943, 1947) show that the two-breed cows produced more than their straight-bred dams.

Results reported by Reed (1951) show that the three- and four-breed cows have produced slightly more milk and butterfat than their two-breed dams. All crossbred cows were tested at Beltsville as first-calf heifers, and were milked three times a day for 365 days. After completion of their first lactation records, they were sent to cooperators' herds for further study under more practical farm conditions, where they were milked twice a day for 305 days or less for several lactations.

Under first-calving conditions--at approximate average calving age, the two-breed cows produced on the average 2,868 pounds of milk and 143 pounds of butterfat more than did their

purebred dams. The 81 three- and four-breed cows tested to date at Beltsville averaged 290 pounds of milk and 7 pounds of butterfat more than did their two-breed dams. Under farm conditions, however, the three-breed cows continued to produce more than the two-breed cows. Table III shows an even more striking difference between the two crosses. Even though these data for any one lactation period were produced at different years of environmental conditions, it is no doubt safe to assume that the second lactation of the three-breed cows was made the same year as the fourth lactation of the two-breed cows--their dams. Not taking into consideration the advantage of two years and three months of age that the two-breed cows have over the three-breed cows in comparing the fourth and second lactations of the two crosses, respectively, the three-breed cows have produced 995 pounds of milk and 33 pounds of butterfat more than the two-breed cows, under practical farm conditions.

Robertson (1949), appraising the crossbreeding experiments with dairy cattle, concluded that while all the conditions of an ideal experiment had not been met by the Beltsville station, some logical conclusions could be drawn. Gilmore (1952) concluded that if it could be assumed that the dams of the thirty-eight crossbred cows

TABLE III

AVERAGE PRODUCTION OF THE BELTSVILLE CROSSBRED COWS IN FIVE COOPERATOR HERDS
(actual production 2 X 365 days or less)
(From Reed, 1951)

Lactation	Cows Tested	Milk	Butterfat		Calving Age
			Percent	Pounds	
			Two-Breed Cows		
Second	39	10,319	4.39	449	3 yrs., 7 mos.
Third	33	10,781	4.38	466	4 yrs., 6 mos.
Fourth	26	10,544	4.42	460	5 yrs., 9 mos.
			Three-Breed Cows		
Second	35	11,539	4.31	493	3 yrs., 6 mos.
Third	21	11,758	4.36	511	4 yrs., 8 mos.

are relatively similar in genotype to the dams of the forty-one purebred cows, the difference of 120 pounds of butterfat in favor of the crossbreeds is strikingly significant as reported by Fohrman (1949). This seems to be a heterosis effect of about 15 to 25 percent. Similar results with fat-corrected milk were obtained

by La Master *et al.* (1950) with fewer cows. If this temporary conclusion on the appearance of heterosis is substantiated, it will be the first clear-cut case, with large numbers recorded, in which dairy cattle are involved.

Grading Up

Few experiments have been planned to show "grading up." However, this type of breeding has been practiced by thousands of breeders who use a succession of registered bulls. After the successive use of this system, grade cattle become indistinguishable from purebred cattle in all measurable genetic characteristics. Still they are ineligible for registration in closed herdbooks.

What was perhaps the first planned grading-up experiment was started in 1907 at Iowa State College. The object of this experiment was to determine the influence of a succession of purebred sires on the production of progeny from foundation scrub cows, as well as the effect of improved feeding and management. McCandlish *et al.* (1919) reported a preliminary analysis of this experiment. Improvement of the environment of the foundation cows --they were moved from Arkansas farm conditions to the conditions of the college herd--caused an increase in production of 14 percent

more milk and 8 percent more fat for mature cows. Those coming in the herd as heifers increased 27 percent in milk and 24 percent in fat production. Three cows--sired by scrub bulls which were either purchased as calves or dropped on the farm--showed an increase of 10 percent in milk and 13 percent in fat. The authors concluded this was due to the more favorable surroundings.

First-generation grades sired by purebred bulls of Holstein, Guernsey, and Jersey breeds showed an average increased production of 39 percent in milk and 35 percent in fat yield. Still the first generation Guernsey grades were quite variable, one decreasing 31 percent in milk and 23 percent in fat yield under her scrub dam. The Holstein and Jersey crosses increased production in all instances. The second-generation grades--when averaged irrespective of breed of sire--showed an increase of 130 percent in milk and 109 percent in fat over the scrub foundation cows. The persistency of production of the grades increased progressively with the generation number. The investigators concluded that grading up of scrubs through the use of purebred sires increased production.

Weaver et al. (1928) reported a further analysis of this experiment. Although the number of cows completing records during the interim of the ten years was relatively small, findings for the

first and second generation grades were essentially the same as those in the earlier report. These results of the first and second generation grades established the value of purebred sires in grading up a herd from common stock. However, it was deemed desirable to continue the grading up with at least one of the breeds, to determine how far the grading up might be continued before a point was reached beyond which increases would not be easily secured.

The matings were carried beyond the second generation only in the case of the Holsteins. The production of four third-generation Holsteins averaged 139 percent greater than that of the scrub cows. They manifested an increase of only 6 percent over their second-cross dams. There were only three grades of the fourth generation to complete records of which the authors take cognizance as being small in number. All three produced less than their third-generation dams--an average decrease of 15 percent. The authors therefore concluded that a point in production had been reached with the third-generation Holstein grades beyond which further improvement could not be regularly anticipated.

Olson and Biggars (1922) reported the results of grading up of grade beef animals by use of purebred dairy sires at the South Dakota station. Their results, consisting of first and second

generation grades, are in close harmony with those of the Iowa experiment.

Skvorcov and Basov (1940) reported the results of grading up of Siberian grade dairy animals with purebred Simmental bulls. The performance of 93 first- and second-generation crosses yielded an average increase in production of 38.1 percent in milk and 25 percent in butterfat over the foundation dams. Garkavi (1945) appraised a grading-up plan aimed at accelerating the production efficiency of cattle on collective and state farms in Russia. He estimated it would take twenty-five to twenty-nine years for a herd of local unimproved cattle to reach a graded-up point of fifth-generation animals. He found, according to the 1939 census, that 84.5 percent of the cows in the collective and state farm herds were first-generation--or more--crosses. In fourth-generation East Friesian and Siberian crosses the butterfat percentage had fallen from 4.2 percent to 3.2 percent, while in fourth generation Simmental and Siberian crosses it was 3.9 percent.

A report on the attempts of grading up native Brazilian cattle with European dairy breeds has been made by Rhoad (1943). The first-generation crosses--resulting from using European dairy bulls on native cattle like the Caracii and Crialo--increased in

milk production. However, further grading up tended to result in inferior animals progressively less well adapted to the environmental surroundings of that region. Valerani (1951) found that the use of Friesian bulls on grade Brown Swiss cows in Italy increased production. Over 15 years, the respective milk yields of the crossbred or graded-up F_1, F_2, F_3, and F_4 cows were 27.6, 35.3, 41.8, and 50.0 percent more, respectively, than the original Brown Swiss dams.

Repeatability of Milk, Butterfat, and Butterfat Percentage

Introduction

Repeatability may be defined as the regression of future performances of phenotype on past performances as measured by the expression of one trait.

Many of an animal's important characteristics vary in their phenotypic expression from one time to another--thereby reducing the repeatability value of that trait. Most of the variations from one time to another are due to variations in the environment which prevail during the expression of the character. A knowledge of repeatability of economic characteristics in modern animal

breeding and selection techniques has become a tool of considerable value, since it is impossible to correct for incomplete repeatability due to environmental factors. Many correction factors have been devised to correct characteristics so that they have more complete repeatability, but the law of diminishing returns usually makes it scarcely worth while to use more than two or three of the most important correction factors.

The purpose of this study was to determine the repeatability estimates for milk and butterfat production of the American Red Danish cattle population. These estimates were necessary in predicting the real producing ability of a cow. It is important that the Red Danish breeders know these statistics for use in their breeding operations.

Methods For Estimating Repeatability

Partial correlation. Stewart (1945) used the partial correlation method for estimating repeatability of prolificacy in swine. Since repeatability (R) is defined as the regression of future performance of phenotype as measured in one expression of a trait, it may logically be estimated by the regression of the second record

on the first. Prasad (1951) explained the equations used in regressing one record on another as follows:

Let (1) and (2) denote the first and second records, respectively, then the regression coefficient is $b_{21} = [Cov._{12}]/\Sigma_1^2$ where $Cov._{12}$ estimates $\sigma y^2 + \sigma c^2$, and Σ_1^2 estimates σp^2 such that $b_{21} = [\sigma y^2 + \sigma c^2]/\sigma p^2$ and $b_{21} = R$.

The correlation coefficient of the first and second record is: $r_{21} = [Cov._{21}]/\sqrt{\Sigma_2^2 \ \Sigma_1^2}$. Provided there has been no selection, the expectation of Σ_2^2 and Σ_1^2 is identical, and thus $r_{21} = [\sigma y^2 + \sigma c^2]/\sigma p^2$, which is equivalent to the regression procedure.

Analysis of variance. Dickerson (1940), Briquet and Lush (1947), and Chandrashaker (1951) have reported the use of the analysis of variance method for determining repeatability. The formula, $R = [\Sigma^2$ within individuals$] \div [\Sigma^2$ within individuals $+ \Sigma^2$ between individuals], where Σ^2 within individuals and Σ^2 between individuals are the variances or mean square components of an analysis of variance, was used by the above investigators to determine an estimate of repeatability between successive phenotypic expressions of a trait.

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Let (1) and (2) denote the first and second records, respectively, then the regression coefficient is

$b_{21} = [\text{Cov.}_{12}]/\Sigma_1^2$ where Cov._{12} estimates $\sigma y^2 + \sigma c^2$, and Σ_1^2 estimates σp^2 such that $b_{21} = [\sigma y^2 + \sigma c^2]/\sigma p^2$ and $b_{21} = R$.

The correlation coefficient of the first and second record is: $r_{21} = [\text{Cov.}_{21}]/\sqrt{\Sigma_2^2 \; \Sigma_1^2}$. Provided there has been no selection, the expectation of Σ_2^2 and Σ_1^2 is identical, and thus $r_{21} = [\sigma y^2 + \sigma c^2]/\sigma p^2$, which is equivalent to the regression procedure.

Analysis of variance. Dickerson (1940), Briquet and Lush (1947), and Chandrashaker (1951) have reported the use of the analysis of variance method for determining repeatability. The formula, $R = [\Sigma^2$ within individuals$] \div [\Sigma^2$ within individuals $+ \Sigma^2$ between individuals$]$, where Σ^2 within individuals and Σ^2 between individuals are the variances or mean square components of an analysis of variance, was used by the above investigators to determine an estimate of repeatability between successive phenotypic expressions of a trait.

Intraclass correlation. This method--permitting the use of all the records by each individual (Snedecor, 1950)--was demonstrated by Lush and Molln (1942) and Prasad (1951).

The intraclass correlation coefficient, r_1, is found such that $r_1 = [m_1 - m_2] \div [m_1 + (K - 1)m_2] = [\sigma_i^2] \div [\sigma^2 + \sigma_i^2]$, where m_1 is the mean square between individuals, m_2 is the mean square between records by the same individual, and K is the number of records per individual. However, if the number of records for all individuals is not the same, K is something less than the mean number and for the intraclass correlation is found by the formula: $K_o = [1/(n - 1)][\Sigma K - (\Sigma K^2/\Sigma K)]$.

Estimates of Repeatability

Linfield (1900), in a study of production records at the Utah Station, published what is probably the first attempt to estimate repeatability of production characteristics of dairy cattle in the United States. He concluded that the average of several years' production was the most reliable index of a cow's productive capacity, since there is a large variation between the records of the same cow. Gavin (1913b) contributed to the early work in estimates

of repeatability and found, when studying over two thousand Holstein-Friesian and Shorthorn production records, that the correlation coefficient between successive records did not rise above 0.6.

Since those early works were published, numerous reports have been published giving estimates of repeatability of production records in dairy cattle. For the sake of brevity, these have been set out in tabular form in Table IV.

Heritability of Production of Milk, Butterfat, and Butterfat Percentage

Introduction

Heritability can be defined as that fraction of the observed or phenotypic variance which is caused by differences between genes or the genotypes of the individuals in a particular population (Lush, 1949). Under this definition it can be used in both a broad and a narrow sense. In a narrow sense, the heritability of a characteristic refers to the degree to which observed variation in that characteristic is due to the average effects of the genes carried by each individual. In a broad sense, the heritability of a characteristic refers to the functioning of the whole genotype as a unit in contrast to the environment. However, according to the Mendelian

TABLE IV

ESTIMATES OF REPEATABILITY FOR PRODUCTION CHARACTERISTICS IN DAIRY CATTLE

Repeat-ability	Method Used to Determine Repeatability	Reference
	I. Repeatability: A. Milk	
0.60	Correlation between records (Holstein-Friesian, Shorthorn 7 day)	Gavin (1913b)
0.67	Intrabreed correlation (Holstein-Friesian A. R.)	Gowen and Gowen (1922)
0.73	Within-herd correlation (Corrected for all environment factors)	Sanders (1930)
0.52	Within-herd correlation (Uncorrected records)	Sanders (1930)
0.50	Intraherd correlation (Correction of Gowen, 1922)	Dickerson (1941)
0.26	Intraherd correlation (Uncorrected for age and calving interval)	Dickerson (1940)
0.35	Intraherd correlation (Corrected for age and calving interval)	Dickerson (1940)
0.55	Intraherd correlation (Guernsey)	Gowen (1924b)
0.50	Intraherd correlation (Jersey)	Gowen (1934)

TABLE IV (Continued)

Repeat-ability	Method Used to Determine Repeatability	Reference
0.50	Intraherd correlation (Holstein-Friesian A. R.)	Verna (1945)
0.48	First record over the later records	Lush and Strauss (1942)
0.29	Intraherd correlation (Holstein-Friesian 305 day, uncorrected)	Laben and Herman (1950)
0.34	Intraherd correlation (Holstein-Friesian 305 day, herd test, 2X.)	Laben and Herman (1950)
0.40	Intraherd correlation (Holstein-Friesian 305 day, 2X. M. E. Association Factors)	Laben and Herman (1950)
0.44	Intraherd correlation (Holstein-Friesian 305 day, 2X. M. E. calculated factors)	Laben and Herman (1950)
0.45	Analysis of Variance (Holstein-Friesian)	Chandrashaker (1951)
0.56	Analysis of Variance (Jersey)	Chandrashaker (1951)
0.49	Analysis of Variance (Guernsey)	Chandrashaker (1951)
0.12	Analysis of Variance (Ayrshire)	Chandrashaker (1951)

TABLE IV (Continued)

Repeat-ability	Method Used to Determine Repeatability	Reference
0.70	Analysis of Variance (Brown Swiss)	Chandrashaker (1951)
0.49	Analysis of Variance (Combined 5 breeds)	Chandrashaker (1951)
	II. Repeatability: B. Butterfat	
0.60	Intrabreed correlation	Gavin (1913b)
0.69	Intrabreed correlation (Jersey A. R.)	Gowen (1920c)
0.71	Intrabreed correlation (Holstein-Friesian A. R.)	Gowen (1924a)
0.55	Intraherd analysis of variance (C. T. A. Records)	Harris *et al*. (1934)
0.33	Intraherd analysis of variance (Random records from same herd)	Harris *et al*. (1934)
0.33	Intraherd analysis of variance (Average between records of same cow)	Harris *et al*. (1934)
0.60	Intrabreed correlation (All herds)	Plum (1935)
0.40	Intraherd analysis of variance	Plum (1935)

TABLE IV (Continued)

Repeat-ability	Method Used to Determine Repeatability	Reference
0.51	Correlation between successive records (Guernsey A. R. partial records)	Gaines (1936)
0.68	Correlation between successive records (Guernsey A. R. 365 day records)	Gaines (1936)
0.43	First records over later records	Lush and Arnold (1937)
0.75	Intrabreed correlation (Jersey A. R.)	Copeland (1938)
0.88	Intrabreed correlation (Jersey H. I. R.)	Copeland (1938)
0.68	Intrabreed correlation (Holstein-Friesian H. I. R.)	Berry and Lush (1939)
0.43	First records over later records	Lush (1940)
0.34	Intraherd correlation	Dickerson (1940b)
0.36	Intraherd correlation (Swedish records)	Johansson and Hanson (1940)
0.43	First and later record correlation (Iowa DHIA records)	Lush and Strauss (1942)

TABLE IV (Continued)

Repeat-ability	Method Used to Determine Repeatability	Reference
0.40	First and later record correlation (Holstein H. I. R. records)	Lush and Strauss (1942)
0.43	Intraherd correlation (8 month Holstin A. R. records)	Verna (1945)
0.49	Analysis of variance (Holstein-Friesian A. R. noncontemporary records)	Laben and Herman (1950)
0.36	Analysis of variance (Holstein-Friesian A. R. contemporary records)	Laben and Herman (1950)
0.34	Analysis of variance (Holstein-Friesian H. I. R.)	Chai (1951)
0.53	Analysis of variance (Holstein-Friesian H. I. R.)	Chandrashaker (1951)
0.59	Analysis of variance (Jersey H. I. R.)	Chandrashaker (1951)
0.67	Analysis of variance (Guernsey H. I. R.)	Chandrashaker (1951)
0.37	Analysis of variance (Ayrshire H. I. R.)	Chandrashaker (1951)
0.46	Analysis of variance (Brown Swiss H. I. R.)	Chandrashaker (1951)
0.50	Analysis of variance (Five breeds combined)	Chandrashaker (1951)

TABLE IV (Continued)

Repeat-ability	Method Used to Determine Repeatability	Reference
	III. Repeatability: C. Butterfat Percentage	
0.52	Intrabreed correlation (Jersey A. R. records)	Gowen (1920a, 1920b)
0.72	Intrabreed correlation (Holstein-Friesian A. R. 365 day records)	Gowen and Gowen (1922)
0.66	Intraherd correlation (Holstein-Friesian 8 month A. R. records)	Verna (1945)
0.76	Analysis of variance (Noncontemporary Holstein A. R. records)	Laben and Herman (1950)
0.61	Analysis of variance (Contemporary Holstein A. R. records)	Laben and Herman (1950)

laws of segregation and recombination of genes, it is impossible that the genotype as a unit be transmitted. Instead, some of the genes may interact with others in such a way as to produce a nonadditive effect, which in certain combinations has effects quite different from their average effects in a given population. The differences between actual effects in each combination and their average effects in the whole population are called dominance deviations and epistatic deviations, which are seldom, if at all, transmitted. Since they would not materially add to one's estimate of heritability of characteristics, these nonadditive influences are generally discounted.

A well-recognized and almost world-wide desire by breeders of dairy cattle for information of any kind concerning the hereditary basis of the production characteristics has led to the conduct of an exceedingly large number of varied investigations. The problem has been tackled from many angles, and results have been published in almost every conceivable manner. Before dealing with the data of more recent date, mention should be made of earlier views on the inheritance of production characteristics. The breeding practices of former times are of extreme interest--especially since many of them still prevail. It cannot be denied that

those old-time practices won for Britain her reputation as the stock farm of the world (Smith and Robison, 1933). At that time, breeding practices were not attuned to the principles of heredity, for the science of genetics was not yet born. The principles of the old-time breeders, such as Bakewell, Cruickshank, and Bates, may be summarized as follows:

1. Conception of the desired type.

2. Mating the best to the best.

3. Appreciation of the pedigree value accompanied by the intelligent application of inbreeding.

4. Use of the progeny test.

The views of the Pre-Mendelian Period are described in detail by Patow (1926), and therefore will be enumerated only briefly. In this period, there were three determinants of the methods of breeding dairy cattle. First, there was formalism; secondly, a conception of heredity based upon Galton's law of ancestral inheritance; and finally, milking tests which were concerned only with absolute yield.

Galton was the first to employ ancestral correlations as a means for the study of heredity resemblance. Rietz (1909) was the first to apply it to the problem of the inheritance of a production

characteristic in dairy cattle, namely, butterfat production. He found the correlation between daughter and dam records to be of the order of 0.30 for Holstein-Friesian cattle. The data used were seven-day "official tests" published in Volumes 11 to 18 of the Holstein-Friesian Advanced Register. It was left to Gowen, however, to make a comprehensive study of the problem of inheritance of butterfat production. Others--especially those of the University of Missouri under Turner, and those from Iowa State under Lush--have subsequently extended the work to all production phases and modified the methods as the requirements of the material necessitated.

It is necessary that breeders know the estimates of heritability for characters for which they are selecting. These statistics for the American Red Danish cattle population are unknown. The purpose of this study was to determine those statistics.

Methods for Estimating Heritability

Depending on the method used, an actual numerical estimate of heritability is usually between the narrow and broad definitions, almost always including a little of the epistatic variance and sometimes a little of the dominance variance. It may include all, part,

or none of the variance caused by the nonlinear or joint effects of heredity and environment (Lush, 1948).

Isogenic line method. An isogenic line is a group of individuals having the same genetic composition. The only example of isogenic lines in dairy cattle is identical twins. However, since the frequency of identical twins in cattle is low, the method is of not much practical importance for the study of heritability of traits in dairy cattle. Long inbred lines do, however, approach the condition of the same genetic composition (Lush, 1948).

The variance between members of the same isogenic line is wholly environmental. Since the relationship between members of an isogenic line is 100 percent, the ratio of the variance or the correlation coefficient is the estimate of heritability. Therefore, the heritability estimate could be obtained in two ways: (1) the method of intraclass correlation, where the variance between the isogenic lines and that within the lines is compared--giving a direct estimate of heritability, and (2) the method of single classification of analysis of variance presents another approach. If we call that variance within isogenic lines W and use B to represent the variance between unrelated individuals in the population under study, heritability can be computed simply as [B - W]/B.

This method of estimating the heritability of traits in dairy cattle is becoming of more importance, since numerous sets of twins are being collected by many experiment stations--particularly those of New Zealand and Sweden. Hancock (1949) of New Zealand has estimated that one set of identical twins replaces twenty pairs of randomly selected animals. Since the New Zealand workers have collected over two hundred pairs of identical twins they can replace over four thousand animals selected at random without loss of statistical efficiency.

Regression of offspring on mid-parent. Nelson (1941) demonstrated the mid-parent offspring correlation or regression method to estimate heritability. Since an average of both parents is needed in the place of one, the literature on this method--as in most other methods--is limited. Most of the studies of heritability--and especially those in dairy cattle--have been of such nature that only one parent exhibited the character that could be directly measured. However, this method may be used where the trait can be measured in both parents--such as fleece-weight in sheep, weight at six months of age in hogs, and pounds gain per unit feed by beef cattle.

Correlation of parent and offspring. This method of correlation was first advanced by Galton and used by Rietz in 1909. Following the work of Rietz, many workers used this method to compile voluminous data on correlations between dam and offspring.

The parent-offspring method is not applicable when one of the parents does not exhibit the characteristics desired to be studied. Resemblance to the sires is not very helpful in data in which the sires are fewer than the dams and, therefore, have been selected intensely on their own phenotypes. In random mating populations, the phenotypic correlation between a parent and an offspring, as described by Lush (1948), is $[1/2][(\sigma G^2/\sigma P^2) + e^2 r_{ee} + i^2 h^2 r_{II}]$. If the $e^2 r_{ee}$ term can be measured and removed, simply doubling the remainder will give an estimate of heritability.

If mating is consanguine, the r_{GG} term becomes $[(1 + m)/2]\sqrt{(1 + F')/(1 + F)}$, instead of simply 1/2. If dominance and epistasis were zero, heritability could be estimated by first removing the error term, doubling, and dividing by $[1 + m]$.

If mating is assortive by phenotypes the same procedure is followed, except that division is by $[1 + r_{sd}]$.

Intrasire dam-daughter regression or correlation. Estimates most commonly available during the last decade are those based on this method. Lush (1940) discussed the methods of intrasire regression and correlation.

In the data where the dams are much more numerous than the sires--as in dairy cattle, this method offers a very useful way of estimating heritability. This device dodges corrections for the mating system, because the differences being investigated are only those which exist between females mated to the same sire. It also dodges many of the difficulties about correcting for the environmental term in the regression or correlation.

The regression is interpreted in the following manner. Let X and Y represent records of offspring and dam, respectively. Then the regression coefficient, b_{xy}, is found as follows: b_{xy} = [Cov. XY] $\div \Sigma^2 Y$, where Cov. and $\Sigma^2 Y$ are the estimated covariance and variance, respectively, as described by Snedecor (1950). Cov. XY estimates $[1/2]\sigma^2 g$ and Σ^2 estimates $\sigma^2 p$ so that $b_{xy} = [(1/2)\sigma^2 g] \div \sigma^2 p$, and $H = 2b_{xy}$.

The correlation coefficient is found as follows: r_{xy} = [Cov. XY] $\div \sqrt{\Sigma^2 X \; \Sigma^2 Y}$.

For the case where $\overline{V}$--the average of n records for each dam--is used in the computation of the intraregression of offspring on dam, H is derived at from this regression in the following manner: $H = 2b_{xy}[(1 + [n - 1]R) \div n]$ (Lush and Strauss, 1942). Averaging records for the offspring has no effect on the deviation of H.

Half-sib correlation. Baker, Hazel, and Reinmuller (1943) have demonstrated that the sire component of variance is a handy tool with which to obtain the intraclass correlation for estimating heritability. However, unless very large amounts of data are available (which would substantially reduce the errors of sampling) this method is not as accurate as other methods previously described.

Data that are analyzed by the intraclass correlation analysis of variance, as outlined by Snedecor (1950), give the required statistic. This, multiplied by four, gives an estimate of heritability. It is necessary to multiply by the factor, four, since the coefficient of genetic relationship between half-sibs, if randomly bred, is 0.25.

Full-sib correlation. This method--more accurate than the half-sib method--is used less in dairy cattle because of the relatively few full-sibs to be found in a population. In swine and sheep this measure could be more readily used.

It is very similar to the parent-offspring correlation method. The coefficient of genetic relationship between full-sibs in a randomly bred population is 0.50; therefore, the regression or correlation coefficient is multiplied by two.

Estimates of Heritability

In view of the variety of the material and the methods by which they have been secured, no attempt has been made here to review the full significance of the figures. These results are tabulated in Table V in as convenient a manner as possible, in an attempt to summarize the investigations.

There are numerous other data pertaining to the estimate of heritability of production characteristics. Smith and Robison (1931) present an extensive list of correlations between milk, fat, and fat percentage of various pairs of relatives computed by many different investigators. The phenotypic correlations between relatives more remote than half-sibs must be multiplied by factors so large that it magnifies the experimental error greatly, and, in the second place, environmental errors are nearly impossible to correct for, since undoubtedly the expressions correlated were expressed at widely separated intervals. Therefore, these data are

TABLE V

ESTIMATES OF HERITABILITY OF PRODUCTION MILK, FAT, AND FAT PERCENTAGE

Charac- teristic	Herit- ability Esti- mate	Breed	Investigator
	A. Regression of Daughter on Dam		
Milk Yield	0.45	Holstein-Friesian	Gowen (1924a)
Milk Yield	0.36	Guernsey	Gowen (1926)
Milk Yield	0.09	Red Poll	Agar (1926)
Milk Yield	0.42	Ayrshire	Smith et al. (1931)
Milk Yield	0.41	Shorthorn	Edwards (1932)
Milk Yield	0.40	Jersey	Gowen (1934)
Milk Yield	0.33	Holstein-Friesian	Lush and Strauss (1942)
Milk Yield	0.38	All breeds	Lush and Strauss (1942)
Milk Yield	0.26	Ayrshire	Gifford and Turner (1928)
Butterfat Yield	0.28	Holstein-Friesian	Rietz (1909)
Butterfat Yield	0.29	Holstein-Friesian	Hills and Bolland (1913)
Butterfat Yield	0.24	Red Poll	Agar (1926)

TABLE V (Continued)

Characteristic	Heritability Estimate	Breed	Investigator
Butterfat Yield	0.26	Ayrshire	Gifford and Turner (1928)
Butterfat Yield	0.23	Guernsey	Gifford (1930a)
Butterfat Yield	0.40	Jersey	Copeland (1931)
Butterfat Yield	0.40	Jersey	Gowen (1934)
Butterfat Yield	0.12	Holstein-Friesian	Plum (1933)
Butterfat Yield	0.28	Holstein-Friesian	Lush and Arnold (1937)
Butterfat Yield	0.25	Holstein-Friesian	Lush et al (1941)
Butterfat Percentage	0.39	Holstein-Friesian	Gowen (1924a)
Butterfat Percentage	0.30	Guernsey	Turner (1925)
Butterfat Percentage	0.42	Guernsey	Gowen (1926)
Butterfat Percentage	0.35	Jersey	Turner (1927b)

TABLE V (Continued)

Characteristic	Heritability Estimate	Breed	Investigator
Butterfat Percentage	0.33	Red Poll	Agar (1926)
B. Intrasire Daughter-Dam Correlation and Regression			
Milk Yield	0.33	Holstein-Friesian	Lush *et al.* (1941)
Milk Yield	0.36	Holstein-Friesian	Laben and Herman (1950)
Milk Yield	0.06	Ayrshire	Chandrashaker (1951)
Milk Yield	-0.27	Holstein-Friesian	Chandrashaker (1951)
Milk Yield	0.26	Jersey	Chandrashaker (1951)
Milk Yield	-0.10	Guernsey	Chandrashaker (1951)
Milk Yield	-0.22	Brown Swiss	Chandrashaker (1951)
Butterfat Yield	0.25	Holstein-Friesian	Lush and Shultz (1936)
Butterfat Yield	0.28	Holstein-Friesian	Lush (1940)
Butterfat Yield	0.30	Swedish	Johansson and Hansson (1940)
Butterfat Yield	0.33	Holstein-Friesian	Lush *et al.* (1941)

TABLE V (Continued)

Characteristic	Heritability Estimate	Breed	Investigator
Butterfat Yield	0.17 (single records)	Holstein-Friesian	Lush and Strauss (1942)
Butterfat Yield	0.27	Holstein-Friesian	Lush and Strauss (1942)
Butterfat Yield	0.29	Holstein-Friesian	Laben and Herman (1950)
Butterfat Yield	0.31	Holstin-Friesian	Chai (1951)
Butterfat Yield	0.17 (single records)	Holstein-Friesian	Chai (1951)
Butterfat Yield	0.17	Holstein-Friesian	Chandrashaker (1951)
Butterfat Yield	0.37	Jersey	Chandrashaker (1951)
Butterfat Yield	0.05	Guernsey	Chandrashaker (1951)
Butterfat Yield	0.21	Ayrshire	Chandrashaker (1951)
Butterfat Yield	-0.26	Brown Swiss	Chandrashaker (1951)

TABLE V (Continued)

Characteristic	Heritability Estimate	Breed	Investigator
		C. Full-sib Correlation	
Milk Production	0.55	Holstein-Friesian	Gowen (1924a)
Milk Production	0.41	Guernsey	Gowen (1926)
Milk Production	0.39	Jersey	Gowen (1927)
Milk Production	0.46	Ayrshire	Smith and Robison (1931)
Milk Production	0.27	Holstein-Friesian	Laben and Herman (1950)
Butterfat Yield	0.478	Ayrshire	Smith and Robison (1931)
Butterfat Yield	0.39	Holstein-Friesian	Laben and Herman (1950)
Butterfat Percentage	0.46	Holstein-Friesian	Gowen (1924a)
Butterfat Percentage	0.44	Guernsey	Gowen (1926)
Butterfat Percentage	0.41	Jersey	Gowen (1927)
Butterfat Percentage	0.46	Holstein-Friesian	Laben and Herman (1950)

TABLE V (Continued)

Characteristic	Heritability Estimate	Breed	Investigator
		D. Half-sib Correlation	
Milk Production	0.36	Holstein-Friesian	Gowen (1924a)
Milk Production	0.38	Holstein-Friesian	Gowen (1924a)
Milk Production	0.13	Guernsey	Gowen (1926)
Milk Production	0.15	Guernsey	Gowen (1926)
Milk Production	0.23	Jersey	Gowen (1927)
Milk Production	0.20	Jersey	Gowen (1927)
Milk Production	0.39	Ayrshire	Smith and Robison (1931)
Milk Production	0.22	Ayrshire	Smith and Robison (1931)
Milk Production	0.28	Ayrshire	Smith and Robison (1931)
Milk Production	0.13	Holstein-Friesian	Laben and Herman (1950)
Milk Production	0.14	Holstein-Friesian	Laben and Herman (1950)

TABLE V (Continued)

Characteristic	Heritability Estimate	Breed	Investigator
Butterfat Yield	0.37	Ayrshire	Smith and Robison (1931)
Butterfat Yield	0.56	Jersey	Copeland (1931)
Butterfat Yield	0.42	Ayrshire	Smith and Robison (1931)
Butterfat Yield	0.46	Ayrshire	Smith and Robison (1931)
Butterfat Yield	0.30	Holstein-Friesian	Laben and Herman (1950)
Butterfat Yield	0.14	Holstein-Friesian	Laben and Herman (1950)
Butterfat Percentage	0.37	Holstein-Friesian	Gowen (1924a)
Butterfat Percentage	0.17	Holstein-Friesian	Gowen (1924a)
Butterfat Percentage	0.17	Guernsey	Gowen (1926)
Butterfat Percentage	0.19	Guernsey	Gowen (1926)
Butterfat Percentage	0.25	Jersey	Gowen (1927)
Butterfat Percentage	0.20	Jersey	Gowen (1927)

TABLE V (Continued)

Characteristic	Heritability Estimate	Breed	Investigator
Butterfat Yield	0.37	Ayrshire	Smith and Robison (1931)
Butterfat Yield	0.56	Jersey	Copeland (1931)
Butterfat Yield	0.42	Ayrshire	Smith and Robison (1931)
Butterfat Yield	0.46	Ayrshire	Smith and Robison (1931)
Butterfat Yield	0.30	Holstein-Friesian	Laben and Herman (1950)
Butterfat Yield	0.14	Holstein-Friesian	Laben and Herman (1950)
Butterfat Percentage	0.37	Holstein-Friesian	Gowen (1924a)
Butterfat Percentage	0.17	Holstein-Friesian	Gowen (1924a)
Butterfat Percentage	0.17	Guernsey	Gowen (1926)
Butterfat Percentage	0.19	Guernsey	Gowen (1926)
Butterfat Percentage	0.25	Jersey	Gowen (1927)
Butterfat Percentage	0.20	Jersey	Gowen (1927)

not presented in this review, although their presence is recognized.

Investigational Procedure

Grading-Up Effect

The data utilized in this analysis have been standardized and processed on IBM Card Number 2.

In calculating the mean production and weighted means, the formula, $\bar{x} = \sum_{1}^{N}(x) \div N$, where $\bar{x}$ equals the mean, $\sum_{1}^{N}$ equals N values summated, x equals the values, and N equals the total number of items in the sample, was used.

In order to describe more completely the variability of the mean and how descriptive it is of the population, the standard deviation of each mean was calculated. The formula for the standard deviation is: $\sigma = \sqrt{[\Sigma(x - \bar{x})^2 \div N}$; where σ represents the standard deviation, $\Sigma(x - \bar{x})^2$ under the square root sign equals the deviation from the mean squared, and N equals total number of items in the sample. However, another formula more adapted to use in IBM calculations can be used. Since the main part of the work is to find the sum of squares of the deviations, it can be shown that:

$\Sigma(x - \bar{x})^2 = \Sigma(x^2) - [\Sigma(x)]^2/N$. This formula is especially useful in machine calculations (Goulden, 1949).

The "t" test was employed to test for the significance of the differences between the various means. Since each group consisted of different numbers of individuals, the following formula (Snedecor, 1950) was employed:

$$t = \bar{x}\sqrt{n_1 n_2 (n_1 + n_2 - 2) \div (n_1 + n_2)\Sigma x^2},$$

where $\bar{x}$ equals difference between the two means to be tested, n_1 and n_2 equal, respectively, the number of items in the two samples, and Σx^2 equals the pooled variance (total sums of squares) of the two samples to be tested.

Repeatability Estimates

The production records involved in this study were made by two categories of animals: (1) mates of the sires, and (2) progeny resulting from the succession of purebred Red Dane sires bred to the foundation cows and the resulting crosses.

The method employed in estimating the repeatability of these data was single classification of analysis of variance, intraclass correlation (Snedecor, 1950). The variance in a sample may be separated into two parts--one reflecting the natural variation of

individuals treated alike, and the other arising from genetic or environmental conditions peculiar to the subsamples. The former is an estimate of σ^2, which may be assumed equal in the sampled populations, while the latter is an estimate of σm^2, the added portion relation to differences among the population means. The sum, $\sigma^2 + \sigma m^2$, is the variance of individuals picked at random from the entire universe made up of the sampled populations. The ratio of the two variances, $\sigma m^2 \div (\sigma^2 + \sigma m^2)$, is known as the intraclass correlation, $r_1 = R$.

The justification for calling this a "correlation" is that correlation is a two-way average of relationship (Snedecor, 1950). However, it is necessary to keep clearly in mind the character of the relation being considered. A characteristic of r is revealed by dividing both numerator and denominator of the ratio by (n - 1):

$$\begin{aligned} r &= \Sigma x_1 x_2 \div \sqrt{(\Sigma x_1^2)(\Sigma x_2^2)} \\ &= \Sigma x_1 x_2/(n - 1) \div \sqrt{[\Sigma x_1^2/(n - 1)][\Sigma x_2^2/(n - 1)]} \\ &= \text{Covariance} \div \sqrt{(\Sigma_1^2)(\Sigma_2^2)} \\ &= \text{Covariance} \div \text{Geometric mean of variance.} \end{aligned}$$

Correlation is thus the quotient of two averages of variation--one, the covariance of the two measurements, x_1 and x_2; the other, an average of the two variances. It is an abstract number measuring covariation--if two related characters each occur in various sizes, their correlation is a measure of the extent to which their variations are concomitant.

In order to calculate intraclass correlation directly from a table of analysis of variance, it is convenient to put the formula in the form: $r_1 = [M\bar{x} - M] \div [M\bar{x} + (K - 1)M]$, where $M\bar{x}$ and M denote mean squares for between individuals and within individuals, respectively. K is the number of items per subsample; if the subsamples differ in size, the average value, K_o, is used.

Since in these data it was desired to use all records of individual cows, K varied in size, and the formula necessary to find an average number, K_o, may be conveniently put in the formula: $K_o = [1/(N - 1)][\Sigma K - (\Sigma K^2/\Sigma K)]$, where N is the number of subsamples, ΣK is the total sample size, and ΣK^2 is the total sum of squares.

Since the methods used for obtaining the necessary statistics for setting up an analysis of variance table can be found in detail in numerous texts of statistics (Snedecor, 1950; Goulden, 1949; Croxton and Cowden, 1949), the detailed procedure for calculation will not be presented here. All calculations--except the several

involved within the analysis of variance table itself--were performed by International Business Machines in order to reduce the errors involved in hand-operated machines.

All the statistics necessary for these analyses were tabulated on the usual long, folded sheet of paper. The tabulations were made by the specific steps necessary to obtain the data from IBM Cards No. 3 and No. 4 (Fig. 3).

The calculations of repeatability were made by grouping the data into three categories: (1) An intrabreed analysis was made grouping all herds together in one large population of records; the number of herds involved in each breed was different, and several of the breeds often came from the same herds. (2) An intrabreed analysis by herds was made, and a single estimate of repeatability for each breed for all herds was then obtained (3) An intrabreed analysis was made grouping all herds together in one large population of records--keeping separate each breed and its successive Red Dane crosses to find the effects on repeatability due to a succession of Red Danish sires.

Heritability Estimates

Of the different methods described for estimating the heritability of production traits, the following three methods were used in this study: (1) intrasire daughter-dam correlation, (2) intrasire regression of daughters on dams, and (3) paternal half-sib correlations.

The following equations were used to estimate the correlations (r), regressions (b), and their standard error (e).

Daughter on dam regression coefficient:

$$b = \Sigma xy \div \Sigma x^2$$

Standard error of the regression coefficient squared:

$$E_b^2 = [\Sigma y^2 - ([\Sigma xy]^2/\Sigma x^2)] \div [(n - 2)/\Sigma x^2]$$

Dam-daughter correlation coefficient:

$$r = \Sigma xy \div \sqrt{(\Sigma x^2)(\Sigma y^2)}$$

Standard error of the correlation coefficient squared:

$$E_r^2 = [1 - r^2] \div [n - 2]$$

Half-sib correlation coefficient:

$$r_1 = M\bar{x} \div [M + Mx]$$

where M is the mean square of the error term and $M\bar{x}$ = [mean square between sires - mean square of error term] ÷ [average number in each sire group].

Standard error of the half-sib correlation coefficient:

$$Er_1 = \sqrt{1 - r^2} \div \sqrt{n - 2}$$

As previously pointed out, heritability was estimated by doubling the dam-daughter correlation and daughter-on-dam regression coefficients, and by multiplying by four the half-sib correlation coefficient. The respective standard errors were multiplied by the same factors.

Investigational Results

Grading-Up Effect

A general survey was made of the foundation breeds of dairy cattle bred to the Red Danish sires in this project to determine their level of production characteristics as measured by the mean, standard deviation, and coefficient of variability of these traits; this survey served as a basic step in this study. This analysis was based on at least 90 percent of the records for each breed.

An analysis of variance for milk production (Table VI) shows a significant difference between breeds ($P < 0.01$). The Holstein breed had the highest milk production average followed

TABLE VI

ANALYSIS OF VARIANCE OF PRODUCTION TRAITS

Trait	Source of Variance	Degrees of Freedom	Sum of Squares	Mean Squares	F
			Foundation Breeds		
Milk	Total	1,357	7,616,690,065		
	Between breeds	5	1,203,272,100	240,654,420	50.7**
	Within breeds	1,352	6,413,417,965	4,743,652	
Butter-fat	Total	1,357	10,469,884		
	Between breeds	5	927,861	185,572	23.0**
	Within breeds	1,352	9,542,023	8,058	
			Red Danish X Foundation Breed Progeny		
Milk	Total	2,129	8,917,057,061		
	Between Crosses	2	24,106,000	12,053,000	2.88
	Within	2,127	8,892,951,061	4,180,983	

TABLE VI (Continued)

Trait	Source of Variance	Degrees of Freedom	Sum of Squares	Mean Squares	F
Butter-fat	Total	2,129	13,498,072		
	Between Crosses	2	606	303	0.04
	Within	2,127	13,497,466	6,346	

** ($P < 0.01$).

by the Brown Swiss, Mixed, Jersey, Shorthorn, and Guernsey breeds, in descending order (Table VII). The Holstein and Brown Swiss breeds were not significantly different, although they differed at the 1-percent level from all other breeds ("t" test). The Mixed, Jersey, and Shorthorn breeds were not significantly different from each other, but were significantly different from the Guernsey breed ($P < 0.01$).

The analysis of variance for butterfat production (Table VI) showed a significant difference between herds ($P < 0.01$). The Jersey breed had the highest butterfat average, followed by the Brown Swiss, Holstein, Mixed, Guernsey, and Shorthorn breeds, in that order. Butterfat production was not significantly different for the Jersey, Brown Swiss and Holstein breeds, while they were different from the Mixed, Shorthorn and Guernsey breeds ("t" test $P < 0.01$). The Mixed and Guernsey breeds were different from the Shorthorn breed.

Table VIII shows the production characteristics of three generations of graded-up Red Danish progeny, irrespective of breed of foundation cow. For milk and butterfat production, the "F" test (Table VI) shows a nonsignificant value. No difference existed

TABLE VII

THE MEAN, STANDARD DEVIATION, AND COEFFICIENT OF VARIABILITY OF MILK, BUTTERFAT, AND BUTTERFAT PERCENTAGE FOR ALL BREEDS USED IN THE RED DANE PROJECT

Breed	Number of Cows	Pounds Milk		
		Mean	Std. Dev.	C.V.
Holstein	335	10,057	2,586	25.7
Brown Swiss	35	9,690	2,010	20.7
Mixed Breed	169	8,355	2,175	26.0
Jersey	149	8,335	1,803	21.6
Shorthorn	302	8,199	1,991	24.2
Guernsey	368	7,470	1,703	22.8
Weighted Avg.	1,358	8,536	2,305	27.6
Red Dane Milkrace	75	9,577	1,347	14.1

TABLE VII (Continued)

Pounds Fat			Percent Butterfat Content		
Mean	Std. Dev.	C.V.	Mean	Std. Dev.	C.V.
380	99	26.0	3.77	0.23	06.1
386	70	18.0	3.98	0.21	05.3
346	87	25.6	4.14	0.17	04.1
396	91	23.0	4.75	0.10	01.8
322	76	23.4	3.92	0.17	04.3
339	77	22.7	4.53	0.13	03.9
354	90	25.3	4.14	0.18	04.1
390	91	23	4.07	0.10	02.4

TABLE VIII

THE MEAN, STANDARD DEVIATION, AND COEFFICIENT OF VARIABILITY OF MILK, BUTTERFAT, AND BUTTERFAT PERCENTAGE GENERATIONS OF PROGENY OF RED DANISH SIRES CROSSED WITH VARIOUS DAIRY BREEDS

Breed	Number of Cows	Pounds Milk			Percent Increase Over Foundation
		Mean	Std. Dev.	C.V.	
First Gen.	1,285	9,045	2,085	23.0	+ 6.0
Second Gen.	710	9,197	1,939	21.0	+ 7.7
Third Gen.	135	9,427	2,177	23 0	+10.4
Weighted Average		9,116	2,407	22.4	+ 6.8

TABLE VIII (Continued)

Pounds Butterfat			Percent Increase Over Foundation	Pct. Butterfat Content		
Mean	Std. Dev.	C.V.		Mean	Std. Dev.	C.V.
372	80	21.5	+5.0	4.10	0.07	01.7
373	78	20.9	+5.3	4.05	0.07	01.7
374	82	21.8	+5.6	3.96	0.12	03.0
372	80	21.4	+5.0	4.07	0.08	02.0

between the first-, second-, and third-generation Red Danish females for milk and butterfat production.

The grading-up effect by use of three generations of purebred Red Danish sires on the various foundation dairy breeds is illustrated in Tables IX through XIII. By use of the "t" test for unequal numbers, the increase in milk and butterfat production that occurred in the Guernsey, Jersey, and Shorthorn progeny was found to be significant ($P < 0.05$ and 0.01). The crosses resulting from the Holstein, Brown Swiss, and Mixed breeds exhibited no significant change from the foundation cows.

In several of the graded-up lines, the means of the crosses were significantly different from each other. Table XIV shows the results of the "t" test values for all the foundation cows and their progeny.

Table XV summarizes the effects on production traits from crossing purebred Red Danish sires with the various dairy breeds in the grading-up project. The "t" test shows the differences between the mean milk and butterfat production to be highly significant. The differences in the butterfat percentage were not significant.

TABLE IX

THE MEAN, STANDARD DEVIATION, AND COEFFICIENT OF VARIABILITY OF MILK, BUTTERFAT, AND BUTTERFAT PERCENTAGE OF HOLSTEIN-FRIESIAN COWS AND THREE GENERATIONS OF THEIR GRADED-UP RED DANISH PROGENY

Breed	Number	Pounds Milk			Percent Increase Over Foundation
		Mean	Std. Dev.	C.V.	
Holstein	147	9,899	2,434	24.5	
First Gen.	187	9,866	2,079	21.0	-0.3
Second Gen.	59	9,116	1,966	21.5	-7.9
Third Gen.	6	9,730	1,159	11.9	-1.7

TABLE IX (Continued)

Pounds Butterfat			Percent Increase Over Foundation	Pct. Butterfat Content		
Mean	Std. Dev.	C.V.		Mean	Std. Dev.	C.V.
373	92	24.6		3.76	0.23	06.1
383	74	19.2	+2.7	3.88	0.07	01.8
366	80	21.7	-1.9	4.01	0.03	00.7
375	44	11.7	+0.5	3.84	0.04	01.0

TABLE X

THE MEAN, STANDARD DEVIATION, AND COEFFICIENT OF VARIABILITY OF MILK, BUTTERFAT, AND BUTTERFAT PERCENTAGE OF GUERNSEY COWS AND THREE GENERATIONS OF THEIR GRADED-UP RED DANISH PROGENY

Breed	Number	Pounds Milk			Percent Increase Over Foundation
		Mean	Std. Dev.	C.V.	
Guernsey	147	7,586	1,649	21.7	
First Gen.	210	8,742	2,078	23.7	+15.2
Second Gen.	83	8,923	1,956	21.9	+17.6
Third Gen.	9	10,337	2,541	24.5	+36.3

TABLE X (Continued)

Pounds Butterfat			Percent Increase Over Foundation	Pct. Butterfat Content		
Mean	Std. Dev.	C.V.		Mean	Std. Dev.	C.V.
341	75	22.0		4.49	0.12	02.7
375	72	19.1	+10.	4.29	0.10	02.3
372	86	22.9	+ 9.1	4.17	0.09	02.2
416	107	25.6	+22.	4.02	0.07	01.8

TABLE XI

THE MEAN, STANDARD DEVIATION, AND COEFFICIENT OF VARIABILITY OF MILK, BUTTERFAT, AND BUTTERFAT PERCENTAGE OF SHORTHORN COWS AND THREE GENERATIONS OF THEIR GRADED-UP RED DANISH PROGENY

Breed	Number	Pounds Milk			Percent Increase Over Foundation
		Mean	Std. Dev.	C.V.	
Shorthorn	139	8,118	1,842	22.6	
First Gen.	157	8,864	1,901	21.5	+ 9.2
Second Gen.	48	9,328	1,924	21.7	+14.9
Third Gen.	11	9,601	2,658	27.6	+18.3

TABLE XI (Continued)

Pounds Butterfat			Percent Increase Over Foundation	Pct. Butterfat Content		
Mean	Std. Dev.	C.V.		Mean	Std. Dev.	C.V.
317	74	23.4		3.90	0.17	04.4
353	79	21.2	+11.4	3.97	0.07	01.8
370	78	21.2	+16.7	3.92	0.03	00.7
376	90	23.8	+18.6	3.91	0.03	00.7

TABLE XII

THE MEAN, STANDARD DEVIATION, AND COEFFICIENT OF VARIABILITY OF MILK, BUTTERFAT, AND BUTTERFAT PERCENTAGE OF JERSEY COWS AND THREE GENERATIONS OF THEIR GRADED-UP RED DANISH PROGENY

Breed	Number	Pounds Milk			Percent Increase Over Foundation
		Mean	Std. Dev.	C.V.	
Jersey	88	8,212	1,740	21.1	
First Gen.	138	8,690	1,691	19.4	+ 5.8
Second Gen.	46	9,568	1,947	20.3	+16.5
Third Gen.	10	11,219	1,811	16.1	+36.6

TABLE XII (Continued)

Pounds Butterfat			Percent Increase Over Foundation	Pct. Butterfat Content		
Mean	Std. Dev.	C.V.		Mean	Std. Dev.	C.V.
382	89	23.3		4.64	0.23	05.5
379	79	20.7	– 0.8	4.36	0.10	02.4
405	72	17.8	+ 6.0	4.23	0.07	01.6
430	72	16.7	+12.6	3.83	0.10	02.6

TABLE XIII

THE MEAN, STANDARD DEVIATION, AND COEFFICIENT OF VARIABILITY OF MILK, BUTTERFAT, AND BUTTERFAT PERCENTAGE OF MIXED-BREED COWS AND THREE GENERATIONS OF THEIR GRADED-UP RED DANISH PROGENY

Breed	Number	Pounds Milk			Percent Increase Over Foundation
		Mean	Std. Dev.	C.V.	
Mixed-Breed	41	8,068	2,008	24.8	
First Gen.	47	8,468	1,649	19.4	+ 5.0
Second Gen.	28	9,049	1,433	15.8	+12.0
Third Gen.	7	8,133	2,661	32.7	+ 0.8

TABLE XIII (Continued)

Pounds Butterfat			Percent Increase Over Foundation	Pct. Butterfat Content		
Mean	Std. Dev.	C.V.		Mean	Std. Dev.	C.V.
349	90	25.8		4.32	0.16	03.7
361	64	17.7	+3.4	4.26	0.05	01.1
361	63	17.4	+3.4	3.98	0.05	01.3
351	68	19.3	+0.6	4.31	0.09	02.2

TABLE XIV

TABLE OF "t" VALUES DETERMINED FOR TESTING THE MEANS OF MILK AND BUTTERFAT FOR DIFFERENCES BETWEEN THE VARIOUS COMBINATIONS FOR GRADING-UP EFFECT

Combination Within Each Graded-Up Line	Milk Production		Butterfat Production		Degrees of Freedom
	M_1-M_2	"t" Value	M_1-M_2	"t" Value	
Guernsey vs. F_1	1,156	5.61**	34.8	4.35**	354
Guernsey vs. F_2	1,337	5.37**	31.0	2.79**	228
Guernsey vs. F_3	2,751	11.55**	75.0	2.25*	154
F_1 vs. F_2	181	0.689	3.0	0.300	290
F_1 vs. F_3	1,595	5.10**	41.0	2.64*	217
F_2 vs. F_3	1,414	1.99*	44.0	2.41*	90
Holstein vs. F_1	- 33	0.133	9.8	1.08	332
Holstein vs. F_2	- 783	2.34*	- 7.0	0.51	204
Holstein vs. F_3	- 169	0.47	2.0	0.03	151
F_1 vs. F_2	- 750	2.45*	-17.3	1.5	244
F_1 vs. F_3	- 136	0.42	- 6.0	0.31	191
F_2 vs. F_3	- 414	0.501	9.0	0.031	63
Shorthorn vs. F_1	746	3.40**	35.5	4.08**	294

TABLE XIV (Continued)

Combination Within Each Graded-Up Line	Milk Production		Butterfat Production		Degrees of Freedom
	M_1-M_2	"t" Value	M_1-M_2	"t" Value	
Shorthorn vs. F_2	1,210	6.30**	53	5.21**	187
Shorthorn vs. F_3	1,483	7.42**	59	8.26**	149
F_1 vs. F_2	464	2.47*	15.3	1.22	303
F_1 vs. F_3	737	1.12	23	0.23	167
F_2 vs. F_3	273	0.341	6.0	0.221	57
Jersey vs. F_1	478	2.04*	2.9	0.051	224
Jersey vs. F_2	1,356	4.07**	23	1.98*	132
Jersey vs. F_3	3,007	5.11**	48	2.70**	96
F_1 vs. F_2	878	2.92**	26.2	1.98*	182
F_1 vs. F_3	2,529	4.20**	51	2.86**	146
F_2 vs. F_3	1,651	2.4*	25.1	0.29	54
Brown Swiss vs. F_1	67	0.012	6.6	0.05	30
Mixed vs. F_1	400	1.00	12.0	0.71	84
Mixed vs. F_2	981	1.27	12	0.65	68
Mixed vs. F_3	65	0.11	2.0	0.13	47
F_1 vs. F_2	581	0.356	0	0	73

TABLE XIV (Continued)

Combination Within Each Graded-Up Line	Milk Production		Butterfat Production		Degrees of Freedom
	M_1-M_2	"t" Value	M_1-M_2	"t" Value	
F_1 vs. F_3	335	0.261	10	1.11	53
F_1 vs. F_3	976	1.20	10	0.532	33

** (P. < 1%).

* (P. < 5%).

TABLE XV

A COMPARISON OF THE WEIGHTED MEAN PRODUCTION OF ALL GENERATIONS OF RED DANISH PROGENY AND OF THE FOUNDATION BREEDS

Production Trait	Foundation Breeds			Red Danish Progeny			Pct. Increase Over Foundation
	Mean	Std. Dev.	C.V.	Mean	Std. Dev.	C.V.	
Milk	8,536	2,305	27.6	9,116	2,407	22.4	+6.8
Butterfat	354	90	25.3	372	80	21.4	+5.1
Butterfat Percentage	4.14	0.18	4.1	4.07	0.08	2.0	-1.7

In order to assess the probable transmitting value for the production characteristics of the Red Danish sires used in this project, a study of their dams' production records was made. Table VII shows the mean milk, butterfat, and butterfat percentage of the dams maintained in the Bureau of Dairy Industry herd at Beltsville, Maryland.

Repeatability Estimates

Table XVII shows the intraherd and all-herds repeatability estimates of milk and butterfat production for the foundation cows entered in the Red Dane project. An inspection of Table XVII reveals that the repeatability coefficients for milk production for the Holstein, Shorthorn, Jersey, and Mixed breeds were harmonious. They were slightly different for butterfat, however. The coefficient of repeatability for milk production for the Guernsey breed was considerably in excess of the other breeds. The coefficient for butterfat production for the Guernsey breed was also high in relation to the coefficients of the other breeds.

When these data were calculated on an intraherd basis, there was a drop in the coefficients. The greatest reduction occurred in the Holstein breed--a decrease of approximately 45 to 50 percent.

TABLE XVI

ANALYSIS OF FIRST-CROSS PROGENY TO DETERMINE WHETHER HETEROSIS APPEARED IN THE DATA

Cross	Number of Dam & Daus. Comparisons	Mean Prod. of Progeny
	Milk Production	
Holstein X Dane	187	9,866
Guernsey X Dane	210	8,742
Shorthorn X Dane	157	8,864
Jersey X Dane	138	8,690
Mixed X Dane	47	8,486
Weighted Avg.*	1,285	9,045
	Butterfat Production	
Holstein X Dane	187	383
Guernsey X Dane	210	375
Shorthorn X Dane	157	353
Jersey X Dane	138	379
Mixed X Dane	47	361
Weighted Avg.*	1,285	372
	Butterfat Percentage	
Holstein X Dane	187	3.88
Guernsey X Dane	210	4.29
Shorthorn X Dane	157	3.97
Jersey X Dane	138	4.36
Mixed X Dane	47	4.26
Weighted Avg.*	1,285	4.10

* This includes all first-cross progeny.

TABLE XVI (Continued)

Mean Prod. of Found. Parent	Mean Prod. of Red Dane Parent	Parental Mean	% Deviation of Crosses from P. Mean
	Milk Production		
9,899	9,577	9,738	1.3
7,586	9,577	8,582	1.9
8,118	9,577	8,848	0.8
8,212	9,577	8,895	-2.4
8,068	9,577	8,823	-4.1
8,536	9,577	9,057	-0.2
	Butterfat Production		
373	390	381	0.6
341	390	366	2.4
317	390	354	0.3
382	390	386	-2.0
349	390	370	-2.5
354	390	372	0.00
	Butterfat Percentage		
3.76	4.07	3.92	-1.1
4.49	4.07	4.28	0.3
3.90	4.07	3.97	0.00
4.64	4.07	4.36	0.00
4.32	4.07	4.20	-1.5
4.14	4.07	4.11	-0.5

TABLE XVII

REPEATABILITY ESTIMATES OF MILK AND BUTTERFAT PRODUCTION OF THE FOUNDATION BREEDS BRED TO RED DANISH SIRES

Breed	Repeatability of Milk		Repeatability of Butterfat	
	Intra-herd	All-herds	Intra-herd	All-herds
Guernsey	0.53	0.69	0.59	0.67
Holstein-Friesian	0.29	0.52	0.30	0.66
Shorthorn	0.30	0.52	0.33	0.60
Jersey	0.30	0.52	0.35	0.57
Mixed	0.41	0.50	0.34	0.55
All breeds	0.36	0.54	0.37	0.66

The Guernsey coefficients were reduced the least--from 15 to 20 percent. The coefficients of the other breeds were in close proximity and between the two extreme situations. The combined repeatability coefficients for milk and butterfat production of all breeds were 0.36 and 0.37, respectively.

The coefficients of repeatability for the various Red Danish crosses are shown in Table XVIII. These findings approximate those of the foundation breeds (Table XVII). As in the foundation breeds, there were variations within a cross. The coefficients of repeatability for milk production were essentially the same for the three crosses. For the butterfat, however, the first cross had a higher coefficient. The combined intraherd repeatability coefficients for milk and butterfat for all crosses were 0.26 and 0.28--somewhat lower than that of the foundation herds.

The coefficients of repeatability for grading up on an all-herd basis are shown in Table XIX. Each foundation breed and its first- and second-cross progeny are shown in sequence. There was considerable variation in coefficients within each progeny group. No exact pattern could be observed from these data; however, there seemed to be a tendency for the coefficients of

TABLE XVIII

REPEATABILITY ESTIMATES OF MILK AND BUTTERFAT PRODUCTION OF THE RED DANISH CROSSES

Cross	Repeatability of Milk		Repeatability of Butterfat	
	Intra-herd	All-herds	Intra-herd	All-herds
First cross	0.25	0.53	0.24	0.74
Second cross	0.25	0.49	0.21	0.61
Third cross	0.30	0.53	0.40	0.66
All crosses	0.26	0.52	0.28	0.67

TABLE XIX

REPEATABILITY ESTIMATES OF MILK AND BUTTERFAT PRODUCTION ON ALL HERD ANALYSIS BY FOUNDATION BREED AND FIRST TWO CROSSES

Foundation Breed and Crosses	Repeatability of Milk Production	Repeatability of Butterfat Production
Shorthorn	0.58	0.55
First cross	0.64	0.56
Second cross	0.88	0.78
Holstein	0.52	0.51
First cross	0.61	0.56
Second cross	0.68	0.71
Guernsey	0.64	0.62
First cross	0.69	0.58
Second cross	0.57	0.73
Jersey	0.46	0.62
First cross	0.52	0.49
Second cross	0.52	0.53

repeatability of milk and butterfat production of the crosses to be slightly higher than those of the foundation parent breed.

Heritability Estimates

In determining the heritability estimates of milk and butterfat production, the dam-daughter and paternal half-sibs were divided into three groups: (1) foundation-first cross dam-daughter pairs, (2) first-second cross dam-daughter pairs, and (3) second-third cross dam-daughter pairs. The paternal half-sib correlations under each group were of the first-, second-, and third-cross paternal-half sisters, respectively.

Table XX shows the estimates of heritability for milk production for the various groups by the three methods used in this analysis. The heritability--estimated by the correlation between half-sibs--is higher than either the regression of daughter on dam or correlation between dam and daughter. This is logical, since the correlation between half-sibs usually includes some environmental correlation, if any exists. The estimates determined for the heritability of butterfat are shown in Table XXI. As can be seen, the paternal half-sib estimate is highest for all groups. The heritability estimates for butterfat production by all methods, tend

TABLE XX

ESTIMATES OF HERITABILITY FOR THE MILK PRODUCTION OF THE THREE GROUPS ON AN ALL-HERD BASIS

Group	Intrasire Regression Estimate	Intrasire Dam-Daus. Corr.	Paternal Half-sib Corr.
I	0.38 ± 0.08	0.39 ± 0.09	0.40 ± 0.21
II	0.43 ± 0.12	0.43 ± 0.11	0.45 ± 0.24
III	0.66 ± 0.20	0.62 ± 0.20	0.70 ± 0.44

TABLE XXI

ESTIMATES OF HERITABILITY FOR THE BUTTERFAT PRODUCTION OF THE THREE GROUPS ON AN ALL-HERD BASIS

Group	Intrasire Regression Estimate	Intrasire Dam-Daus. Corr.	Paternal Half-sib Corr.
I	0.42 ± 0.10	0.44 ± 0.10	0.46 ± 0.21
II	0.36 ± 0.12	0.34 ± 0.12	0.54 ± 0.24
III	0.67 ± 0.19	0.72 ± 0.21	0.80 ± 0.45

to be slightly higher in groups I and III. The paternal half-sib method gave the largest estimate for butterfat production; this was also true for milk production.

The heritability coefficients of all the groups were probably increased due to the intrasire analysis not correcting for the intraherd variance. In view of the intraherd variance entering into these heritability estimates, an intraherd-intrasire analysis should give a more nearly correct estimate of the heritability of butterfat and milk production.

It is felt that these heritability estimates could be expressed on an intraherd basis by using a reduction factor obtained from the difference between the all-herd and intraherd repeatability herd coefficients, since the intraherd analysis of repeatability removes that portion of the correlation due to the records being made in the same herd when all herds are considered.

The estimates for the third group are exceedingly high and probably due to only seventy-three observations being made for twenty-two sires. If this be the case, it could be concluded that there appeared to be no difference between the estimates of heritability of the different groups for milk and butterfat production.

Discussion and Conclusion

Grading-Up Effect

In these data, an attempt has been made to determine the improvement--if any--made by breeding a succession of purebred Red Danish sires to foundation grade dairy cows.

This investigation was designed statistically to analyze the accumulated data produced by this project in order to furnish information for the Red Dane breeders in Michigan. Several press articles have appeared, but they were written in a popular style. These were good for promotion of the breed, but the information presented did not explain the mode of inheritance of various traits of the Red Danish breed.

From a critical examination of the Tables VI to XV, one can observe the effects that the Red Danish sires have had on the means of these production characteristics--both in an average effect and a grading-up effect of each foundation breed. Table XV gives a picture of the entire effects that the grading-up project had on milk and butterfat production and butterfat percentage. The Red Dane progeny--one-half, three-fourths, and seven-eighths Red Danish--increased the mean milk production 580 pounds, or

6.8 percent, which is a highly significant increase over the combined foundation herd average. The crosses increased the butterfat mean by 18 pounds, or 5.1 percent, which is also statistically significant at the 1-percent level. The mean butterfat percentage was lowered seven-hundredths of 1 percent (1.7 percent), which is nonsignificant. This increased mean milk and butterfat production was due to the grading up of the Guernsey, Jersey, Shorthorn, and Mixed breeds. The coefficients of variability of all three traits were lower in the Red Danish progeny than in the foundation cows. This indicates that on an over-all basis the crosses were significantly less variable than their dams ("t" test $P < 0.01$).

The results previously stated show the effect of successive purebred Red Danish sires on the various foundation breeds.

In conclusion, it was found that the average milk production of the various crosses resulting from the Guernsey, Shorthorn, and Jersey foundation breeds showed a significant increase from generation to generation ($P < 0.05$ and 0.01). The progeny of the Holstein and Red Danish crosses gave a reduced mean milk production; however, statistics were significant at the 5-percent level in only one instance. The means of the progeny of the Brown Swiss and Mixed breed foundation cows were no different than their dams.

Table XVI shows that the inheritance of total milk production was very close to the means of the parental breeds for this character. On an average basis, the first cross was 0.2 percent nearer the better parent; however, this cannot be considered as a significant deviation from the parental mean. Consequently, one can conclude from these data that no heterosis was evident. The analysis of the butterfat production data for heterosis shows that the means of the first cross progeny were even nearer those of the parental breeds than for milk production. The weighted average of the first cross was precisely that of the weighted average of the parental breeds. Table XVI indicates that the butterfat percentage exhibited an even greater tendency to be half-way between the parental percentages. An inspection of the Tables VIII to XIII will reveal that this tendency carried through for all generations. These data are in conformity with those described by Wriedt (1930), in his report of Red Danish and Jersey crosses in Denmark where he found that the F_1 generation produced very near the mean of the parental breeds. This study does not substantiate the data reported by Gilmore (1952), where he estimated heterosis of nearly 15 to 20 percent in the data reported by Fohrman (1949). Undoubtedly, the differences between Fohrman's findings and these studies are

probably due to the difference in numbers of animals involved. This study represents 1,235 first-cross or crossbred cows, whereas the study cited by Gilmore reported on 28 crossbred cows.

In the chapter on the influence of three nonhereditary factors, statistical treatments were employed to determine whether this increase in mean milk and butterfat production was due to time trend and/or other environmental attributes. The mean production for the foundation cows and crosses was plotted separately, and no differences in time trends were observed. It should also be considered that each year as many grade cows are being subscribed to the program as there were at the beginning in 1940-41. If improvement in environment and general time trends were in effect, the average of the foundation breeds would be as favorably affected as the Red Danish crosses.

Repeatability Estimates

The intraherd and all-herd correlations for milk and butterfat production between the successive records of foundation breed cows are shown in Table XVII. This intraherd correlation measures the degree of permanence of milk production as an individual characteristic of each cow. When compared with the variation existing

in the whole population of records, it expresses to what extent a cow tends to produce the same amount of total milk yield, lactation after lactation. The all-herd correlation tends to make the correlation coefficient larger, since when several herds are considered as a single population, the degree of likeness between records of any particular cow is due not only to her own inherent producing ability, but also to the fact that her records were made in the same herd and under similar conditions of feeding and environment. The intraherd correlation more nearly expresses the degree of likeness due to the inherent ability, if the testing environment within the herd is reasonably uniform and removes the likeness between records due to being in the same herd.

These repeatability estimates varied in the same direction, when comparing the intraherd correlations with the all-herd correlations, as those reported by other workers. For these data the all-breed single population repeatability coefficients for milk and fat production were 0.54 and 0.66, respectively, while those on the intraherd basis were 0.36 and 0.37. An inspection of Table XVII reveals that there was quite a variation between breeds for both analyses. The Guernsey breed was highest in both cases, and the Mixed breed was lowest. The Holstein, Shorthorn, and

Jersey breeds showed a very close degree of likeness in the all-herd coefficients.

The all-herd coefficients found in this study are not greatly different from those of other findings. Gowen and Gowen (1922) found 365-day lactation records for Holstein-Friesians to be +0.67 for milk. Harris et al. (1934) found the correlation between butterfat records of the same cow to be +0.56 when herds were considered as a single population. Sanders (1930), in his studies of records made by cows belonging to many herds, was the order of +0.73 for total milk yield. Likewise, in a population of Danish cows from many herds, Gaines and Palfrey (1931) found an average correlation of +0.50 for yield of fat-corrected milk. This estimate is lower than the preceding ones which also included herd differences. The reduction of the repeatability estimate in Gaines' and Palfrey's data may be due to the highly selected group of cows they were dealing with, since a cow had to have ten or more records to be included in their study.

Dickerson (1940) pointed out that when Gowen and Gowen's (1922) estimate of repeatability is expressed on an intraherd basis it becomes about +0.50 for milk production. Harris et al. (1934), expressing their findings on an intraherd basis, found that the

all-herd correlation of +0.55 became +0.33 when calculated on an intraherd basis. Plum (1933), from Iowa Cow Testing Association records, calculated an intraherd repeatability of +0.40. Johansson and Hansson (1940) reported an intraherd repeatability of +0.36. Dickerson and Chapman (1940) utilized the intraherd repeatability as a measure of genetic worth of five different kinds of records. The intraherd correlation between age-corrected 305-day 2X butterfat records, as used in this study, was +0.34. Verna (1945), in a study of one herd--the Iowa State College Holstein herd--found the estimates of repeatability of the order of +0.50 for milk and +0.43 for butterfat yield. Laben and Herman (1950) found the estimates of repeatability for the University of Missouri herd to be +0.41 for milk and +0.36 for butterfat production. Chandrashaker (1951) and Chai (1951) found the repeatability of butterfat production to be +0.34 and +0.49, respectively, on an intraherd analysis of Holstein-Friesian cattle in Michigan state-owned herds. The estimates of repeatability on an intraherd basis found in this study were of the order of +0.36 for milk and +0.37 for butterfat production. These agree very closely with the statistics obtained by numerous other investigators.

An attempt was made to analyze what the grading-up effect might have had on repeatability estimates of the various crosses from the different foundation breeds. It was found that an analysis of this type was beyond the scope of this study, when done on an intraherd basis. The results as obtained on a single-population study, all herds combined, are set out in Table XIX. An inspection of the data reveals that very little change occurred in the degree of repeatability of records of the foundation breeds and their progeny. The repeatability estimates of the graded-up progeny tended to be slightly greater than those of the foundation breeds. However, these differences are not statistically different.

The repeatability estimates for the various crosses of graded-up progeny are set forth in Table XIX. It was found that the single-population estimates resembled those of the foundation breeds very closely. However, it is peculiar that when the estimates were expressed on an intraherd basis, the coefficients for the crosses were somewhat less than those of the foundation breeds. Within the crosses the intraherd coefficients of repeatability are rather harmonious and more in agreement than those within the foundation breeds. The high values found for the Guernsey breed on an intraherd basis tend to make the all-breeds estimate high, since

the Guernsey breed represented the largest group of foundation cows and this would be reflected in the average estimate. The smallness of the estimates of repeatability of the crosses may be due to unsuitable correction factors used to correct for age at freshening. This is substantiated by the findings of Laben and Herman (1950) and Dickerson (1940), who found the repeatability estimates to be of the order of +0.26 and +0.29, respectively, for records uncorrected for age. It is worthy of note here that the correction factors used for the crosses were mixed-breed factors, since factors for this breed have not been calculated as yet.

To know the correlation between records made on an intra-herd basis by the same cow in the American Red Danish cattle population is of importance from the practical standpoint. If the true ability of a cow belonging to these herds is to be estimated as a basis for some culling or breeding choices, the exact knowledge of the repeatability of records in this particular population is needed. The coefficients of correlation (estimates of repeatability or r) as found in this study supply that information. Of this population, the third-cross graded-up Red Danish females are the most important in estimating a cow's real productive ability, since they are the

dams of future herd sires to be used in this project. The supply of purebred sires from the parent Red Danish herd are exhausted and this will necessitate the breeders selecting their own sires (fourth-cross males are registerable if certain production requirements of the female lines are met), and it will be worth their having the required statistics for computing an estimate of a cow's real producing ability for the purpose of certain matings designed to produce bulls of greater transmitting ability. It seems reasonable from the data obtained in this study to recommend the use of such figures as +0.30 and +0.40, respectively, for milk and butterfat production for use in estimating each cow's real producing ability in the third-cross population.

The equation given by Lush (1949) for estimating a cow's real producing ability is as follows: [herd average] + [(nr) ÷ (1 + [n - 1]r)] x [cow's own average - herd average], where n is the number of lactations in the cow's average, and r the intra-herd repeatability of records of the same cow.

While the above formula gives the procedure by which a cow's real producing ability for any kind of record may be estimated, the accuracy of the coefficients of correlation used in the fraction, nr/[1 + (n - 1)r], will determine in part the amount of

confidence which can be placed on such an estimate. The writer feels that enough numbers were involved in the calculations of the estimates of repeatability for the first and second crosses--707 and 442, respectively, for them to be accurate. However, for the third cross, data on only fifty-seven observations were available since the Red Dane project had been in progress for only ten years at the start of this study. It is quite inconceivable to expect to have large numbers of third-generation females with two or more production records available in such a period of time. Therefore, it seems necessary that a study of this type be repeated with the records of the third-cross females in a short time.

Heritability Estimates

The estimates of heritability found in these data approached those found by other workers. Lush and Shultz (1936) estimated the heritability of butterfat production to be 0.25, while Johansson and Hansson (1940) estimated the genetic portion of the intrabreed variance in single records to be 0.30 to 0.40 for fat percentage. Gowen (1934) estimated one-half of the variation in milk yield was due to hereditary differences. Most of the studies reported in the literature have found the intraherd heritability of differences in milk and

butterfat production records to be of the order of 0.3 to 0.4. When the estimates of the present study are expressed on an intraherd basis, they are reasonably within that range.

The significance of knowing the estimates of heritability for the Red Danish cattle population is for its utilization in the selection differential formula for determining the permanent improvement one can expect in the population average each generation. According to Lush (1949), the increase expected per generation should equal the selection differential X standard deviation X heritability. Using this formula, one could estimate how much selection need be practiced to attain a specified increase per generation in milk and butterfat production, or how much improvement per generation should be expected with a specified selection rate.

In these data, the heritability of butterfat for the second cross was estimated to be 0.28 on an intraherd basis. The intraherd coefficient is derived by multiplying the all-herd coefficient times that portion of correlation due to the records being made in the same herd when numerous herds are considered. That portion can be determined by observing the percentage reduction of the repeatability coefficient from an all-herd basis to an intraherd basis. Assuming that only a 10-percent selection was practiced with the

second cross, the percentage of the population saved would be 90 percent, giving a selection differential of 0.20, as shown in Lush's selection differential table. The expected increase per generation with this rate of culling can be calculated as follows: 0.20(78)(0.28) = 4.4 pounds butterfat, where 0.20 is the selection differential, 78 is the standard deviation of the mean, and 0.28 is the heritability estimate. Since a generation is composed of something like four years in dairy cattle, this would be an increase of only 1 pound of butterfat per year. Lush (1949) points out that the actual permanent improvement in the population average each generation is a fraction of the selection differential, as epistatic differences causes approximately one-half of this gain, and their beneficial efforts are lost in later generations due to recombination. The actual increase found in this data between the first and second cross was only 1 pound (Table VIII) and not 4, as calculated with the selection differential. This indicates that very little culling--if any--had been practiced. For an improvement of 10 pounds of butterfat per generation, it would be necessary for the breeders of cattle in this population to cull 25 to 30 percent of the cows with the lowest production records per year.

Summary

A study of the effect of purebred Red Danish sires on milk and butterfat production and repeatability and heritability estimates--when bred to cows of various dairy breeds--was made. All records of 270 to 365 days in length were used and calculated to a 305, 2X mature equivalent basis. A lifetime average was calculated for each cow and used as her producing ability for the comparisons between generations and heritability estimates. The same records were used for the repeatability study, although on a single-lactation basis.

A total of 1,358 foundation cows were compared to their graded-up progeny, both by grading up within breeds and as an all-breed average. It was found that the average milk and butterfat production for the foundation breeds was 8,536 and 354 pounds, respectively, while the averages for three generations of crosses were 9,116 and 372 pounds, respectively, which was a significant increase ($P < 0.01$).

For the graded-up lines within a breed, it was found that no significant increase or decrease was evident for the graded-up progeny of the Holstein-Friesian, Brown Swiss, and Mixed breeds,

while the production for milk and butterfat of the progeny of the Jersey, Shorthorn, and Guernsey breeds was significantly higher.

There was no evidence of nicking or of heterosis among the various breeds and crosses.

The estimates of repeatability were made on a single-population basis and on an intraherd basis. The estimates found for the various foundation breeds were similar to those found by numerous other investigators. The weighted mean repeatability for all breeds on a single-population basis was 0.54 and 0.66 for milk and butterfat production, respectively. When calculated on an intraherd basis, the weighted mean repeatability estimates were reduced to 0.36 and 0.37 for milk and butterfat production, respectively. This was a reduction of approximately 30 to 40 percent --a figure found by most other investigations.

The estimates of repeatability of the crosses reacted slightly differently from those of the foundation breeds. The single-population estimates were essentially identical to those of the foundation breeds. When expressed on an intraherd basis, however, they reduced approximately 50 to 55 percent. The reason for this is not apparent, although it may be surmised that since the number of records for the crosses was only slightly more than two per animal,

the repeatability was lowered because many of the animals may have freshened in a poor condition--resulting in an increased second-lactation record, although both were used as corrected records. An inspection of the records revealed that inconsistency.

When calculations of the estimates of repeatability were made on a single-population graded-up line basis, there were no significant differences between the estimates of the foundation breeds and their progeny.

Estimates of heritability were found by utilizing the intrasire regression of daughter on dam, intrasire dam and daughter correlation and paternal half-sib correlation for the foundation breed to the first cross (Group I), the first cross to the second cross (Group II), and the second cross to the third cross (Group III). The estimates found for the heritability of milk production by the intrasire regression estimate for the three groups were 0.38, 0.43, and 0.66, respectively, while those for butterfat productions were 0.42, 0.36, and 0.67, respectively. There appears to be some environmental correlation in these estimates, since the sires were used both artificially and in bull blocks. Therefore, dam and daughter pairs tended to be more alike due to their records being made in the same herd. The heritability estimates for the third

group were considerably higher than those of the other two groups. This may have been due to an increased heritability of production from dam to daughter or by sampling error because of only seventy-three dam-daughter pairs distributed between twenty-two sires. An additional study on an intrasire, intraherd basis should be made when more data are available to substantiate these findings with the third group.

EVALUATION OF THE PRODUCTION-TRANSMITTING ABILITY OF THE PUREBRED RED DANISH SIRES USED IN MICHIGAN

Review of Literature

Introduction

Dairy cattle are bred primarily for milk production, a character manifested in only the female sex. The males, however, carry the genetic factors determining ability to produce milk, and the male parent exerts an influence essentially equal to that of the female upon the productive ability of the female offspring. Due to the relatively large number of offspring he leaves in the herd, the selection of the herd sire is a matter of great consequence. After twenty years of sire selection, or the sixth successive sire, 99 percent of the herd inheritance would be from the bulls selected, while only 1 percent remains from the foundation females.

The factors used for determining the actual transmitting qualities of dairy sires are generally accepted today as being milk and butterfat production. Type classification plays a somewhat minor role. Both of these factors are the results of a combination of inheritance and environment working together, which results

in making the actual transmitting ability of sires very difficult to determine. That this is generally accepted is attested by the great number of various devices proposed by numerous investigators in evaluating or predicting the transmitting abilities of dairy sires.

The purpose of this study was to determine the sires with superior transmitting ability as measured by the production of their progeny and dam-daughter comparisons.

Methods for Evaluating a Sire's Transmitting Ability

Early writings of livestock breeding emphasize that the most logical method to evaluate a sire is by the performance of his progeny. Cruickshank and Bakewell rented out what they assumed were good young sires and then took them back if their progeny proved worthwhile. Other measures have been constantly sought. However, most sires are usually selected by breeders before they have progeny in production by which to evaluate them. Admittedly, the selection of bulls on the basis of their progeny test is preferred, but it does not necessarily invalidate the use of other measures in evaluating an animal. Since a dairy bull yields no milk, his transmitting inheritance must be assayed by

means of his type, his pedigree, or the production facts of his offspring. Over the past thirty years, many suggestions have been made for working out an estimate of the production facts of a sire's progeny. In general, the idea has been to get a genetic picture by studying his daughters' or sons' daughters' records.

Pearl and associates (1919) proposed one of the early sire indices, based on age-corrected milk production and butterfat percentage records. They suggested the quartile method of arriving at a bull's transmitting ability. This method consisted of compiling a frequency-distribution table of milk production and butterfat percentage of dams and daughters. Then the table was divided into quartiles, and the quartiles were designed as follows: (A) the amount of milk or butterfat percentage above the third quartile line, (B) the amount between the median and third quartile line, (C) the amount between the first quartile line and the median, and (D) the amount of milk or butterfat below the first quartile line. In this way, the change in the milk production or butterfat percentage between any dam and her daughter may be expressed by two letters. For instance a record of the relative milk production AC means that the dam's milk production is over the third quartile line and the daughter's milk production between the first

quartile line and the median. A milk-production record of DB means that the dam's production is below the first quartile line and the daughter's production between the median and third quartile line. The authors recommended that in recording a bull with two or more daughters, it seems best to put these pairs on the basis of one hundred. Thus, a bull with two tested daughters out of tested dams, and one dam is--inrespect to milk production--in class A, her daughter in B, and the pair recorded as AB; the other dam in class C, her daughter in class A, and the pair recorded as CA; the record for the bull will then be 50AB + 50CA on the two pairs. The extension of this method allows the recording of any number of pairs. However, it can become rather complicated as can be seen by the evaluation formula suggested for Hood Farm Torono 20th: 11AA + 5AB + 5AC + 11BB + 11BC + 5BC + 5CA + 11CB + 5CC + 16CD + 5DB + 5DC + 5DD. This method also left unanswered to the breeder the number of pounds of milk and what fat percentage this bull would transmit to his daughters.

Yapp (1924) studied the ability of sires to transmit production capacity to their daughters. The Advanced Registry records of the Holstein, Jersey, and Guernsey breeds were used,

quartile line and the median. A milk-production record of DB means that the dam's production is below the first quartile line and the daughter's production between the median and third quartile line. The authors recommended that in recording a bull with two or more daughters, it seems best to put these pairs on the basis of one hundred. Thus, a bull with two tested daughters out of tested dams, and one dam is--inrespect to milk production--in class A, her daughter in B, and the pair recorded as AB; the other dam in class C, her daughter in class A, and the pair recorded as CA; the record for the bull will then be 50AB + 50CA on the two pairs. The extension of this method allows the recording of any number of pairs. However, it can become rather complicated as can be seen by the evaluation formula suggested for Hood Farm Torono 20th: 11AA + 5AB + 5AC + 11BB + 11BC + 5BC + 5CA + 11CB + 5CC + 16CD + 5DB + 5DC + 5DD. This method also left unanswered to the breeder the number of pounds of milk and what fat percentage this bull would transmit to his daughters.

Yapp (1924) studied the ability of sires to transmit production capacity to their daughters. The Advanced Registry records of the Holstein, Jersey, and Guernsey breeds were used,

and wide differences in the ability of sires to transmit production were found. A formula was proposed to predict a sire's transmitting ability from these data. It was expressed in 4-percent milk-fat basis by the formula X = 2A - B. Here X = sire's transmitting ability, A = daughter's average records converted to 4-percent fat basis, and B = dam's record converted to a 4-percent fat basis. Yapp also suggested the conversion of these indices to percentages of the average of the breed for purposes of comparison. For example, if the breed average was 400 pounds and a bull had a 400-pound index, his transmitting ability would be 100 percent; if his index was 500 pounds, he would be known as a 125-percent bull, meaning his index was 25 percent above breed average. This general type of method, without correction for fat content, has been widely used.

Turner (1925) studied Guernsey sires having ten or more Advance Registry daughters. He further extended the study to determine the relation between production of the daughters and their dams. He concluded that the apparent difference between the sire and dam on their daughters' fat production was due to the fundamental difference in the index of germinal composition of the male and female. He found that for each 100 pounds of fat per

year increase in the production of the dams there is a corresponding increase of 15 pounds in the daughters. He assumed, therefore, that the dams contribute 15 percent and the sires 85 percent for each 100 pounds of fat produced by the daughters. From these results, he advanced the following formula as the sire's potential transmitting ability: X = [Daus. fat production - 0.15 (dam's fat production)] ÷ 0.85. Then Turner (1927a) in his later studies suggested modification of the formula presented in 1925. He analyzed Jersey sires with Register of Merit daughters and proposed the formula, X = daughter's average fat production - 0.15 dam's fat production, as the best estimate of a sire's transmitting ability.

Graves (1926) studied the transmitting ability of twenty-three Holstein-Friesian sires and suggested comparing the dams' and daughters' records and letting the difference (plus or minus) stand for the bull's index. This system has been adopted by the Dairy Division of the United States Department of Agriculture for proving bulls whose daughters have been tested in the Dairy-Herd Improvement Association Testing program.

Goodale (1927) derived the Mount Hope Index from a study of Dr. Gowen's crossbreeding experiments with cattle at the Maine

Station. After considerable study--which included the records of fifty-eight Jersey Sires, fifty-eight sires of various breeds, and a large series of Guernsey records--Goodale formulated the following index as a guide for breeding operations at the Mount Hope farms. This, incidentally, attracted wide attention among other breeders. Briefly the index was formulated as follows. When dams exceeded the daughters, the Sire's Milk Index = daus. ave. + 0.429X (daus. ave. - dams ave.). The Sire's Fat Index = daus. ave. + 1.5X (daus. ave. - dams. ave.); when the daughters exceeded the dams, the Sire's Milk Index = daus. ave. - 2.333X (dams ave. - daus. ave.). Sire's Fat Index = daus. ave. - 0.6777X (dams ave. - daus. ave.).

Gifford (1930a) made an analysis of the progeny performance of Holstein sires in order to determine the transmitting ability of the sires. The sires were grouped according to their average progeny performance records in groups ranging as follows: 500 to 599, 600 to 699, 700 to 799 pounds, and 800 or more pounds butterfat. Coefficients of correlation were calculated for each subgroup. This grouping had a tendency to hold the sires fairly constant, and furnished data which were somewhat less influenced by the minimum entrance requirements than were the data representing

the entire population. The weighted-average coefficient of correlation obtained was 0.197 and is substantially identical to the results obtained by calculating the partial correlation. Gifford concluded that since Holstein-Friesian cows, on the average, only contributed approximately 0.20 of a pound of butterfat for each pound increase in their records to the yearly butterfat record of their daughters above the potential transmitting ability of the sires with which they were mated, it is possible to obtain the value of the sire's transmitting ability where there are relatively large numbers of dam-daughter pairs by means of the following formula, Spt. = d - 0.2D, where Spt. is the sire's transmitting ability, d the average yearly butterfat records of the daughters, and D is the average yearly production of the dams of the daughters.

Gifford (1930b) studied eighteen Guernsey sires, selected at random, that had twenty or more daughters out of tested dams. He also calculated the Mount Hope Index (Goodale, 1927) and the difference in production as used by the United States Department of Agriculture (Pearl and associates, 1919; Graves, 1926), and compared the indices with all the daughter's average production of a sire, and concluded that the daughter's average was of more value

in predicting records of daughters than the sire indices presented by the other investigators.

Wright (1931) reviewed the formulas suggested by Yapp (1924) and Goodale (1927) for estimating the transmitting ability of dairy sires. He concluded that Goodale's formula was biased because of being formulated from the performance of crosses of two breeds as abstract as the Jersey and Aberdeen Angus. However, in taking an average value of the two formulas suggested by Goodale and comparing it with the ones proposed by Yapp, he found the two to differ only slightly. Wright was critical of Yapp's formula in that it did not offer a measure for taking into account the number of daughter-dam pairs available in the comparison. Wright suggested a formula based on the genetic theory of multiple-factor inheritance, giving weight to the breed average, where the number of daughter-dam comparisons is small and increasing weight to the daughter-dam comparisons as the number of these comparisons increases. He proposed the following formula: $\Sigma = [2/(n + 2)][A + n/(n + 2)][2O - D - A]$, where n = the number of daughter-dam comparisons, A = the breed or herd average in production, O = daughters' average production, D = the dams'

average production, and Σ = the bull's transmitting ability or index value.

Ward and Campbell (1940) reported on the "sire-survey work" in New Zealand. Under the program, when the first daughters of a sire have completed a testing year, a "preliminary" survey of the sire's performance is issued to the breeder. The survey is continued from year to year. At the end of the second testing year an "intermediate" survey is issued. This contains the performance of the second records of the sire's daughters and any additional first records, second records, and third records of daughters would be included in the survey; this would be issued in the form of a "final" survey of the sire. Age-correction factors (New Zealand data) are used only for two-year and three-year records. The New Zealand workers present an evaluation of forty-one sires with "final" sire surveys. The general use of a single index by which to express the breeding value of a bull is not likely to be very accurate in practice, but the average production of all daughters is a better approximation to the bull's probable breeding value than the intermediate parent index. They also suggest that many of the serious practical limitations ascribed to sire indices are more academic than practical in their implications

and that the practical breeder or dairy farmer can make use of sire-survey work.

Rice (1944) and Rice and Andrews (1951) reported that because of its simplicity and approximate accuracy, the "Equal-Parent" index, also known variously as the "intermediate," "American," or "Yapp-Hansson," is being widely used today. The "Equal-Parent" index is generally calculated by finding the differences between the average amount of milk and butterfat test of a group of cows and the similar averages for their daughters by a given bull. For both amount of milk and butterfat test, if the daughters' average exceeds the dams' average, twice the difference is added to the daughter's average to secure the bull's "Equal-Parent" index; if the daughter's average falls below that of the dam's, twice the difference is subtracted from the daughter's average to secure the index. This method, therefore, always places the daughters intermediate between the dam's actual average and the bull's "Equal-Parent" index. This can be resolved into the formula $EP = 2d - m$, where EP equals bull's index, d equals daughter's average, and m equals dam's average.

Rice (1944) examined the bull-index problem and proposed a new index called the Regression Index. It is based on the

findings that the regression of daughters' records on those of groups of dams was 0.5. The regression index can be found by getting the difference between a sire's daughter's actual and "normally expected" production and adding this difference to the breed average. Rice suggested that if normal tables of expectation were not available, the normal expectation for any group of daughters could be ascertained by adding the respective breed averages in milk and test to the dam's average milk and test and dividing by 2. This is done on the basis that daughters regress 0.5 toward breed average from their dam's average. Similarly, an optional manner and the easiest way of finding a bull's Regression Index would be to find his EP index in the usual fashion, twice daughters' averages minus the dams, then add the respective breed average and divide by two.

Allen (1944) used the data compiled by the nationwide survey of dairy sires proved in dairy-herd improvement associations by the Bureau of Dairy Industry which made available 5,886 proved sires of the five major dairy breeds. The data for each breed were considered separately. He assembled these data according to the dams to which the individual sires were mated. Milk production, fat production, and fat percentage were considered separately.

From these data--for each breed and for each of the three performance factors--the average level of performance of the sires' progeny was estimated in relation to the average level of the dams to which they were mated. These findings were set up in graphical form, to be used as a guide in evaluating progeny-tested bulls and in predicting probable production of future daughters.

Dickey and Labarthe (1945) have proposed a system to evaluate the probable transmitting abilities of young bulls by an analysis of their pedigrees. Data for this study were obtained from USDA Miscellaneous Publications No. 487, June, 1942. Each Holstein-Friesian proven sire listed in this publication was used and called a "son." Then the sire and dam of each of these "sons" were determined. If the sire was proven and the dam had a record, the "son" and his pedigree was used. The investigators succeeded in obtaining 241 such pedigrees for this study. The formula used for predicting records of "sons'" daughters by means of the regular pedigree value was PR = (C + D) ÷ 2, where PR is the predicted records, C is the son's pedigree value found by adding Equal-Parent Index of sire to son's dam's record and dividing by 2, and D is the son's mate's records. The correlation between the predicted records and the actual records of

the son's daughters were 0.565 for milk production, 0.531 for butterfat yield, and 0.630 for butterfat test.

At the time the study by Dickey and Labarthe was in progress, Rice (1944) announced his regression index for proving dairy sires, and the authors applied a regressed pedigree value to these data for predicting son's daughters' production. The procedure was the same except for finding the son's pedigree value equals C = (A + B) ÷ 2, where A is the Regression Sire Index (equal-parent index + breed average) 0.5, and B is the dam's transmission Index (her record + breed average) 0.5. By this method the correlations between predicted and actual records were slightly higher than by the regular pedigree value method. Also, when the values were plotted to a straight-line regression the regressed pedigree values more nearly fitted a straight line or approached one for milk and butterfat yield. This led the authors to conclude that the regressed pedigree value is superior to the regular pedigree value in predicting the transmission of milk production and butterfat production; however, the two methods are about equal in predicting the transmission of butterfat test. They also suggested that perhaps by regressing the "son's mates" production with the average breed production, or by applying correction factors

to the "son's" pedigree at varying levels of production, some refinement can be added to the prediction of milk and butterfat production and butterfat test.

Washbon (1947, 1948, 1950, 1951, 1952), in a series of publications, has undertaken the evaluation of a sire's transmitting ability through the performance of his sons. He has studied all bulls proven by the Division of Dairy Herd Improvement, Bureau of Dairy Industry, that have five or more proven sons. Bulls studied in the Holstein breed include those with official Holstein association proofs. The bulls were all proven by the method of Graves (1926). He has constructed tables which evaluate all proven sires by the proof level of their sons.

Eldridge (1948) presented a "Multiple Regression Method" of sire selection. He studied the proof levels of 1,451 Holstein sires proved in the State of New York and listed in the Animal Husbandry Extension files of Cornell University. A method was developed for selecting young, unproved dairy bulls that predicted the production of the daughters of such sires. The formula, $\hat{Y}A = 29.6 + 0.75X + 0.03X_2 + 0.01X_3 + 0.34X_4 - 0.21X_5$, developed by Eldridge, gave a predicted production value which was correlated 0.70 with the actual production. Another formula presented by

to the ''son's'' pedigree at varying levels of production, some refinement can be added to the prediction of milk and butterfat production and butterfat test.

Washbon (1947, 1948, 1950, 1951, 1952), in a series of publications, has undertaken the evaluation of a sire's transmitting ability through the performance of his sons. He has studied all bulls proven by the Division of Dairy Herd Improvement, Bureau of Dairy Industry, that have five or more proven sons. Bulls studied in the Holstein breed include those with official Holstein association proofs. The bulls were all proven by the method of Graves (1926). He has constructed tables which evaluate all proven sires by the proof level of their sons.

Eldridge (1948) presented a ''Multiple Regression Method'' of sire selection. He studied the proof levels of 1,451 Holstein sires proved in the State of New York and listed in the Animal Husbandry Extension files of Cornell University. A method was developed for selecting young, unproved dairy bulls that predicted the production of the daughters of such sires. The formula, $\hat{Y}A = 29.6 + 0.75X + 0.03X_2 + 0.01X_3 + 0.34X_4 - 0.21X_5$, developed by Eldridge, gave a predicted production value which was correlated 0.70 with the actual production. Another formula presented by

Eldridge, $\hat{Y}_B = 0.1 + 0.75X_1 + 0.01X_3 + 0.23X_4 - 0.22X_5 + 0.24X_6$,

gave predicted values correlated 0.69 with actual production.

$\hat{Y}_A$ is the predicted average mature equivalent production of the daughters of the bull, when

X_1 is the average production of the cows to which this bull "is to be" or "was" bred.

X_2 is the average production of the maternal half-sisters of the bull.

X_3 is the production of the dam of the bull based on the average of the maximum number of records available.

X_4 is the average production of the paternal half-sisters of the bull, and

X_5 is the average production of the dams of the paternal half-sisters.

$\hat{Y}_B$ is the predicted average mature equivalent production of the daughters of the bull, when

X_2 is replaced by X_6, which is the average production of the daughters of the maternal grandsire of the bull.

Edwards (1932) analyzed production records of Jerseys in England to estimate the number of daughters needed to give the best estimate. He also applied five of the indices discussed

previously--Pearl and associates (1919), Yapp (1924), Wright (1931), Goodale (1927), and Gifford (1930b)--to these data and concluded that the daughters' average production (Gifford, 1930b) was the better for determining a sire's transmitting ability than any of the others. However, he cautioned that all data must be studied closely and that these findings might well not apply to other data. His findings bear out those of Gifford (1930b).

Rice (1944) sets up a criterion that a bull index should meet, as follows: sound from a genetic viewpoint, easily understood, calculated in terms of breed average, and comparable in variability to groups of animals rather than to individuals. According to Rice, a bull index should also perform the following: rank bulls in their proper order, provide a definite measure of a bull's transmitting performance, provide a means for predicting future daughters' production, and provide as accurate a means as possible for evaluating pedigrees. He measured the Equal Parent Index and the Regression Index against the above-named criteria and concluded the Regression Index more nearly fitted the expectations.

Lush and Nelson (1943) evaluated the methods available for measuring transmitting ability in sires and cows and the biased errors which enter into such evaluations. They suggested that in

most data the biased errors will be large enough that the random errors are already reduced to secondary importance by the time there are as many as five daughters. Further increases in the number of daughters raises the accuracy of the estimate of transmitting ability only a little unless those biased errors are reduced by other methods. Lush and Nelson advanced four principal sources of biased errors: (1) The general environment under which group of daughters made their records may vary from sire to sire. (2) The general environment of the daughters of a sire may not have been the same as the general environment of his mates. (3) The average genetic merit of the mates may vary from sire to sire. (4) Selection of the mates may have been more intense for some sires than for others, thus making the average record of the mates farther above their average transmitting ability in some cases than in others.

In applying these biased errors to the most widely used measures of transmitting ability, (A) the average of the daughters, (B) the increase of daughters over dams, (C) the various indices such as equal-parent, Mount Hope, Yapp-Hansson, etc., using the sum of A and B, the writers concluded that these measures are affected as follows by the biased errors. A is affected most and

B least by error (1). B is affected most and A not at all by (2). A and B are affected in opposite directions by (3) while C is unaffected. B is affected most by (4) while A is not affected. They concluded that error (1) is generally the most serious source of error although (2) can be in some cases. Selection of mates (4) can only rarely be of major importance since opportunity to vary widely the intensity of selection of mates will not often occur. Measure C is believed to be more widely useful than the other two but, since the measures are not equally vulnerable to all kinds of errors, there may be some sets of data in which measures A or B would be more accurate. If there are data in which it is known that errors (2), (3), and (4) were very small or zero, while error (1) was large, measure B would be more accurate for analyzing these data. However, if the reverse is true, error (1) is small and errors (2), (3), and (4) are large, A will be more accurate. They suggest that where some or all of the dams are untested, measures B or C can be used to good advantage by using in place of the missing records the average production of the contemporaries of the daughters in the same herd. This helps correct for errors (1) and (2).

Minimum Number of Progeny for Sire Evaluation

The question of how many progeny should be considered as a sufficient number to be used to measure the relative breeding value of a sire has been a prevalent one. It is evident that, as the number of progeny considered in a progeny test increases, the resulting predictions are more accurate. However, there must be a point at which an increase in numbers is of little value in increasing prediction accuracy and likewise there must be a point at which a decrease in numbers will cause an increase in inaccuracy. The Bureau of Dairy Industry has adopted the number of progeny to be five when using daughters of a sire in a "sire proof." Washbon (1947), in his "Sire Directory," used five or more as the number of sons for evaluating a sire. Several investigators have undertaken to determine statistically the optimum number of progeny to use in sire evaluations.

Daughters

Davidson (1925) studied the Register of Merit of The American Jersey Cattle Club to determine the number of tested daughters of a sire whose average production could be used as a relative

measure of a sire's breeding value. He selected all Jersey sires having at least fifteen tested daughters. From a preliminary study of the data Davidson found that it may be assumed that the variability in the production of the first fifteen daughters of a Jersey sire is representative of the variability in the productions of any large number of his tested daughters since the mathematical constants used to measure the variability in the production were many times their probable error. He also used the same assumption in using fifteen daughters as the basis with which any smaller number of tested daughters may be compared. In order to determine the smallest number of a sire's first tested daughters whose average productions would closely approximate any large number of his tested daughters, Davidson set up a classification listing the daughters by chronological order as they appeared in the Register of Merit. Then a grouping of these was made: the first daughter made the first group, the first and second daughters made up the second group, and so forth, until the first fifteen daughters made up the fifteenth group. The coefficients of correlation were calculated between each group with the fifteenth group of daughters and were fitted to a curve. The curve rose very rapidly at first and then gradually flattened out into an almost straight line. The point at

which this flattening in the curve began to be pronounced lies in the region of the sixth coefficient of correlation, which represents the sixth daughter-groups. The coefficients calculated from the fitted curve increased from +0.526, the coefficient of the sixth aggregate, to +1.000 for the coefficient of the fifteenth aggregate. Approximately three-quarters of the total increase in the correlations from the first to the fifteenth aggregate is reached by the sixth aggregate, thus showing that after the sixth aggregate, additional daughters influenced the correlations only slightly. Davidson therefore concluded that on the average, the mean milk yields of the first six tested daughters of the 133 sires studied, are a very close approximation to the mean milk yields of their first fifteen tested daughters.

Lush (1931) investigated the minimum number of progeny needed to make a rather reliable prediction of a sire's future daughters. He set up a general formula for the correlation between the average record of the daughters and genotype of the sire for factors affecting milk production. Lush suggests that if we let "s" represent the path coefficient from the sire's genotype to the daughter's record, and if we let "e" represent the path coefficient from the herd management or common environment (including also the average

relationship of the dams to each other) to the daughter's record, then it is evident that the primary observed correlation between the records of half sisters equals $e^2 + s^2$. The value of s would be 0.50 in a random-bred population where there was no dominance and where milk and fat production were entirely determined by heredity. The value of e^2 is 0.15 as determined from Advanced Registry data. Expected correlation between sire's genotype and the average record of various numbers of daughters at selected values of s and e^2 were calculated. In the calculations, s had been figured at four different values; namely, 0.30, 0.40, 0.50, and 0.60, whereas e^2 was figured at 0.00, 0.10, 0.20, 0.30, and 0.40. Lush concluded from the calculated curves using different values of s and e^2 that at low values of s and e we may gain a very noticeable increase in the reliability of the progeny test by increasing the number of daughters even past eight or ten. At the other extreme, with high values of e and s, there is little accuracy to be gained by increasing the number of daughters even past three or four. For what appears to be the most probable values for s and e, only a little increase in accuracy is to be gained by including more than five daughters in the progeny test. Of course one would

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want to base his estimate on all that are available, no matter how many there may be.

Edwards (1932) employed the formula, V = [Sum (for all groups) of sum of squares of deviations from group mean] ÷ [Total daughters minus number of groups], or $V = [\Sigma(x - \bar{x})^2$ for all groups] ÷ [T daus - N groups], to calculate the variance of one daughter, in order to obtain an indication of the minimum number of daughters necessary to prove a sire. By this method Edwards calculated the σ of the milk yield of a single daughter and the σ for the mean of an increasing number of daughters up to fifteen by the corresponding root of the number. He found that for two sires with one daughter each, the difference--to be significant--between milk yields had to be 5,521.5 pounds; with 15 daughters each, it had to be 1,425.6 pounds; with 52 daughters, 770 pounds. The author concluded that, since a breeder desires to know with a minimum of daughters the value of a sire, six daughters are necessary to evaluate the ability of a sire. With six daughters the difference to be significant between the averages of the milk yield of daughters of sires must be 2,469.3 pounds.

Sons

Washbon (1949) investigated the possibility that "D. H. I. A. Proved Sons" of a sire might be used to evaluate the inheritance of a sire or a sire family. One hundred and seventy-four Holstein sires with more than fifteen proved sons were studied to determine the least number of proved sons necessary to most accurately estimate the performance of those proved later. Highly significant correlations (r = 0.58) indicated that the average butterfat production of the daughters of the first three proved sons was nearly as accurate as data on more sons in estimating the average butterfat production of the daughters of the next three, five, or ten proved sons of a sire. Similarly, the significant correlations (r = 0.33) for the son's daughters' increase or decrease in butterfat production from their dams indicated that data on the first three or four proved sons were nearly as accurate as data on a larger number in predicting what might be expected from the next three, five, or ten proved sons in this respect. For the percentage of sons showing plus proofs, the correlations were significant when the first four, five, and six sons were compared with the next ten (r = 0.25).

Investigational Procedure

Numerous investigators have shown that the production of the progeny of a sire and the dam-daughter comparisons within each sire are as good a measure of a bull's transmitting ability as any of the available methods. These two methods were used in this study.

The sires were grouped according to three sire-family groups, since all bulls used as sires are either sons or grandsons of the three imported bulls (one imported in dam). The mean production, standard deviation, and coefficients of variability for the progeny of each sire were calculated using the same procedure as previously described.

All data pertinent to this part of the study were obtained from the IBM Card No. 6, "Heritability and Sire Evaluation Card" (Fig. 4). A series of sortings, calculations, and tabulations was performed with the final products printed on the usual folded sheet of paper.

Investigational Results

An inspection of the pedigrees revealed that the imported sires D501, D502, and D505 had thirty-four, thirty-three, and

seventeen sons and grandsons, respectively, used in this project. In order to determine whether differences between sire families existed, the sons and grandsons were grouped according to the three imported bulls. Table XXII shows the statistics obtained for each sire within a sire family. In analyzing these bull families, it is seen that the production of the daughters was essentially the same for families 501 and 505. The progeny means in sire family 502 were on the average 10 pounds below the level of the progeny of the sires in the other two families. It could be possible that by random chance the level of production of the mates was lower for that family; however, this is not probable, since the sires were moved each year to a new herd and some from each group were used artificially; therefore, the chance of being mated to mates of different levels was unlikely. However, when rated according to the sire's transmitting ability as calculated from these data, there appeared to be no apparent difference in the sire families.

It is interesting to note that each family had one or two sires that have a substantial minus proof level. On the whole, however, the proof levels were good since 81 percent of the sires increased production over their dams.

TABLE XXII

PERFORMANCE OF RED DANISH SIRES BY FAMILY GROUPS

Sire No.	Inbreed- ing of Sire	No. Daus.	Avg. Fat	Std. Dev.	Coef. Var.	No. Dam- Daus. Pairs	Proof Dif- ference	Sire's[3] T.A.
				Sire Family 501				
1507	00.8	34	338	67	19.3	15	- 8	340
1561	00.8	45	376	65	17.5	30	+12	388
1562	03.1	25	304	59	19.4	13	-49	262
1569	00.4	17	326	79	24.2	13	-36	282
1572	00.8	21	377	72	19.4	17	+40	464
1575	00.8	60	396	56	14.1	50	+35	428
1578	00.8	27	373	68	18.2	16	+18	444
1603[1]	37.5	46	376	69	18.4	24	+31	440
1607	00.0	46	388	89	20.9	32	+16	416
Avg.[2]		35.7	369	74	20.0	23	+15	405
				Sire Family 502				
1508	00.0	29	332	53	16.0	15	+32	383
1556	01.6	45	375	64	17.0	32	+25	429
1557	00.0	103	356	67	18.8	74	+22	407
1558	02.3	62	350	68	19.4	35	+34	411

TABLE XXII (Continued)

Sire No.	Inbreed-ing of Sire	No. Daus.	Avg. Fat	Std. Dev.	Coef. Var.	No. Dam-Daus. Pairs	Proof Dif-ference	Sire's[3] T.A.
1559	03.1	72	373	74	19.8	39	+32	435
1560	00.0	7	351	55	15.7			
1567	00.0	19	384	76	19.8	15	+ 8	419
1568	13.3	27	375	65	17.3	22	+30	438
1582[1]	14.3	28	320	95	29.7	21	-48	246
1604	13.3	24	361	59	16.5	12	+73	504
1611	00.0	40	350	68	19.4	25	+ 2	365
Avg.[2]		41.5	358	74	20.7	29	+20	402
				Sire Family 505				
1563	07.8	17	372	61	16.4	10	+11	372
1564	07.8	21	351	57	16.2	15	+ 4	350
1566	00.6	46	373	74	19.3	24	+35	441
1570[1]	00.2	35	413	67	16.2	31	+47	499
1571[1]	00.4	46	347	63	18.1	30	- 4	339
1573[1]	00.2	34	368	52	14.1	26	+17	403
1574[1]	01.0	11	359	85	23.6	7	-47	285

TABLE XXII (Continued)

Sire No.	Inbreeding of Sire	No. Daus.	Avg. Fat	Std. Dev.	Coef. Var.	No. Dam-Daus. Pairs	Proof Difference	Sire's[3] T.A.
1577[1]	00.0	7	395	64	16.2	4	-10	365
1579[1]	00.0	14	342	56	16.3	11	+42	426
1580[1]	14.3	12	375	62	16.5	11	+20	412
1602[1]	07.8	26	352	36	10.2	14	+13	382
Avg.[2]		24.5	368	69	18.8	16.6	+18	404

[1] Grandsons of imported sires.

[2] Weighted average based on dam-daughter pairs.

[3] Sire's transmitting ability determined by adding twice the daughter's difference to the dam's average. This is based on results obtained from the study on grading up.

To determine the effect of the inbreeding of a sire on the variability of his get, a study of Table XXII was made. There were seven sires that were inbred more than 7 percent, or an average of 14.5 percent. In studying the standard deviations and coefficients of variability, it appeared that the standard deviations were less for the gets of the inbred sires than the standard deviations of comparable means for the gets of the noninbred sires. However, when a weighted analysis of the data was made by pooling the total butterfat production and sums of squares for the inbred and noninbred groups, a different conclusion was made (Table XXIII). These results show no apparent differences between the variance of the gets of noninbred sires as compared to those from inbred sires.

Discussion and Conclusions

An attempt was made in this study to separate the Red Danish sires into sire families and analyze their transmitting ability by daughter averages and dam-daughter comparisons. As was expected, three sire families were identified, because all the Red Danish sires used in Michigan originated from the three imported sires. To date, there has been only one importation;

TABLE XXIII

RELATION OF VARIANCE OF PROGENY TO INBREEDING OF THE SIRE

Group	Avg. I.B.C. of Sire	No. Daus.	Avg. Fat	Std. Dev.	Coef. Var.
Noninbred	0.0	686	367	71	19.3
Inbred	14.5	173	370	73	19.7

consequently, the pedigrees of all Red Danish animals will trace back to the animals in this importation.

It was not expected, however, to find such close conformity of the progeny averages and dam-daughter comparisons for the three families. On inspection of Table XXII, one sees quite a large variation between sires within a family, but on a family average the three are rather close. One of the families can perhaps be considered slightly inferior to the other two. In analyzing the reason for the apparent 10 pounds difference, it appears that the sires of family 502 were mated to cows of a lower mean production. The proof level difference between dam-daughter comparisons

was +20 pounds, which is slightly more than found in the other families. This conforms with the findings of Table XVI, where it was observed that the production of the progeny was essentially that of the mean of the two parents. So if by random chance, the sires of family 502 were mated to cows with a lower mean production than those of sire families 501 and 505, it is very conceivable that the results such as observed can be expected. To analyze this difference more thoroughly, the average production of the mates of each group must be calculated to determine if the averages were different.

In analyzing the transmitting ability of these Red Danish sires, the effects of selection of the foundation cows must be considered. Prior to entering the program of breeding to Red Danish sires, it must be assumed that normal selection or culling was practiced by the breeder. According to Lush (1949), there is approximately a 25-percent turnover of herd numbers, with over half of these for reasons of low production. Gilmore (1952) stated that for each 10 percent of the low-producing daughters of a sire that are culled, the average production of the remaining daughters increases 12 pounds. When a dairyman entered the Red Danish program, he agreed to raise all Red Danish progeny, milk them at

least one lactation, and to remove all foundation cows as rapidly as possible. This regulation placed the Red Danish sires under the handicap of not having their daughters undergo the normal selection for production which occurs in all other herds. Also, the first year that Red Danish heifers came into milk production in a herd, some of the foundation cows were culled in order to make room for the freshening Danish heifers. This, in turn, increased the selection of the foundation cows to an even greater degree. After several such selections of the foundation cows, only those with the highest production records remained. Certainly the Danish sires bred to these highly selected mates were at a disadvantage, since this same type of selection was not practiced with their daughters. An added impetus to milk everything, so to speak, was induced by the formation of the open herd book of the American Red Danish Cattle Association. The rules allow for a third-cross female to be registerable, provided she makes a production record (no required amount), and provided all the females including the foundation cow in the graded-up line be production tested. The investigator feels that it is essential for one to know these existing conditions to properly evaluate and criticize the production traits of the progeny of the Red Danish sires. There is no direct

method of measuring the difference but it is felt that the Red Danish sires were proved under a minimum handicap of 20 to 25 pounds of butterfat when applying the observations made by Gilmore (1952) to these data.

Summary

Thirty-one sires were evaluated for their transmitting ability by the mean butterfat production of their daughters and a dam-daughter comparison. They were grouped into three sire families for analysis. The average production of the progeny from the three groups was very similar; however, the progeny for family 502 was 10 pounds lower than the other two families.

When comparing the families according to their average transmitting ability, it was found that there was a still greater uniformity between the families. Within families there was found a great variation between the average production of the different sire's progeny as well as their transmitting ability. Eighty-one percent of the sires had plus proofs.

Seven of the thirty-one sires were inbred an average of 14.5 percent. An analysis was made to determine the effect of inbreeding a sire on the variation of his progeny. The daughters

of the inbred sires were compared with those of the noninbred sires and no appreciable difference was found in the variability of the two groups.

THE EFFECTS OF MILD INBREEDING ON MILK AND BUTTERFAT PRODUCTION AND THE OCCURRENCE OF DEFECTS

Review of Literature

Introduction

In the development of many of our breeds of livestock, inbreeding has played an important role. Bakewell successfully used this method in his breeding operations with sheep and Shorthorn cattle. Yoder and Lush (1937) reported that the Brown Swiss breed in the United States is descended entirely from 129 cows and 21 bulls which were imported to this country. Over half of the random pedigree lines of the Shorthorn breed go to one bull, Favourite, and, in American Rambouillet pedigrees, about 45 percent of the lines traced back at random end in sheep from the von Homeyer flock in Germany.

Even though inbreeding has successfully molded various breeds, it has found little favor in practical breeding programs. Its deleterious effects have been long known and well recognized. However, it is quite generally recognized that superior stock can

be successfully inbred. In recent years and at the present time, inbreeding projects are being conducted by a number of experiment stations to obtain a more conclusive answer on how to derive greater benefit from this system of mating.

The main purpose of this study was to determine the effects of mild inbreeding on the yield of milk and butterfat production and the occurrence of lethal defects.

Inbreeding of Laboratory and Farm Animals

The studies by King (1918, 1919) on rats reopened the possibilities of utilizing inbreeding effectively in animal improvement. At the end of twenty-five consecutive generations of full-brother full-sister matings, the rats were superior in size and fertility to the stock of outbreds carried as a check. However, selection for those two characteristics was very severe. Wright (1922), reporting on the inbreeding of guinea pigs by the United States Department of Agriculture, found that on the average, at the close of twenty generations of full-brother times full-sister mating of guinea pigs, there had been a decline in all elements constituting vigor; however, there were several families which had not suffered any very apparent degeneration. Crosses between different inbred

families resulted in a marked improvement over both parental stocks in every respect.

Morris, Palmer, and Kennedy (1933) developed two strains of rats from a common foundation, which, in the ninth generation, through continued full-brother times full-sister matings accompanied by careful selection, differed markedly in efficiency of food utilization. The low line was 40 percent less efficient and more variable than the high line. Waters and Lambert (1936) inbred White Leghorn fowl over a ten-year period, during which time they developed six inbred families, with coefficients of inbreeding ranging from 41 to 82 percent. No general decline in fertility and egg production occurred, and the more intensely inbred birds matured sexually sixteen days earlier.

On the other hand, Winters and associates (1943, 1948), in appraising the early inbreeding experiments with swine, chickens, and laboratory animals, and giving what is probably the best and latest review in this field, found a general negative trend. They concluded that these negative results found with farm animals were due to small numbers, thus preventing rigid culling; performance was not given enough attention; and there was too much adherence to experimental patterns to give the best results. Willham and

Craft (1939) and the 1936 Yearbook of Agriculture presented good reviews of the work with farm animals in this field.

Inbreeding of Dairy Cattle

Nearly all of the data available on the inbreeding of dairy cattle have come from the experiments conducted by the Bureau of Dairy Industry at its Beltsville station and by the New Jersey and California Experiment Stations. More recent inbreeding experiments have been inaugurated at several other stations. Some other data have been made available by several workers analyzing the effects of inbreeding as it occurred among private herds--not as a planned experiment, but as a system of mating in trying to fix a definite trait.

Production

Plum (1933) studied the production records of 183 cows of a private herd where considerable inbreeding had been practiced. He found a significant negative correlation within groups of daughters by the same sire which indicated a tendency for the more inbred daughters to be the poorer producers. A positive correlation between sires indicated that as a whole the sires with the inbred daughters

also had daughters whose production was above average. Plum concluded that inbreeding in general lowers production. Bartlett et al. (1939) observed somewhat similar results in analyzing the records of the New Jersey experiment. However, in this case inbreeding had to be considerably high (0.25) in order for it to have a negative effect on production. F_2 cows, 25 percent inbred, produced 2.7 percent less milk and 8.5 less butterfat than did their dams, whereas F_6 cows, 60 percent inbred, produced 31 percent less milk and 38 percent less butterfat than did F_1 cows.

Asdell (1945) studied the breeding systems used to produce the highest yielding cows of the Guernsey and Holstein-Friesian dairy breeds. He observed that the system of breeding was of little significance in the production of cattle with the highest milk or butterfat yield. However, he deduced that strong inbreeding was detrimental in preventing the expression of genes for high yield, since the best results were obtained in one Holstein-Friesian herd when the coefficient of inbreeding was reduced. Woodward and Graves (1946), studying the effects of inbreeding on grade Holstein-Friesians, found results that compare with those of Bartlett et al. (1939). Inbreeding did not have much effect, if any, until the coefficient of 20 percent was reached. Cows inbred 25 to 29 percent

produced 10 percent less milk and 9 percent less fat than did cows inbred less than 20 percent. Cows inbred 50 percent or more produced 20 percent less milk and 25 percent less butterfat than did cows inbred less than 20 percent. Ralston et al. (1948), studying the effect of crossing two inbred lines, observed the effect of inbreeding on production. They observed that outbred daughters of a sire produced 363 pounds of butterfat while his inbred daughters, inbred 12.5 percent, 25 percent, 31.25 percent, and 37.5 percent, produced 288, 269, 190, and 164 pounds of butterfat, respectively. The regression coefficient for an increase of each degree of inbreeding showed a decrease of 5.1 pounds of butterfat.

Nelson and Lush (1950) found that production decreased as inbreeding increased. The regression of butterfat on inbreeding was -4.5 pounds per 1-percent inbreeding. It was possible in this herd to practice enough selection for production to counterbalance the effect of inbreeding and to raise the genetic ability for butterfat production approximately 40 pounds during the twelve years studied. Nelson suggests that if a breeding plan is followed in which the increase in intensity of inbreeding is less than 2 percent per generation, it should be possible to practice enough selection to counterbalance the decline in production expected to result from

inbreeding. Findings of Tyler et al. (1946) bear out those of Nelson. They found that milk production declined 73 pounds and butterfat, 2.3 pounds, for each 1-percent increase in inbreeding. They also found that the variation in the partial regression coefficients between sires was large enough that the offspring of some sires might be inbred as much as 25 percent without any apparent decrease in milk and butterfat production. Swett et al. (1949) found essentially the same results in their study of the results of the Beltsville inbreeding experiment. Production dropped approximately 17 percent in cows inbred more than 30 percent.

Laben and Herman (1950) analyzed the effect of mild inbreeding by the intrasire regression of production on inbreeding. A significant decline of 66 pounds of milk and 2 pounds of butterfat per 1-percent increase in inbreeding was observed. There was no significant effect on butterfat percentage.

On the other hand, some investigations have shown that inbreeding has no adverse effects on production. Woodward and Graves (1933), Bartlett and Margolin (1944), and Vainikainen and Nikkilä (1946) have concluded that inbreeding does not adversely effect milk and butterfat production when superior animals are selected to start inbreeding with. Hays (1919), analyzing the inbreeding experiment

inbreeding. Findings of Tyler *et al.* (1946) bear out those of Nelson. They found that milk production declined 73 pounds and butterfat, 2.3 pounds, for each 1-percent increase in inbreeding. They also found that the variation in the partial regression coefficients between sires was large enough that the offspring of some sires might be inbred as much as 25 percent without any apparent decrease in milk and butterfat production. Swett *et al.* (1949) found essentially the same results in their study of the results of the Beltsville inbreeding experiment. Production dropped approximately 17 percent in cows inbred more than 30 percent.

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onducted at the Delaware Experiment Station, found that a small
mount of inbreeding--under 10 percent--appeared to be associated
ith the best production. Cows of the Rose May breeding--inbred
the extent of 10 percent--appeared to be heavier milkers and
owed a higher percentage of butterfat than those of less inbreed-
g.

rth Weight

In a progress report of inbreeding work carried on at the
nois station to determine the possibilities in the development and
ization of distinct superior lines of dairy cattle, Dickerson
l0a) reported on the average effect of inbreeding on birth weight.
/es 16 percent inbred averaged nearly 10 percent lighter at birth
did noninbred calves by the same sires after correction for
ht differences due to sex and age of dam. This decline in
weight held for six of eight sires. Dickerson concluded that
weight is determined to an important degree by the calves'
itance, since the dams of the calves in this report were not
d. Ljutikov (1944) analyzed the birth weights of 2,698 Bestuzev
s. One thousand, three hundred, and forty-two were inbred
12.5 percent as compared to 1,356 outbred calves. The inbred

eraged 7 percent lighter at birth than the outbred calves.
ıgs are in close agreement with those of Dickerson (1940a).
1945), studying the consequence of close inbreeding at the
state farm, "Brody," found that the birth weight of inbred
ıs markedly less.

ʏler et al. (1946) reported the extent and variability of in-
effects in dairy cattle on birth weight by comparison of
ıd outbred progeny of the same sires. They found that the
regression of birth weight on 654 calves--adjusted for the
of size of dam and sex--on their percentage of inbreeding
ificant, with b = 0.28 pounds. Later work by Tyler et al.
ı three unrelated herds of Holstein-Friesians bears out
·lier findings. The mean birth weight of 794 calves was
ıds and 85.5 pounds for outbred and inbred calves, re-
y. Birth weight declined 0.28 pounds for each increase
cent inbreeding, with sex of calf and size of dam held
They concluded that the degree of heritability of birth
rom additive gene effects in these data was about 50 to
ɛnt.

Voodward and Graves (1946), reporting on a long-time in-
; experiment conducted by the Beltsville station, found that

of generations of inbreeding had a more pronounced
ct on birth weight of calves than did the degree of in-
The weight of sixth-generation inbred calves was uni-
than that of outbred calves, when the degree of inbreed-
sidered. Nelson and Lush (1950) found that regression
ight on inbreeding of bulls and heifers showed a decrease
th of a pound in birth weight for each increase of 1
inbreeding. On the basis of this regression, a first-
parent-offspring or full-sib mating would be expected
verage birth weight by about 3 pounds. The effect of
of the dam on birth weight of the calf was also studied.
ssion of birth weight on inbreeding of the dam was -0.05
calves and -0.14 for bull calves. The weighted mean of
ve a decrease of approximately one-eleventh of a pound
for each 1-percent increase in inbreeding. These find-
similar to those of Ralston et al. (1948), who found the
n coefficient for an increase of one degree of inbreeding
14 pound.

the other hand, however, Bartlett et al. (1939), Bart-
. (1942), and Margolin and Bartlett (1945), reporting on
me inbreeding experiment by the New Jersey station,

that the degree of inbreeding or generation of inbreed-
t adversely affect the birth weight of calves. Reports
.in and Nikkilä (1946) and Tyler et al. (1949) are in harmony
indings. Vainikainin and Nikkilä, in studying the Ayrshire
arge Finnish estate, descended from one bull and eight im-
:rs, found 10 percent of the population to be inbred more
cent. The birth weights of these inbred animals were no dif-
n those of the outbred population. Tyler et al., studying
s of unrelated cattle, designated all animals under 6
outbred and those inbred over 6 percent as inbreds.
s no significant difference between birth weights of inbred
ed calves.

Weight at Two Years and Over

lson and Lush (1950), studying the effects of mild inbreed-
herd of Holstein-Friesian cattle, found the regression co-
of weight on inbreeding increased up to two years of age.
hough the mean weight continued to increase, the regres-
fficients decreased with advancing age up to five years.
icates that inbreeding not only resulted in lighter calves
but slower gains during the first two years of life. After

:he inbreds apparently gained faster than the outbreds years of age, approached or exceeded the outbreds The outbred individuals merely approached their ma- s at a younger age. These findings are similar to those (1944), who found a definite depression in the develop- : from birth to eighteen months of age of inbred heifers ed to outbreds.

er et al. (1949) reported the effect of inbreeding on dairy cattle at eighteen months of age and at maturity. d that the regressions of weight on inbreeding at eighteen d at maturity were not significant. Swett et al. (1949) vever, that at eighteen months of age inbred heifers were tely 12 percent lighter than outbreds and at maturity they rcent lighter than the outbreds, while Vainikainin and Nikkilä orted that inbreeding had no apparent effect on the conforma- rowth of the animals studied. Ralston et al. (1948) found the between the weight of inbred daughters--37.5 and over-- red daughters of the same bull to be significant at the t level.

aker et al. (1945) found in the inbred daughters of one -Friesian sire that a significant proportionate decrease in

rred with an increased coefficient of inbreeding. These
in harmony with those of Woodward and Graves (1946),
hat in the sixth generation of inbreeding the weight of
two years of age was 20 percent below outbreds, and
ths after the fourth calving they were still 10 percent
outbreds in weight. Bartlett et al. (1942, 1944) reported
ndings--that unless animals were more than 20 percent
appreciable difference in weight of outbreds or inbreds
ved.

artlett et al. (1942), at the New Jersey station, studied the
of inbreeding on the type-rating of dairy cattle selected
ee areas--the New England States, New Jersey, and New
They concluded that the inbreeding of a family of Holstein-
s produced animals that exhibited no relation between in-
of inbreeding and type classification. A total of 112 ani-
s classified in these findings. The later findings of
and Margolin (1944) on further studies of the same family
at, although animals with an inbreeding coefficient exceed-
0 percent were inferior in size, their body type was superior

ıose of the outbred controls. The report by Vainikainin and llä (1946) is in harmony with the findings of the New Jersey ɔn. They studied the effects of inbreeding on the Ayrshire population of a large estate in Finland. They concluded he type-ratings of the inbred individuals were as high as of the outbred animals.

Woodward and Graves (1946), at the Beltsville station, however, that, as inbreeding increased, the animals became sh, acquired a rough hair coat, and were stubborn in appear- Their conclusions can be interpreted as a reduction in type ication of the inbred animals. Nelson and Lush (1950) re- the effects of mild inbreeding on type classification. They ed all animals each year, resulting in most animals being ed several times. The official terms of type classification ed, and it was intended that each class was divided into bclasses: low, medium, and high--thus resulting in a total en type classifications. Heifers were also classified prior g. Each subclass was given a numerical value starting r low producers and going to 18 for high excellent. The score for the herd was 7, which is equivalent to a classi- f middle good. Data were available on the classification

.5 individuals whose average inbreeding was 4.6 percent. They sired by thirty-seven different bulls, and the differences be- groups of daughters from different bulls were not statistically 'icant. The intrasire correlation between inbreeding and type -0.12 and the regression of type on inbreeding was -0.04. the regression coefficient obtained here, it would require an ise of inbreeding of 25 to 30 percent to lower the average lassification one-third of a class.

ity

Research investigations and observations have indicated that y is affected by the genotype of mates. If a cow family ally inferior for good fertility were inbred, the homozygosity type of mating should increase the appearance of low fer- vhereas inbreeding could as well make a family homozygous d fertility. Several workers investigating the effects of in- g on dairy cattle have upheld these observations.

Woodward and Graves (1946), in analyzing the inbreeding Holstein-Friesians at the Beltsville station, found that one ored 50 percent, and his daughters, inbred 37.5 percent, d a low conception rate, whereas the conception rate of

r sires and their daughters was not affected. Akopjan :iting some cases of bad consequences of close inbreeding ussian state farm, "Brody," reported that the first conse- 'f inbreeding was a loss of fertility. Matings of inbred :eded, on the average, not less than seven services in settle the cow, whereas outcrosses became pregnant, on age, with two matings. Vainikainin and Nikkilä (1946) re- ıat the inbreeding of Ayrshire cattle in Finland resulted in :rably lowered fertility rate. Bartlett et al. (1939) found that, 'eral generations of inbreeding among Holstein-Friesians at Jersey station, the rate of fertility declined. Nielsen (1943), her hand, reported no decrease in the fertility rate when he ed Danish Milkrace cattle. Nielsen's findings are in agree- h the observations of Woodward and Graves (1946), who ıt certain inbred families had a fertility rate that was or superior to that of outbreds.

r of Calves

'oodward and Graves (1946) studied the mortality rate of ılves as compared to outbred calves born between January to September 1, 1941. They observed 108 inbred female

and 41 outbred female calves born during the experiment. of the inbred calves died within a year, or 15 percent. the outbred calves died. They concluded that the inbred were not as vigorous as the outbred calves. Bartlett et al. ound that the mortality rate among inbred calves was higher the outbreds. This increase in mortality rate was primarily the appearance of a lethal factor, "Bulldog," and other body nations in one of the inbred families. Ljutikov (1944), stud- 42 inbred and 1,356 outbred matings found the mortality be 14 percent higher in the inbreds than in the outbreds. (1945) studied the effects of inbreeding in Finnish Ayrshire nd found that the inbred calves were less vigorous and showed r mortality rate.

nce of Lethal Defects

n cattle, defects which cause death--either prenatal or l--under conditions of normal environment are referred to al defects." Other terms such as "sublethal," "semilethal," leterious characters" have been used by various reviewers ifying the observed mutants in dairy cattle.

The total loss due to inherited lethals is not known. They
l constitute a portion of the calves born dead; this statistic
een reported by several workers. Linn et al. (1949) have
ted that approximately 5 to 6 percent of the calves born to
as D. H. I. A. cows were born dead, in a study of 25,000
gs. Miller and Gilmore (1949) reported a death loss of 4,
l 13 percent, respectively, for three Minnesota Agricultural
iment Station herds. These authors attributed 4 to 5 percent
loss as normal and 9 percent as due to a sex-linked lethal
herd with the high death loss.

In recent years a number of reviews have been presented
ail which report the appearance of defects in domestic and
animals. Among these are Hutt (1934), Eaton (1937), Lerner
and Gilmore (1949, 1950, 1952). The most thorough and
is that by Gilmore (1952), in which he provides numerous
s of the now known twenty-nine lethal defects in dairy

Investigational Procedure

The data used in the present analysis of Red Danish cattle
– and third-generation crosses) are the inbreeding coefficients,

ned by the application of Wright's (1922) formula, applied
3M procedure as outlined in a previous section of this
The lifetime average of each cow was used as the mea-
her producing ability.

Production records of milk and butterfat production and in-
coefficients of 317 cows representing the progeny of
ve sires were available. The production records of 122
d progeny of twenty-one of these sires were available for
son purposes.

he amount of inbreeding in this population was due to the
coming from the same herd--the parent Red Dane herd
SDA. No special attempts were made to produce inbred
. The coefficients of inbreeding are nearly all due to the
ing related and bred to related females by random chance.
fforts were made to move the bulls to the different bull
n such order to keep inbreeding at a minimum.

he correlation and regression analysis was conducted on
ire basis with all calculations completed by an IBM pro-
xcept for the mechanics of constructing the analysis of
e tables.

The data relative to the study of the appearance of lethal ects were determined from the cow-worksheet and calving- ɔort forms. IBM Card No. 1 contained the calf data for each :shening of a cow as well as the sire and other details. These re summarized by sorting and tabulation.

A six-generation pedigree was constructed for each reported thal defect in order to study the appearance of the possible trans- itters in each pedigree and to identify each sire as a trans- itter.

A breeding test was employed in which the expected or cal- ulated values were based on the assumption that 12.5 percent of he progeny should be defective when heterozygous sires were nated to progeny of heterozygous sires.

The formula, $[p + q]^2 = [p^2 + 2pq + q^2]$, was used in order to determine the gene frequency of the defects in the American Red Danish cattle population and to test the randomness of mat- ings which resulted in the observations.

Investigational Results

The Effects of Mild Inbreeding on Milk and Butterfat Production

The amount of inbreeding in this population was low, since was due to the random mating of related females and bulls. lthough a total of 317 females were inbred, only 17 cows were ıbred over 10 percent. Of the cows with records, one had a co- fficient of 30 percent and four had coefficients of 25 percent. hese 317 inbred cows were sired by thirty-five sires. All of ıe inbred cows were either second- or third-generation Red anish, since the first-generation females were the progeny of an utcross of two unrelated animals. The average inbreeding coef- cient for the inbred second- and third-generation females was 4 ercent and 7 percent, respectively. This shows that the relation- hip existing between the sires used for this project increased, nd also that the inbreeding of the dams, second generation, con- ributed to the increase.

Table XXIV shows the records made by cows sorted into ifferent inbreeding groups. From this grouping of production ecords by inbreeding groups, it would appear that a mild inbreed- ng of 1 to 5 percent caused an increase in average milk and

TABLE XXIV

THE EFFECT OF INBREEDING ON PRODUCTION

Inbreeding Group	Avg. Coef.	No. of Cows	No. of Sires	Avg. Milk
0-0	----	122	21	8,690
0.01-0.05	0.03	213	31	9,213
0.06-0.10	0.07	87	28	9,157
0.11-0.18	0.13	12	6	9,924
0.25 +	0.26	5	4	11,047

TABLE XXIV (Continued)

Std. Dev.	Coef. of Var.	Avg. Fat	Std. Dev.	Coef. of Var.	Pct. Fat
1,649	19.0	345	63	18.3	3.97
1,713	18.6	376	66	17.5	4.08
1,866	20.4	370	80	21.6	4.04
2,104	21.2	396	70	18.0	3.99
2,025	18.3	435	81	18.6	3.93

butterfat production. The differences for milk and butterfat are significant at the 1-percent level of probability for this amount of data. There appears to be a slight decrease in milk and butterfat production with an increase of inbreeding coefficients for the grouping of 6 to 10 percent. This is relatively small and is not significant at the 1- or 5-percent levels of probability. The increases in the 11 to 13 and 25+ coefficients groups should probably be attributed to the small number of observations in these groups, since an analysis of variance of the inbred daughters proved to be non-significant at either level of probability for butterfat production and barely significant at the 5-percent level for milk production. In the latter case, the statistic could occur, even by chance, one time out of twenty for a sample of this size.

An intrasire correlation and regression of production on inbreeding analysis was conducted to determine the effects of inbreeding on production on an intrasire basis. These findings are presented in Table XXV. The regression estimates indicate that milk production decreased about 23 pounds and butterfat production decreased about 0.3 pound for each increase of 1 percent in inbreeding. The intrasire effect of inbreeding is shown more clearly in Table XXVI. The number of daughters in the various

TABLE XXV

INTRASIRE CORRELATION AND REGRESSION OF PRODUCTION ON INBREEDING

Record	Correlation	Regression (lbs.)
Milk Production	-0.15 ± 0.03	-23.1
Butterfat Production	-0.05 ± 0.02	-0.30

categories is rather small in some instances, since it was not designed during any stage of this project to obtain inbred and outbred daughters of each sire. The inbred and outbred progeny are all due to the random chance of bulls being bred to related or unrelated females. It is evident from Table XXVI and substantiated with a highly significant "F" test by the analysis of variance that considerable variation exists between sires. Some sires' progeny performed better when inbred, whereas others showed a downward trend. From the intrasire regression coefficients shown in Table XXV, it appears that the over-all trend was downward; however, the variation between the progeny of the different sires was enough to keep this negative regression relatively small.

TABLE XXVI

DAUGHTER'S PRODUCTION BY SIRES HAVING TWO OR MORE DAUGHTERS IN TWO OR MORE INBREEDING GROUPS

Sire No.	No. of Daugh- ters	Inbreeding Group	Avg. Milk	Avg. Butter- fat	Avg. Pct. Fat
1557	7	0.01-0.05	9,790	375	3.83
	11	0.06-0.10	8,246	326	3.95
	2	0.25 +	9,677	404	4.17
1558	18	0.00	7,981	340	4.26
	4	0.01-0.05	8.152	361	4.42
	5	0.06-0.10	8,355	350	4.18
1561	19	0.01-0.05	9,581	376	3.92
	5	0.06-0.10	11,116	449	4.03
1564	3	0.01-0.05	8,211	321	3.90
	4	0.05-0.10	9,863	423	4.28
1566	7	0.00	8,882	362	4.07
	6	0.01-0.05	8,628	356	4.12
1568	3	0.00	9,196	354	3.84
	8	0.01-0.05	8,753	367	4.19
	8	0.06-0.10	9,465	357	3.77
1569	3	0.01-0.05	7,472	308	4.10

TABLE XXVI (Continued)

Sire No.	No. of Daugh- ters	Inbreeding Group	Avg. Milk	Avg. Butter- fat	Avg. Pct. Fat
	8	0.06-0.10	8,164	328	4.01
1570	18	0.01-0.05	10,022	431	4.30
	2	0.06-0.10	9,922	378	3.80
1571	6	0.00	8,918	360	4.03
	16	0.01-0.05	9,354	363	3.88
1572	2	0.00	6,060	277	4.56
	15	0.01-0.05	9,828	390	3.96
1573	3	0.00	8,279	338	4.08
	24	0.01-0.05	9,548	375	3.92
	4	0.06-0.10	9,065	373	4.11
1575	2	0.00	10,947	415	3.79
	11	0.01-0.05	10,169	396	3.89
	7	0.06-0.10	9,660	381	3.94
	6	0.11-0.18	11,145	418	3.75
1578	11	0.00	8,865	350	3.94
	9	0.01-0.05	9,528	388	4.07
	2	0.06-0.10	9,688	375	3.87

TABLE XXVI (Continued)

Sire No.	No. of Daugh-ters	Inbreeding Group	Avg. Milk	Avg. Butter-fat	Avg. Pct. Fat
1579	3	0.01-0.05	8,382	316	3.76
	3	0.06-0.10	8,216	350	4.25
1582	2	0.00	8,601	329	3.82
	3	0.01-0.05	7,358	334	4.53
	2	0.06-0.10	9,283	373	4.01
1607	12	0.01-0.05	9,179	393	4.28
	3	0.06-0.10	9,665	431	4.45

Lethal Defects

The line-breeding and mild inbreeding practiced as a random occurrence in this project has brought to light two hereditary recessive defects in a number of the cooperating herds.

One of the hereditary defects that has been segregated was a type of lameness or paralysis. This abnormality was present at birth and persisted until the death of the affected individual from other causes--usually at about two weeks. Inflammation of the kidneys due to incomplete drainage of the bladder with urination and lack of circulation in the extremities have been observed as the causative factors of death due to the animals' being unable to stand to allow proper drainage of the bladder and circulation in the legs.

The affected calves lie on one side, usually with outstretched limbs and often with extremely bent hocks. The permanent lying position leads to sores and loss of hair. None of the calves survived, although the owners improvised slings to allow the calves to stand. Even then, after six weeks or longer, no appreciable improvement could be detected.

Attending veterinarians were the first to suspect that the condition might possibly be an inherited anomaly, since all therapeutic attempts were of no avail. Several of the calves affected with this

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condition were brought to the outpatient clinic at the Veterinary Center of Michigan State College; no response to treatment was observed by the clinicians. X rays were also made which showed no gross deformities of the vertebrae or limbs (Langham, 1952).

The author succeeded in obtaining two affected calves from widely separated herds--290 miles apart--and observed them for several weeks and found the symptoms to be the same as reported by the breeders in whose herds these anomalies appeared. Gross and histological studies were made of the spinal cord and brain tissues; the results are not available at this writing. Figures 7 and 8 show photographs of these calves and the gross appearance of the anomaly.

Sixty-five afflicted animals--thirty-eight heifers and thirty-seven bulls--have been reported by twenty-seven dairymen in all sections of the state. Five-generation pedigrees were constructed of each defective calf, and it was found that these sixty-five calves were sired by seventeen Red Danish sires. From a study of these pedigrees, it was found that four additional sires could be classified as heterozygous for the paralyzed condition, since they appeared as the sire of a first-generation dam which produced the defective calf. In order to determine the kind of inheritance pattern these

Figure 7

Plate A illustrates the voluntary movements of the forelimbs and body with incoordinate voluntary movements of the rear limbs.

Plate B shows the calf in a supported upright position with the forebody supported by the forelegs. The hind limbs, however, demonstrated no ability to support the weight of the body. A typical deviation of the tail is illustrated which snaps back into place after being straightened passively.

A

B

Figure 8

Plate A illustrates the typical lying position which this calf assumed without being able to move other than raising its head, incoordinately moving the fore and hind limbs, and jerkily moving the tail.

Plate B illustrates the inability of the calf to sustain its own weight, especially with the hind limbs. This was more pronounced in this calf than the one in Figure 7.

A

B

data fitted, a summary was made of the progeny of these sires when mated to daughters of heterozygous sires. This is presented in Table XXVII. The expected values are based on the assumption that 12.5 percent of the progeny should be defective.

This was an excellent agreement between the observed results and the theoretical expectations.

Judging from the results of this study, this lethal condition --paralyzed hindquarters--is conditioned by a single autosomal recessive gene.

The second hereditary defect observed during the course of this investigation was one of a type of mummification or ankylosis of the neck and limbs. The affected calves were born at full term or two weeks premature. They exhibited a shortened, thickened, and stiffened neck and stiffened legs, sometimes bent backwards with the joints ankylosed and distinctly thickened. The hoofs and skin were well developed. In many cases veterinary aid was necessary, since in all cases parturition was extremely difficult and often resulted in permanent sterility of the dam due to injury of the uterus. Attending veterinarians called the dairymen's attention to a similar condition reported in Danish cattle in Denmark.

TABLE XXVII

THE OBSERVED AND EXPECTED RESULTS OF MATING SIRES HETEROZYGOUS FOR THE PARALYZED CONDITION TO THEIR OWN DAUGHTERS AND TO DAUGHTERS OF OTHER HETEROZYGOUS SIRES

	Normal Calves	Defective Calves	Percent	Total
Observed	566	65	12.24	531
Expected	464.63	66.37	12.50	
Difference	+1.37	-1.37	-00.26	

$\chi^2 = 0.0004$.

Forty-two of these ankylosed fetuses occurred in the herds of eleven dairymen. In the majority of the cases, the sex of the defective fetuses was not observed. However, in the instances noted, it appeared evenly divided between male and female. Fourteen sires were found to have sired these defective fetuses, thereby being heterozygous for the defect. From the construction of pedigrees of these affected fetuses, it was found that four additional sires could be classified as heterozygous for the defect since they were sires of first-generation females producing offspring with the anomaly.

A summary of the progeny of these sires mated to their own daughters and the daughters of the other heterozygous sires is presented in Table XXVIII. The expected or calculated values were based on the assumption that 12.5 percent of the progeny should be defective. Table XXVIII shows that the difference between the observed and expected frequencies was exceedingly small.

From these findings it can be concluded that a single autosomal recessive gene conditions the lethal defect--mummification.

In the analysis for the gene frequencies of the two defects, an analysis of the paralyzed condition is shown.

Let p = frequency of Pr (normal) and q = frequency of pr (paralyzed). Then,

$$p + q = 1$$

$$(p + q)^2 = p^2 + 2pq + q^2 = 1$$

$$q^2 = 0.022 \therefore$$

$$q = \sqrt{0.022} = 0.149$$

$$p = 1 - 0.149 = 0.851$$

$$p^2 = 0.7242$$

$$2pq = 0.2538$$

$$p^2 + 2pq + q^2 = 0.7242 + 0.2538 + 0.022 = 1.00$$

TABLE XXVIII

THE OBSERVED AND EXPECTED RESULTS OF MATING SIRES HETEROZYGOUS FOR THE ANKYLOSED CONDITION TO THEIR OWN DAUGHTERS AND TO DAUGHTERS OF OTHER HETEROZYGOUS SIRES

	Normal Calves	Defective Calves	Percent	Total
Observed	301	42	12.24	343
Expected	300.13	42.87	12.50	
Difference	+0.87	-0.87	-00.26	

$\chi^2 = 0.0005$.

The above analysis suggests that 25 percent of the American Red Danish cattle are heterozygous for the paralyzed condition.

An analysis of the observed occurrence (1.4 percent) of the mummified defect suggests that 11 percent of the population are heterozygous for the defect.

The Chi-square test was employed to determine if matings had been random or whether the occurrence of the defects was due to selection of mates. Since $\chi^2 = 0.004$; therefore, it can be concluded that the matings were random.

Other Effects

Calf Mortality

No attempt was made to determine the number of calves that died within one month of birth, which would have been a partial measure of the vigor of the inbred calves. However, the number of calves dead at birth was recorded in order to ascertain the possibilities of one of several lethals of this type being found in this population. Table XXIX shows the percentage calf mortality of the various foundation breeds and of the crossbred females. It is interesting to note that the percentage calf mortality increased with each crossbred generation. This increase could not be attributed to the occurrence of a lethal defect other than the mummified condition as described earlier in this paper. The evidence of calf mortality did not increase as the degree of inbreeding increased. Further study is needed to ascertain if a factor or factors are responsible for the increase of calf mortality with successive generations of Red Danish sires.

TABLE XXIX

CALF MORTALITY AT BIRTH FOR THE FOUNDATION BREEDS AND CROSSBRED GENERATIONS

Breed	Percent Inbreeding	Percent Calves Dead at Birth	Total Calves Observed
Guernsey	0.00	2.33	425
Holstein	0.00	1.42	410
Shorthorn	0.00	0.69	291
Jersey	0.00	1.37	136
Mixed	0.00	1.78	225
First cross	0.00	3.71	1,700
Second cross	0.04	7.73	913
Third cross	0.07	9.34	333

Sterility

Three categories of sterility were included among a number of other reasons for disposal of a cow. Percentage figures were determined for the percentage of the sterility of total disposals. The three categories of sterility were: (1) bred four times or more in normal heat periods, but did not settle; (2) complete lack of heat periods; and (3) apparently settled, showed signs of heat three or more months later.

Table XXX shows the percentage of cows by combined foundation breeds and by crosses that were disposed of for one of the three types of sterility. The rate of incidence of sterility was no higher in inbred cows than in outbred animals.

Further study is required to determine if this increased sterility in successive crosses is due to an inherited condition.

Discussion and Conclusion

The Effects of Mild Inbreeding on Milk and Butterfat Production

The regression of production on inbreeding observed in this study is something less than that found by several investigators--Nelson and Lush (1950), Laben and Herman (1950), Tyler *et al*. (1949), and

TABLE XXX

PERCENT OF COWS OF THE FOUNDATION BREEDS AND CROSSES DISPOSED OF BECAUSE OF STERILITY

	Percent Inbreeding	Percent Disposal Due to Sterility	Total Observations
Foundation breeds	0.00	13.1	469
First cross	0.00	20.23	420
Second cross	0.04	25.8	256
Third cross	0.07	28.8	65

Ralston et al. (1948). On the other hand, the present observations are in close conformity to those of Hays (1919), Woodward and Graves (1933), Bartlett and Margolin (1944), and Vainikainin and Nikkilä (1946), where production performances of inbreds--not over 10 percent inbred--were superior to those of outbreds.

One should expect the results of these observations to differ somewhat from those of other reports, since the genetic composition of the cattle observed in this study is certainly of a different nature. The reported literature dealing with the regression of production on inbreeding indicated that the animals observed in those studies were either purebred or high-grade animals of many

generations of breeding of a single line and strain. The inbred animals in this observation carry either one-fourth or one-eighth blood of an entirely different breed than the ancestry responsible for the coefficients of inbreeding. It is rather surprising that even greater differences did not occur.

The intrasire effect of inbreeding on milk production, tabulated in Table III, illustrated that some sires can stand the tests of inbreeding, while others cannot. It is evident that considerable variation between sires as to the effects of inbreeding exists. Tyler et al. (1949) found this to be true in their study. There also appeared to be some differences in response by progeny of the different inbreeding groups within a sire. However, since these records are expressed on a single population basis--many herds together--some of the differences between the inbreeding groups between and within sire progeny groups must be attributed to differences in the expression of the genotypes of the animals due to the variation in environmental conditions existing between herds. The intrasire regression of inbreeding on production have been adapted to correct for the variations between animals due to genetic differences between sires by most of the workers reporting on the effects of inbreeding on production, and also with the assumption

that most of the daughters of a sire are in one herd and exposed to the same environmental effects at the same time. Today, however, as in this study, it is not unnatural to find daughters of a sire in many herds and expressing their genetic composition at widely separated intervals due to the use of sires in artificial breeding studs. The writer recognizes that these findings would be more nearly accurate if analyzed on an intraherd, intrasire basis; however, it was beyond the scope of this study to obtain those statistics. Future studies of this aspect should be directed in that direction.

Lethal Defects

The appearance of two lethal defects became apparent after a preliminary investigation of reports by dairy farmers cooperating in the Red Danish project; namely, that numerous calves were born too weak to stand alone, and others had enlarged, stiffened joints and were dead at birth. These same conditions have been reported in the Red Dane Milkrace cattle in Denmark by Loje (as cited by Hutt, 1934). His observations were of limited number and did not entirely fit the one-factor hypothesis. Later reports on the paralyzed condition in Red Dane Milkrace cattle were made by Nielsen

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(1942) and Rasmussen (1943). Neilsen reported that the first observation of this condition in Red Dane cattle was made in 1924. Up to 1941, the total observations made were 294, sired by thirty-nine bulls with the frequency (reported in 1941) being fifty-six paralyzed calves. Nielsen found that his data did not fit the one-factor hypothesis clearly--that it appeared that two factors conditioned the anomaly. However, Rasmussen (1943) found that the data did fit the one-factor hypothesis, which is the same as that found in the present study.

A similar condition, observed by Drimmelen (1942) and Tuff (1948) in African and Norwegian Red Poll cattle, respectively, have been reported. Tuff's findings of ninety normal and fifteen lame calves in 105 observations of heterozygous bulls mated to daughters of heterozygous bulls substantiated the present conclusions that this paralyzed condition is caused by a single recessive autosomal gene.

The ankylosed condition found in the Danish cattle by Loje (as cited by Hutt, 1934) has not been reported recently. However, Tuff (1948) found a very similar condition in Norwegian Red Poll cattle. His observations were rather limited, but his conclusions were that the condition was caused by a single recessive autosomal

character. Gilmore (1952) made mention of similar observations that have been made in Guernsey cattle in the United States. However, to the writer's knowledge, similar conditions of either the paralyzed or ankylosed anomalies have not been reported for other breeds of cattle not reviewed here.

To dispel the possibility that these conditions were caused by environmental factors, attention should be called to the appearance of these conditions in numerous herds located in different sections of the state. It would seem impossible that only herds of Red Dane cattle in those sections would be deficient in some essential vitamin or mineral. Then, too, many of the paralyzed calves have had therapeutic treatments by attending veterinarians in the field or Veterinary Clinic of Michigan State College. The evidence that these two factors--paralyzed hindquarters and mummification, as originally named by Loje (as cited by Hutt, 1934) --are conditioned by a single recessive autosomal character is the closeness of fit of the expected to the observed results in Tables XXVII and XXVIII.

That these two conditions were not carried by the foundation breeds used in this project is evidenced by the fact that of 3,854 reported calvings from Red Danish sires crossed with the

foundation breeds, no defects were observed. The first observation of either defect was the result of matings of a Red Danish sire to a first-cross female.

Other Effects

Calf mortality and sterility increased with successive generations of purebred Red Danish sires. The incidence was not correlated with the degree of inbreeding. Further study is needed to establish if inherited factors are operating. These findings do not agree with those previously reviewed.

Summary

A study was made on the effect of inbreeding in the American Red Danish cattle population. The effect of inbreeding on milk and butterfat production, appearance of lethal characters, calf mortality, and sterility was investigated. The second-cross animals were the first to have inbreeding coefficients, since the first-cross were the progeny of an outcross. The inbreeding of the inbred animals of the second cross averaged 4 percent, while those of the third cross averaged 7 percent.

The analysis of the effect of inbreeding showed that the inbred animals increased milk and butterfat production 3 and 8 percent, respectively, over the noninbred animals. This indicated that the percent of butterfat increased with inbreeding which the analysis revealed as true. However, within the inbred groups it was found that for each 1-percent increase in inbreeding, milk and butterfat production decreased 23 and 0.3 pounds, respectively.

This study revealed the occurrence of two lethal defects—paralyzed hindquarters and mummified fetuses. The number of observations of both defects fits the expected Mendelian ratio of 12.5 percent occurrence when heterozygous sires were mated to daughters of heterozygous sires. Therefore, it was concluded that both lethal characters are inherited independently as single autosomal recessive factors.

Additional study is advisable to determine if the observed increase in calf mortality and sterility with successive generations of purebred Danish sires is an inherited condition.

THE INFLUENCE OF THREE NONHEREDITARY FACTORS: TIME TREND AND YEARLY ENVIRONMENTAL CHANGES, MONTH OF CALVING, AND CALVING INTERVAL ON MILK AND BUTTERFAT PRODUCTION

Review of Literature

Introduction

It is important to know the extent to which differences between production records are caused by environmental factors. The more pronounced ones are age at calving, times milked daily, and length of lactation. Many investigators, however, have investigated the effect of other environmental factors such as year-to-year variations, time trends, calving interval, season of freshening, and length of service period on milk and butterfat production. The results obtained in these studies have been varied, although it appears that the most important of the minor environmental factors are year-to-year variations and time trends, length of dry period, and length of calving interval.

The present study was undertaken to measure the relative importance of year-to-year variations and time trends, length of

dry period, and length of calving interval as causative factors of variation among records of the American Red Danish cattle population.

Year-to-Year Variation and Time Trend

Plum (1935) studied Iowa Cow Testing Association records from ninety-five herds of Guernsey, Holstein, and Jersey cattle. He found that during the eleven years included in that study, the average production increased about 50 pounds of butterfat. However, only 2.8 percent of the total variance is due to yearly changes. The influence of year-to-year changes within a herd accounted for 6 percent of the total variance or roughly 10 percent of the intraherd variance. These findings were somewhat lower than those found by Patow (1930), who seemed to consider year-to-year variation as the major environmental cause of variation.

Laben and Herman (1950) analyzed the effect of yearly variation and time on the total variance of production for the Missouri Station Holstein-Friesian herd from its foundation in 1902 to January 1, 1950. They found a significant upward time trend in production. Differences between five-year periods accounted for

5.5 percent of the total variance in milk production, 20.4 percent of the total variance in butterfat production, and 38.8 percent of the total variance in butterfat percentage. The portion of variance attributed to butterfat and butterfat percentage was due to continued effort to select high-testing sires with essentially the same milk production as the herd average.

Chai (1951) analyzed the production records of three Holstein herds owned by Michigan State institutions. He found the portion of intraherd variance due to difference between years to be 4.9 percent, while that portion due to total variance was 3.7 percent. He utilized Hoel's simplified runs method for analyzing time trends and found no significance.

Influence of Month of Calving on Milk and Butterfat Production and Butterfat Percentage

There are several factors contributing to the apparent variations in production caused by different seasons of freshening. Numerous observations have been made on the effects of these factors on production characteristics. It has been shown by Turner (1927a) that a rapid increase in milk and butterfat production occurs immediately following freshening, and reaches a peak level during the first one and one-half to two months, and then declines

to the time of cessation. The height and maintenance of the peak determines the total production. Therefore, any environmental factors affecting the persistency of the peak increases the slope of the declining lactation. If a cow freshens at an optimum month, so that the peak can reach and maintain its maximum height and persistence, and then toward the end of her lactation receives another favorable environmental boost, she will produce more than if freshened at any other time of the year.

From management and economic consideration there may be reason for having cows freshen in different seasons; particularly either fall or spring. However, the main objectives of the present study have been to test statistically whether or not there is any significant relation between the month of calving and the production in the lactation period following it.

Effect of Season of Calving

Ragsdale and Brody (1922a) analyzed three kinds of records--Guernsey data on a national scale, Jersey data from a single state (Missouri), and Holstein data from a single herd. They concluded that best production records were obtained when cows calved in September or October. The percentage of fat in milk when plotted

followed a general curve--being lowest during the summer months, then gradually rising, reaching a peak during the winter months, and then declining during the spring and summer. Ragsdale and Brody (1922b), observing ten cows over 41 days (March 13 to April 22) at the Missouri station, noted that with mean daily temperature ranges between 27° and 70° F., there was a depression of almost 0.2 percent in the average fat content of the milk for each increase of 10° F. between the observed temperatures.

Hays (1926), studying the entire Missouri station dairy herd under uncontrolled conditions for 258 days, from January, 1924, observed a 0.079-percent fat decline with each 10° F. rise in mean temperature. Temperature, Hays concluded, is a major factor in the seasonal variation in percentage of fat in cow's milk. Eckles and Shaw (1913) concluded that the effect of season is apparently the result of weather conditions, especially heat and humidity. They found that during a period of hot, humid weather the percentage of fat was depressed, while during dry and cool conditions the test is increased. Baker and Cranfield (1933), studying the average fat percent at collecting depots in England, observed a below-normal fat percent for the summer months of 1925 to 1929 inclusive, as compared to a twenty-year average. They found this

decrease to be correlated with a below-normal rainfall for those years. This agrees with the findings of Turner (1923), who found that the principal variations in milk production in regard to season of calving were the changes in pasture during the spring and summer months. However, Wylie (1925), in a study of more than 2,900 R. O. M. records of Jersey cows, found that cows with the highest milk production did not necessarily show a seasonal effect and that July was an optimum month.

Cannon (1933) analyzed 68,000 Iowa Cow Testing Association records to observe season of calving effect on subsequent production.. He grouped the records into months of calving and found that cows freshening in November gave the highest yields. In the November to June groups, the ones freshening each month had a larger production than the group of the preceding month. Cannon developed a set of correction factors to be used when comparing cows' records starting in different months. He suggested that these can also be applicable to the North Central states. Headley (1933), studying the records of Nevada Agriculture Experiment Station herd, observed from a total of 124 records that cows freshening before March averaged 40 pounds daily with a gradual decline for those starting in later months until the average for

September was 32 pounds. Following September, a gradual increase was found until a peak of 40 pounds was reached in December.

Plum (1935) assembled records of ninety-five herds of the Iowa Cow Testing Association between 1922 and 1932, comprising 6,900 records of three breeds--Holstein, Jersey, and Guernsey, both purebred and grade. He analyzed these data to determine the causes of the variations in cows' records and observed that cows calving from November to January produced 13.6 percent more butterfat than cows calving from May to July. Although the season of the year has a significant influence upon production, it is a minor cause of total variation--measuring only 3 percent of the total. Woodward (1945) tabulated 15,422 records of cows in dairy-herd improvement associations from twelve states. His findings are similar to numerous other investigators. He found July the lowest yielding month, with November the highest, but that the difference was not very great. He concluded that it was evident that the total quantity of milk produced in a lactation period is not a factor of major importance for the dairyman to consider in determining the best time to have his cows freshen--if he is able to provide adequate feed for his herd at all seasons

of the year. Frick and co-workers (1947) analyzed 22,212 Connecticut Dairy Herd Improvement Association lactation records and found very similar data to that of Plum (1935). They found February the most favorable month of freshening, which exceeded by 13.7 percent the least favorable month, July. This association of milk yield with month of calving was similar for each of four breeds studied: Guernsey, Holstein, Ayrshire, and Jersey breeds.

On the other hand, two groups of workers, Oloufa and Jones (1948) and Arnold and Becker (1935), working with Oregon and Florida data, respectively, found no difference in total production due to season of calving. Both groups of workers concluded that the difference in seasons was not of enough variance to cause seasonal differences. Dickerson (1940) analyzed Wisconsin Dairy Herd Improvement Association records in an attempt to determine the relative genetic worth of corrected and cow records. He calculated each cow's records in terms of five kinds of records: 240-day, 305-day, 365-day, total lactation, and testing year. He concluded that season of calving had little effect on records of about 305 days' duration, since only 4 percent of the total variance could be attributed to season of calving with only 1.9 percent for records of about 305 days' duration.

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Chandrashaker (1951) analyzed the production of butterfat in relation to the month of calving in five breeds--Holstein-Friesian, Jersey, Brown Swiss, Ayrshire, and Guernsey--in the Michigan State College dairy herd. By using the analysis of variance method of analysis, he found the "F" test between months to be nonsignificant. He concluded that the month of freshening had no appreciable and significant influence on the yearly butterfat production. Chai (1951) analyzed the butterfat production records of three Michigan State institutional herds composed of Holstein-Friesian cattle and found the effect of month of calving to be significant in two of the three herds. He found the highest butterfat production for the month of March, it being significant from any other month. About 2 percent of the total variance was accounted for by the different months of calving.

<u>Effect of Low Temperature</u>

That the dairy cow withstands long periods of exposure to temperatures as low as zero degrees Fahrenheit with little loss in production has been shown by numerous workers.

Buckley (1913) at Maryland found that there is no greater variation in the flow of milk from cows exposed to a temperature

of -14 degrees in an open stable than in those cows in a closed stable which were exposed to a temperature of +11 degrees. He concluded that the effect of low temperatures is practically negative in reducing the flow of milk. Davis (1914) observed similar results in an "open-shed housing versus closed-stable" experiment under Pennsylvania conditions. He also concluded that the drops in atmospheric temperature did not affect the cows in the open shed any more than it did those in the closed stable.

Kelley and Rupel (1937), studying the relationship of environmental conditions to milk production under Wisconsin conditions, found that 50° F. appeared to be about the optimum temperature for dairy cows; however, temperatures below this optimum did not decrease production after the first three milkings following the fluctuation. Dice (1940) found that cows turned out into a snow-filled yard during the day maintained as good a production as those kept in. Cows that were bedded down in an open shed maintained production as well as those cows housed in a closed stable. He concluded from his observations that milk cows can stand exposure to cold temperature and that they produce as well in an open stable as they will when temperature is maintained at 50° F. An explanation published by Armsby (1917)

explains why the cow can resist extreme low temperatures without detrimental effects to production. Using experiments by Kellner, he showed that of the energy evolved as heat by a fattening steer on full feed, about 62 percent of it was used to maintain body heat and 38 percent was surplus at optimum temperatures. To bear this out, Armsby cited work by Jordan (1908) to show that the heat produced by one dairy cow was greater by 85 percent and for another was 54 percent greater than that amount needed for maintenance and that ''so far as mere maintenance of body temperature goes, no reason appears why a cow might not be subjected to comparatively low temperatures without causing any increased ketabolism for sake of heat production solely.'' Ragsdale et al. (1950) found, however, that milk yield begins to decline earlier in Jersey cows at temperatures below 40° F. than it did in Holstein cows. The critical low temperature for Jerseys seemed to be 8° F., whereas at this temperature the Holstein showed little effect--if any-- in decline of milk yield.

Effect of High Temperature

Temperatures in excess of 85° F. have, however, a marked detrimental effect on milk production as found by Rhoad (1935) in

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Effect of High Temperature

Temperatures in excess of 85° F. have, however, a marked detrimental effect on milk production as found by Rhoad (1935) in

Brazil. He observed that nine Holsteins imported into the tropics, produced on a Cornell ration only 56 percent of the corrected average production of their dams and two granddams as given on the pedigree sheets. That this reduction in apparent capacity was due to continuous high temperature is borne out by observations of Villegas (1939). He observed that Holstein cows imported into Singapore and kept in an air-conditioned barn at 70° F. averaged 24 pounds of milk a day as compared to 9 pounds a day for a similar group in an open, well-ventilated barn, exposed to tropical temperatures.

Regan and Richardson (1939) have shown, under controlled conditions, that as atmospheric temperature increased from 40° to 95° F., milk production gradually dropped from 29 to 17 pounds a day. With water buffaloes, Sinha and Minett (1947) have shown that cooling of the animals by splashing with cool water gave a significant increase in yield of milk over a nonsplashed group. On the other hand, Miller et al. (1951) reported that there appeared to be no relationship between the amount of milk produced and the sprinkling of Jersey and Holstein cows, although the sprinkling was effective in cooling the cows as evidenced by decreasing respiration rates and body temperatures. However, the authors suggested

that further studies should be conducted with the temperature considerably above 80° F. This bears out some of the observations of Riek and Lee (1948), who reported that Jersey cows subjected to temperatures ranging from 85° to 110° F. twice weekly for 7 hours demonstrated no effect in milk yield and butterfat percentage.

Weaver and Matthews (1928) observed that, as temperature increased both inside and outside of the barn, fat percentage declined. They found that the amount of variation in fat percentage declined. They found that the amount of variation in fat percentage due to outside temperature changes ranged, according to a regression equation, from 0.0017 for the Ayrshire to 0.0103 for the Guernsey, and that for inside temperature changes ranged from 0.0023 for Holsteins to 0.0148 for Jerseys. Ragsdale and Brody (1922a, 1922b) found that the percentage of fat in milk, when plotted, follows a general curve, being lowest during the hot summer months, gradually rising and reaching a peak during the winter months, and then declining during the spring and summer.

Ragsdale *et al*. (1948, 1949, 1950, 1951), in a series of experiments at the Missouri laboratory, found that as temperature increased over 50° F., milk production declined. These workers

concluded that 80° to 85° F. appeared to be the critical temperature for milk production.

That there are breed and species differences in response to elevated temperatures have been shown by Hammond (1931) in observations made in the countries of Jamaica and Trinidad. He observed that the Shorthorn and Ayrshire breeds were the least able to withstand the high temperatures as measured by milk production. It was also noted that the Jersey, Holstein-Friesian, and Red Poll breeds appeared more adaptable--in that order. These observations noted by Hammond were borne out by the findings of Rhoad (1936), who has shown that when European and Indian cattle were crossed, the resulting crosses yielded more milk than their European dams under Brazilian conditions. Regan and Richardson (1938), comparing the heat tolerance of the Holstein, Jersey, and Guernsey breeds, found that as the mean temperature was increased by 10° F. increments, there was a small decline in daily milk production. Depending on breed, a sharp decline was observed when 80° to 85° F. was reached, with the Holstein cows showing less heat tolerance than the Jersey and Guernsey cows. Seath and Miller (1947) compared the heat tolerance of Jersey and Holstein cows by using correlations on an intraherd basis and found that

the Holstein cows had a significantly lower heat tolerance than did the Jersey cows.

Gaalaas (1947), observing seventy-four Jersey cows for five years, which involved 137 heat-tolerance coefficients, made the following observation. Not much change in the average heat tolerance of the herd occurred from year to year; a definite difference in heat tolerance existed in the different age groups; heat tolerance coefficient is a reasonable stable individual characteristic at the age of four years and above, but not at two or three years of age; there is a real difference in physiological response of different cows to the same environmental conditions as measured by body temperature. He also found that the stage of lactations and gestation has little, if any, effect on the heat tolerance, and that there is some difference in the response of groups of daughters of various sires when measured at two and three years of age, but little, if any, when measured at four years or more of age.

Ragsdale _et_ _al_. (1948, 1949, 1950, 1951) observed a breed and species difference in the critical high temperature with reference to milk production. They observed that 75° to 80° F. was the critical high temperature at which the depressing effect on milk production became evident for Holstein cattle, 80° to 85° F.

for Jersey and Brown Swiss cattle, and 90° to 95° F. for Brahman cattle.

Influence of Calving Interval on Milk and Butterfat Production

The variations in production records due to this portion of environment can be attributed to two factors working within this classification--that part of the variation due to length of service period after freshening, and that part due to length of dry period preceding the lactation.

Numerous workers have found that the latter months of gestation have an inhibitory effect upon the production of milk. Gavin (1913a) found that if cows were bred five to eight weeks after calving, a sharp drop in milk production occurred from the twenty-first to twenty-fourth week after calving. Whereas cows bred from seventeen to twenty weeks after calving did not show the characteristic drop until the twenty-ninth to thirty-second week after calving. Eckles (1923) reported a 19-percent decrease in annual milk production for a group of cows bred to calve within twelve months as compared to the same group when bred to calve at more than fifteen months' interval.

Hammond and Sanders (1923) found that a short service period reduced total milk yield whereas a long service period increased it. These observations imply that a cow early in gestation during a lactation will produce less than one that is late in gestation during a lactation period. Hammond and Sanders suggested correction factors to apply to records of cows either affected or not affected by gestation. They found that in cows conceiving within nineteen days after calving, a correction of 30 percent should be added to the total milk yield. These correction figures decreased with each nineteen-day interval of increased service period up to ninety to one hundred days after calving, which is 0 percent correction. For cows not serviced until after one hundred days after calving, they suggested a minus correction factor to be applied for each nineteen-day interval up to a -11 percent for 160- to 179-day service period. These observations were borne out by Sanders (1923). He devised a factor for lactations which he called the "Shape Figure" and found a positive correlation between the "Shape Figure" and length of the service period. As the length of the service period increased, the "Shape Figure" increased. Sanders also observed a positive

correlation between height of the "Shape Figure" and the total lactation yield.

Brody et al. (1923), studying the records of Advanced Registry Guernsey cows, found that cows kept farrow until within five months of the end of the lactation produced more than cows bred so that more than five months of gestation appeared in the lactation period. Gaines and Davidson (1926), studying 4,552 records of the Advanced Register of the American Guernsey Cattle Club, found results very similar to those of Brody et al. (1923). Gaines and Palfrey (1931), using 352 Red Danish cows with ten uninterrupted calvings, found the average calving interval to be 401 days. They found a positive correlation between the calving interval and total yield.

Hammond and Sanders (1923) found that the length of dry period had a great effect on subsequent production to a certain point. Any length beyond this changed total production slightly. They observed that a dry period length from 0 to 39 days caused a 13-percent reduction in total yield; 40 to 79 days dry period caused a 2.5-percent reduction in yield; 80 to 119 days were considered as having no effect on subsequent yield, and a dry period of 120 days plus caused only a 2-percent increase in total yield.

Dickerson (1940), studying Wisconsin D. H. I. A. cow records, observed that 6 to 9 percent of the total variance was to the preceding dry period. However, he concluded that preceding dry periods had little effect on 305-day records. Klein and Woodward (1943) studied 15,442 lactation records of D. H. I. A. cows from twelve states. They found that cows dry one to two months gave 9.2 percent more milk than when dry zero to one month; cows dry two to three months gave 4.3 percent more than when dry one to two months and 13.5 percent more than when dry zero to one month. Cows dry three to four months gave 14.9 percent more than cows dry zero to one month. They concluded that a dry period of fifty-five days was the optimum length for cows calving at twelve-month intervals.

Chai (1951) studied the effects of calving interval on the same lactation and the next lactation. He found the effect of difference lengths of calving intervals to be quite large. Over 14 percent of the total variance was credited to different lengths of calving intervals for the same lactation and 3 percent of the total variance due to its effect on the following lactation. He concluded that the total variance due to different calving intervals totaled 18 percent of environmental effects. He developed a set of correction factors based on twenty-day intervals which appeared to

be as important as correcting for age at freshening and even more so than corrections for length of lactation.

Investigational Procedure

The survey forms which have been used to collect data for the investigation of the genetics of the Red Danish cattle included appropriate spaces to include the year and month of freshening and calving interval relative to each production record reported.

One hundred and eighty-eight dairy farmers, cooperating in the Red Dane project and testing monthly under supervision of the Dairy Herd Improvement Association, cooperated in completing the survey forms needed for this study. Eighteen counties were represented in the survey located in the northern, eastern, southern, and western section of the state.

All production records were corrected to a 2X, 305-day, M. E. basis. A cow freshening in any particular month was credited to that month. The same was true for year of production. It was felt that since a considerable number of records was involved, the systematic errors would cancel each other. For the year of production study, three general groupings were made of the breeds involved. The Holstein-Friesian, Jersey, and Brown

Swiss breeds were pooled into Group I; the Mixed, Shorthorn, and Guernsey breeds into Group II; and the first-generation, second-generation, and third-generation graded-up Red Danish crosses were placed into Group III. The purpose of this grouping was an attempt to remove some of the variance due to differences betwe n herd management. It was beyond the scope of this study to analyze nine breeds for 188 herds on an intraherd basis. Since the "t" test had shown the differences between the mean production of the breeds within each group to be nonsignificant, it was felt that some of the similarity between the mean production of the breeds, as grouped, was due to contemporary herd environments.

The calving interval was calculated by thirty-day class intervals. If a calving interval extended beyond the class mark it was placed into the next class. With enough numbers involved as in this study, the systematic errors should cancel each other.

Since all of the data had been punched on IBM cards, the procedure followed to extract the desired data for this study was one of sorting and tabulation involving card number 3.

The method used in this study for analyzing the effect of yearly environmental changes, calving interval, and month of

freshening was the unequal subclass numbers analysis of variance given by Snedecor (1950).

For determining time trends in data there are several methods of analysis available. The method used here, after Hoel (1948), and recently used by Chai (1951) on production records, is the so-called "runs"--a kind of test of randomness of sequences. The median average for each group was determined as outlined by Snedecor (1950), and the weighted mean yearly average for each group was also determined. The same was completed for the groups when combined. The average production for each year for each group and for the three groups together were assigned the letter "a" if they were less than the median, and the letter "b" if they were greater than the median for their respective groups.

It was felt that for the yearly environmental changes and time trend analysis that the mean butterfat production would show the necessary results and it would be unnecessary to test the mean milk production for these factors.

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It was felt that for the yearly environmental changes and time trend analysis that the mean butterfat production would show the necessary results and it would be unnecessary to test the mean milk production for these factors.

Investigational Results

Time Trend and Yearly Environmental Changes

The average yearly butterfat production figures for each of the three groups are given in Table XXXI. Figure 9 shows these figures in graphic form.

Tables XXXII and XXXIII show that there was a highly significant difference between different years for butterfat production either for a single group or after combining the three groups. There are indications that the averages of the last three years may have a time trend since they are considerably higher than the averages of the earlier years. However, the averages for the last year in each group is somewhat lower than the preceding two--indicating that the high averages for the years 1949 and 1950 may have been due to yearly variations. The portion of the intragroup variance which was accounted for by differences between years was slightly above 3 percent, while the portion of total variance due to differences between years was close to 7 percent.

In analyzing the time trend of these data the following four sets of arrangements were computated:

TABLE XXXI

A LIST OF YEAR AVERAGES OF BUTTERFAT PRODUCTION

Year	Group One		Group Two		Group Three		Total	
	No. of Records	Avgs.	No. of Records	Avgs.	No. of Records	Avgs.	No. of Records	Wtd. Avgs.
1939	17	335	11	335	---	---	28	335
1940	26	352	21	328	---	---	47	341
1941	34	390	28	329	---	---	62	362
1942	20	385	17	300	19	363	56	352
1943	28	354	40	328	54	334	122	337
1944	26	376	51	333	71	350	148	349
1945	22	348	53	312	118	363	193	347
1946	32	351	43	312	157	364	232	353
1947	51	373	71	313	216	342	338	341
1948	82	390	137	328	325	371	544	363
1949	71	412	171	349	452	379	694	375
1950	53	421	132	354	451	390	636	385
1951	29	400	58	347	250	375	337	372
Weighted Average		384		335		372		364

Figure 9

Average yearly butterfat production of the Holstein-Friesian, Jersey, and Brown Swiss breeds (Group I); the Mixed, Shorthorn, and Guernsey breeds (Group II); and the first-, second-, and third-generation Red Danish cross females.

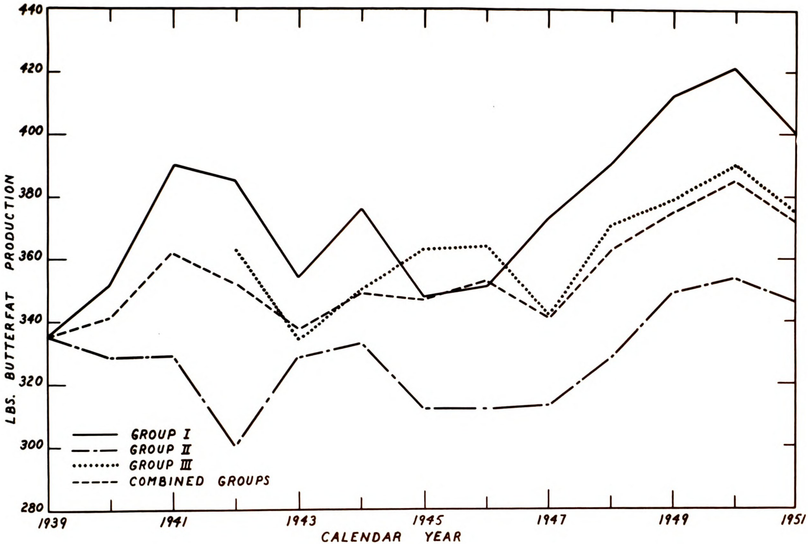

440
420
400
380
360
340
320
300
280
LBS. BUTTERFAT PRODUCTION
GROUP I
GROUP II
GROUP III
COMBINED GROUPS
1939
1941
1943
1945
1947
1949
1951
CALENDAR YEAR

TABLE XXXII

ANALYSIS OF VARIANCE OF YEAR EFFECT ON BUTTERFAT PRODUCTION OF EACH GROUP

Group	Source of Variance	Degrees of Freedom	Sum of Squares	Mean Squares	F
	Total	490	4,422,168		
I	Between years	12	302,236	25,186	2.92**
	Within years	478	4,119,932	8,619	
	Total	832	5,229,059		
II	Between years	12	209,806	17,484	2.85**
	Within years	820	5,019,253	6,121	
	Total	2,112	3,469,233		
	Between years	9	510,078	56,675	40.00**
	Within years	2,103	2,959,155	1,407	

** ($P < 0.01$).

TABLE XXXIII

ANALYSIS OF VARIANCE OF YEAR EFFECT ON BUTTERFAT PRODUCTION OF THE GROUPS COMBINED

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F
Total	3,437	26,809,140	7,800	
Between groups	2	1,018,370	509,185	6.78**
Within groups	3,435	25,790,770	7,508	
Between years	33	1,022,120	30,973	4.25**
Within years	3,402	24,768,650	7,281	

** ($P < 0.01$).

Portion of intragroup variance due to difference between years =

$$\frac{7,508 - 7,281}{7,508} = 3.02\%$$

Portion of total variance due to difference between years =

$$\frac{7,800 - 7,281}{7,800} = 6.65\%$$

Group I

Averages: 335, 352, 390, 385, 354, 376, 348, 351, 373, 390, 412, 421, 400.

Median: 380.

Sequence of letters: aabbaaaaabbbb.

Group II

Averages: 335, 328, 329, 300, 328, 333, 312, 312, 313, 328, 349, 354, 347.

Median: 329.

Sequence of letters: babaabaaaabbb.

Group III

Averages: 363, 334, 350, 363, 364, 342, 371, 379, 390, 375.

Median: 366

Sequence of letters: aaaaaabbbb.

Groups combined

Averages: 335, 341, 362, 352, 337, 349, 347, 353, 341, 363, 375, 385, 372.

Median: 361.

Sequence of letters: aabaaaaaabbbb

Explanation of symbols:

na = the number of a's.

nb = the number of b's.

ra = the number of runs of a's.

rb = the number of runs of b's.

u = ra + rb.

For Group I:

na = 8, nb = 5, ra = 2, rb = 2, u = 4. Significant such that p $(u \leq u_{.05}) \leq 0.05$.

For Group II:

na = 7, nb = 6, ra = 3, rb = 4, u = 7. Nonsignificant.

For Group III:

na = 6, nb = 4, ra = 1, rb = 1, u = 2. Significant such that p $(u \leq u_{.05}) \leq 0.05$.

For Group IV:

na = 8, nb = 5, ra = 2, rb = 2, u = 4. Significant such that p $(u \leq u_{.05}) \leq 0.05$.

When comparing the u values obtained for the different groups with the "u" table found in Hoel (1948), it was found that the values for the I, III, and combined groups are significantly low, while that for the II group is nonsignificant. This leads one to inspect the data for what might appear to be time trends. It is interesting to note that all groups tend to increase and decrease in the same year with approximately the same ratio. Therefore, it seems plausible to be able to compare the various groups without interference of a time trend operating in one group and not in the other.

Effect of the Month of Calving on Milk and Butterfat Production

Table XXXIV shows the number of cows that calved in each calendar month, the average milk production, butterfat production, and butterfat percentage for that month. These figures for each month are shown in graphic form in Figures 10 and 11, for milk and butterfat production and number of calvings, respectively.

As can be readily seen from Table XXXIV and Figure 11, the number of cows freshening each month reaches a peak in March and falls to a low point in the months of June and July. As the curve is smoothed, it shows a gradual decrease from March until June and July; then it rises slowly until March.

The averages of milk and butterfat show a somewhat similar curve except that two peaks in these curves are evident. Table XXXIV and Figure 10 show that the highest month for milk and butterfat production was December, with a somewhat smaller peak in February for milk and March for butterfat. As the curves are smoothed, they show a gradual rise from January to early spring and then a somewhat rapid decline to the summer months, June, July, and August, where they are relatively level;

TABLE XXXIV

AVERAGE MILK PRODUCTION, BUTTERFAT PRODUCTION, AND BUTTERFAT PERCENTAGE OF COWS CALVING IN THE DIFFERENT MONTHS

Month	Records		Milk Production		Butterfat Production		
	No.	% Total	Mean	% of Maximum	Mean	% of Maximum	% Test
January	345	9.87	9,031	97.07	366	95.56	4.05
February	341	9.75	9,183	98.71	370	96.60	4.03
March	407	11.64	9,134	98.18	374	97.65	4.09
April	301	8.61	8,678	93.28	360	93.99	4.14
May	268	7.66	8,282	89.02	344	89.81	4.15
June	174	4.98	8,248	88.65	336	87.72	4.07
July	192	5.49	8,398	90.27	347	90.60	4.13
August	220	6.29	8,447	90.79	347	90.60	4.11
September	256	7.32	8,756	94.01	366	95.56	4.18
October	317	9.06	9,098	97.79	380	99.22	4.17
November	343	9.81	9,177	98.64	382	99.73	4.16
December	333	9.52	9,303	100.00	383	100.00	4.11

Figure 10

Effect of Month of Freshening on Total Milk and Butterfat Production for the Current Lactation

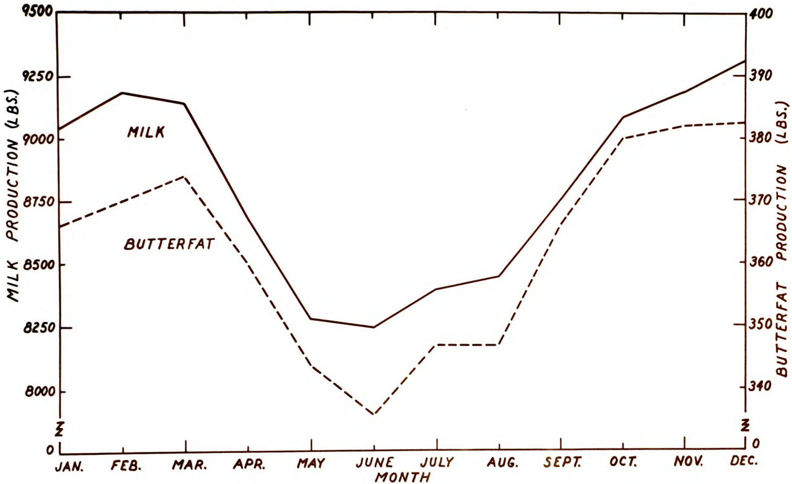
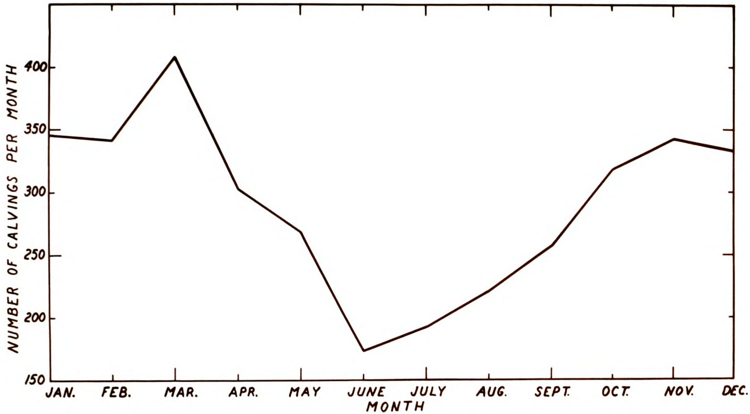

MILK PRODUCTION (LBS.)
9500
9250
9000
8750
8500
8250
8000
0
MILK
BUTTERFAT
BUTTERFAT PRODUCTION (LBS.)
400
390
380
370
360
350
340
0
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
MONTH

Figure 11

Frequency of Calvings for the Different Months


NUMBER OF CALVINGS PER MONTH
400
350
300
250
200
150
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
MONTH

then they rise rather rapidly from August to October, thence slowly to December, and then drop slowly to January.

Table XXXV shows that the month effect on milk and butterfat production was significant ($P < 1\%$). The portion of total variance due to month effect on milk and butterfat production was 1.9 percent and 2.4 percent, respectively.

According to the level of difference needed for significance between averages of milk production, the means for the months of October, November, December, January, February, and March were not significantly different. They did differ significantly from the other months. The means for April and September were not significantly different, however. They differed significantly from the winter months and from the summer months of May, June, July, and August. The differences between means of the summer months were not significant. Therefore, from analyzing the means with the "t" test ($P < 0.05$), it was concluded that the means for milk production were grouped into a peak of six late fall, winter, and early spring months, with the low points for production being in the summer months and a month of transition lying between the high and low points.

TABLE XXXV

ANALYSIS OF VARIANCE OF YEAR EFFECT ON BUTTERFAT PRODUCTION OF EACH GROUP

Production	Source of Variance	Degrees of Freedom	Sums of Squares	Mean Squares	F
Milk	Total	3,446	18,985,052,670	5,509,300	
	Between months	11	416,908,000	37,900,727	7.01**
	Within months	3,435	18,568,144,670	5,405,470	
Butterfat	Total	3,446	23,358,895	6,779	
	Between months	11	631,494	54,409	8.67**
	Within months	3,435	22,727,401	6,616	

** ($P < 0.01$)

Portion of total variance due to month effect:

Milk:

$$\frac{5{,}509{,}300 - 5{,}404{,}570}{5{,}509{,}300} = 1.9\%$$

Butterfat:

$$\frac{6{,}779 - 6{,}616}{6{,}779} = 2.4\%$$

The means of butterfat production showed a slightly different trend. A peak occurred for October, November, and December, but the difference between means was not significant ($P < 0.05$). The differences between the means of these months and the other months were significant. The low mean months, May, June, July, and August, did not exhibit significant differences between their means. As in the case of milk production, there were transition months on either side of the high- and low-mean months. From the tests of significance, the peaks in butterfat production were very similar to those of milk production. This was expected, since total milk production and total butterfat production were significantly correlated.

The frequency of calvings for the different months are shown both as numbers per month and percentage of total observed. The largest frequency of calvings occurred during the month of March, with the frequencies for the months of October, November, December, January, February, and April somewhat similar but below that of March. The lowest frequency occurred in June, followed closely by July and August. These same data are shown graphically in Figure 11.

Effect of Calving Interval on Milk and Butterfat Production

Table XXXVI shows the distribution of the records and average production for each calving interval. These same figures for milk and butterfat production are shown graphically in Figure 12. These data show that the effect of the calving interval on the next lactation was rather pronounced.

As the calving interval lengthened, there was a steady increase in average milk production. This increase was linear until the interval 440 to 469 was reached. Thereafter for the next intervals plotted, the milk production leveled off and seemed not to be increased or decreased by a longer interval.

The same general trend for butterfat production is exhibited by Table XXXVI and Figure 12. However, the mean butterfat production as affected by the calving interval reached its maximum height one interval later--470 to 499--than milk production. In the next two intervals it declined.

From Table XXXVI and Figure 12, it was concluded that the calving interval for securing best mean production for the next lactation was a calving interval of 440 to 469 for milk production and 470 to 499 for butterfat production.

TABLE XXXVI

DISTRIBUTION OF RECORDS AND THE MEAN MILK AND BUTTERFAT PRODUCTION OF NEXT LACTATION FOR THE DIFFERENT CALVING INTERVALS

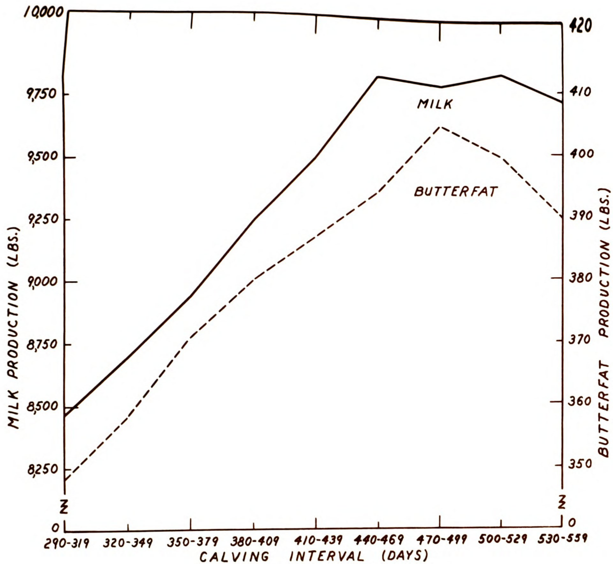
Interval Days	Records		Production			% of Max. Yield[2]
	No.	% of Total	Mean Milk	% of Max. Yield[1]	Mean Butter-fat	
290-319	139	7.59	8,457	86.49	348	87.43
320-349	423	23.09	8,699	88.97	358	89.94
350-379	573	31.28	8,933	91.36	371	93.21
380-409	333	18.18	9,230	94.49	380	95.47
410-439	152	8.30	9,491	97.07	387	97.23
440-469	85	4.63	9,816	100.03	394	98.99
470-499	47	2.56	9,763	99.85	405	100.50
500-529	50	2.73	9,817	100.04	399	100.03
530-559	30	1.64	9,712	99.33	390	97.98

[1] An average of the last four intervals.

[2] An average of the last three intervals.

Figure 12

The Effect of Length of Calving Interval on Milk and Butterfat Production of the Subsequent Lactation


10,000
9,750
9,500
9,250
9,000
8,750
8,500
8,250
0
MILK PRODUCTION (LBS.)
420
410
400
390
380
370
360
350
0
BUTTERFAT PRODUCTION (LBS.)
MILK
BUTTERFAT
290-319
320-349
350-379
380-409
410-439
440-469
470-499
500-529
530-559
CALVING INTERVAL (DAYS)

An analysis of variance--Table XXXVII--was calculated to find whether the effect of calving interval on milk and butterfat production for the next lactation was statistically significant. The results shown in Table XXXVII were highly significant. The portion of the total variance due to differences caused by calving interval effect was 3.0 percent and 3.2 percent for milk and butterfat production, respectively.

By use of the "t" test--to test for significance of the differences between the mean milk and butterfat production for the various intervals, it was found that the differences were not significant until two intervals or sixty days had elapsed. This was true for both milk and butterfat production. However, beyond the interval of 440 to 469 the differences between the means were not significant.

Table XXXVIII shows the average calving intervals for the various breeds and crosses in this study. As can be seen, the differences between the mean intervals for the various breeds and crosses are not significant.

TABLE XXXVII

ANALYSIS OF VARIANCE OF EFFECT OF CALVING INTERVAL ON MILK AND BUTTERFAT PRODUCTION OF THE NEXT LACTATION

Production Character	Source of Variance	Degrees of Freedom	Sum of Squares	Mean Squares	F
Milk	Total	1,832	9,025,973,505	4,926,841	
	Between intervals	8	301,649,490	37,706,186	7.88**
	Within intervals	1,824	8,724,324,015	4,783,072	
Butterfat	Total	1,832	13,958,253	7,619	
	Between intervals	8	502,571	62,821	8.51**
	Within intervals	1,824	13,455,682	7,377	

** ($P < 0.01$)

Milk:

$$\frac{4,926,841 - 4,783,072}{4,926,841} = 3.0\%$$

Butterfat:

$$\frac{7,619 - 7,377}{7,619} = 3.2\%$$

TABLE XXXVIII

AVERAGE CALVING INTERVALS SHOWN BY MONTHS AND CLASS INTERVALS FOR THE VARIOUS BREEDS AND CROSSES STUDIED

Breeds	Class Interval	Month Avg.	Number
Guernsey	350-379	12.2	350
Holstein	380-409	12.7	384
Shorthorn	380-409	12.5	341
Jersey	380-409	12.8	167
Brown Swiss	380-409	12.6	48
Mixed	380-409	13.1	187
First cross	380-409	12.6	1,207
Second cross	380-409	13.2	557
Third cross	380-409	12.7	98
Average	380-409	12.7	
Total			3,339

Discussion and Conclusions

Time Trend and Yearly Environmental Changes

The factors which account for this effect such as climate, economical changes, feed conditions, all have a direct or indirect effect on milk and butterfat production of dairy cows. These factors are the ones that primarily cause year-to-year fluctuations in production averages. The effects of these are usually cancelled out, if the data extends over a reasonable period of time. However, factors such as better feeding practices, better housing, better management practices, all have a direct or indirect effect that cause what is known as a time-trend effect. When analyzing data, the time-trend effect can bias the analysis much more than the year-to-year fluctuations. In these data there was a time trend toward higher production during the later years which was only slightly significant. Even though a slight time trend existed in these data, the animals composing each group which were compared for various traits were distributed over the entire period considered, thus essentially eliminating any bias.

The portion of the intragroups variance which was accounted for by difference between years was 3 percent. The portion of the

total variance which was accounted for by difference between years was 6.7 percent. These figures are in close agreement with Chai (1951) and Dickerson (1940).

Effect of Month of Calving on Milk and Butterfat Production

The results of the effect of month of calving on milk and butterfat production in this study coincide roughly with findings of other workers who observed a seasonal effect. As would be expected, the months showing maximum effects were different because of different geographical regions differing in temperatures, rainfall, pasture conditions and other environmental factors.

It is felt that the findings of this study differed from the results of the two investigations of this nature in Michigan due to sampling and environment. The studies of Chandrashaker (1951) and Chai (1951) were with data from one and three herds, respectively, while these data for the present study were from 186 herds in all sections of the state. Chandrashaker (1951) studied the effect of month of calving on butterfat production of the Michigan State College herd and found the portion of variance due to month effect nonsignificant. That his findings are reasonable is accepted, since the college herd had an undoubtedly standardized environment and

al variance which was accounted for by difference between years s 6.7 percent. These figures are in close agreement with Chai 51) and Dickerson (1940).

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ort is made to maintain it as such. Chai (1951), in in-
g the environmental and genetic factors affecting Holstein-
cattle in three state institutional herds found that month
; had a significant effect on mean butterfat production in
e three herds studied. The high month for mean production
h, with June and August, the low months. The peculiarity
sults was that the mean production for the month of July
ficantly higher than those for June and August. He at-
his to either sampling errors or to certain management
that compensated for the usual adverse conditions for
ing in that month. His findings of the mean production
as being the peak production month is in disagreement
indings of the present study in which December appears
ak month.

nnon (1933) analyzed 68,000 Iowa Cow Testing Association
observe month-of-calving effect on subsequent production.
November as the peak month with June, July, and August
months. Plum (1935), studying similar data for ninety-
, combined 6,900 records of three breeds in Iowa and
ted the earlier findings of Cannon. Woodward (1945)
15,000 D. H. I. A. records from twelve states into

s of calving and found July to be the month of lowest yield on subsequent lactations and November the highest. From y of Table XXXIV and Figure 10, it can be readily seen that dings of the present study were in almost complete agree- rith the findings of Cannon, Plum, and Woodward. There was :eption in these data, however. The peak month was De- . Although the maximum production for both milk and but- vas reached in December, the means are not significantly t from those of November. Essentially then, these data ıgreement with those of other workers studying D. H. I. A. T. A. records.

The portion of total variance due to month effect found in ly compares very favorably with the findings of other work- ai (1951) attributed 2 percent of the total variance he ob- n his data to month effect. Dickerson (1940b), in analyz- onsin D. H. I. A. records, found that 4 percent of the iance observed could be attributed to month of freshening, 1.9 percent when all records were of 305-day duration, present study, while Plum (1935) found that 3 percent of variance was caused by month-of-freshening effect. The of variance of the data in the present study, Table XXXV,

t the portion of total variance due to month-of-freshening s 1.9 percent and 2.4 percent for milk and butterfat pro- respectively.

nother aspect (of minor importance to the present study, terest from a general point of view) which grew out of the -freshening study was the frequency of calvings per month. d of information has not been previously ascertained for section of dairy cattle in Michigan. Chandrashaker (1951) d on his findings in the Michigan State College herd and o difference in frequency of calvings for the different months year. Chai (1951) found significant differences in the fre- of calvings for the three state institutional herds. He con- that the frequency was not controlled to the maximum s for production. The frequencies during the low months were h or higher than the peak production months. In the present , it was found that the frequency of calving followed the trend lk production. The calving frequency for the highest month oduction was nearly twice that of the low month of production. ugh it must be added that the month with the highest calving uency in these data--March--was not the highest production th; it was a secondary peak month.

he reasons that calving frequencies are not more closely ed with maximum months of freshening for production in ta could be due to various reasons: (1) farmers' ignorance ffect of month on production and consequent lack of attempts ol the time of freshening, (2) milk markets such that farm- st supply a certain amount of milk during specific months ive a much lower price for extra milk during flush periods, roductive troubles may cause cows not to settle at the proper nd (4) dairying is a year-around business from the invest- f capital concerned and it is of the best interest for a an to be milking cows twelve months of the year. Enough nce in production means for several of the months existed hen comparing small numbers of animals such as in bull , it may be advisable to take into account the month of ning for the various lactations, if those data were available population under study. In the present study the widest nce between means was in the amount of 12 percent, which make quite a difference in a dam and daughter comparison. animal calved in the low month and the other in the high , the month effect alone would make a difference of 48 pounds on a 400-pound level.

Effect of Length of Calving Interval on Milk and Butterfat Production

The data observed in this study compare favorably with f Dickerson (1940). He observed that 6 to 9 percent of al variance could be attributed to the preceding dry period. records were calculated to 305 days in length, the variance reduce approximately 50 percent. A long calving interval in an increased production in the following lactation s, 1923; Gaines and Palfrey, 1931). In this study, 3 and rcent of the total variance of milk and butterfat production, ctively, was attributed to the length of preceding calving in- .

Hammond and Sanders (1923) found that a dry period length o 39 days caused a 13-percent reduction in total yield. For terval of 290 to 319 in this study (Table XXXVI) which cor- nds roughly to 0 to 39 day interval of Hammond's and San- study, it was found that total yield was reduced by 13 and rcent for butterfat and milk production, respectively, as ared to the calving interval of 440 to 469 days which gave mum production. Chai (1951) proposed correcting the butterfat

:ion by 14 percent when the preceding calving interval was
319 days.

When comparing the production records of a relatively few s--such as five dam-daughter pairs, it would be well to take :count the length of preceding dry periods. When large num- re involved, it would probably become unnecessary since the nd short intervals would tend to balance.

Summary

A slight time trend was evident in these data. Although the ges of all categories of cows reached a high peak the last ears, there was a sharp drop in the last yearly average.

The analysis of variance showed that 7 percent of the total ice could be attributed to differences between years. Since ction records were obtained from foundation breeds during the periods as those of the crosses, it was concluded that the changes and time trend, did not bias the data; consequently, was no necessity of a correction for time trend.

The analysis of the effect of month of calving showed that freshening during the months of May, June, July, and August ced from 10 to 12 percent less milk and butterfat. The cows

ıening in the month of December produced 1,055 and 47 ds more milk and butterfat, respectively, than did cows fresh- ; in June. An analysis of variance of these data attributed oximately 2 percent of the total variance of milk and butterfat uction to month-of-freshening effect. However, when comparing .1 numbers such as dam-daughter comparisons in a bull proof, suggested that the month of freshening be taken into account.

An analysis of the effect of calving interval on the subse- t lactation showed a significant increase in milk and butterfat uction as the interval lengthened. With intervals of thirty , it was found that milk and fat production increased 3 to 4 ent with each increase of one interval. Cows with 290 to 319 calving intervals produced approximately 13 percent less milk butterfat than did cows with 440 to 469 day calving intervals. analysis of variance attributed 3 and 3.2 percent of the total ance of milk and fat production, respectively, in these data to length of calving interval.

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APPENDIX

BIRTH REPORTING RULES:

Anyone breeding Red Danish cattle for the purpose of final registration of third and succeeding generations must comply with the following rules:

1. (VERY IMPORTANT!) All first and second cross heifer calves, and all Red Danish females and males who are or will become eligible for registration must be birth reported within 90 days of birth; after 90 days there is a penalty of $1.00 per month or fraction thereof until animal reaches the age 9 months. If not birth reported before it reaches the age of 9 months it is no longer eligible for birth reporting and assumes the status of a foundation animal.

2. A foundation cow must be birth reported at the time its first Red Danish female calf is reported.

3. All birth reports must be made on special birth reporting pad (form No. 1) available at Secretary's office at $10 to members and $15 to non-members. This pad contains 25 application blanks for birth reports or transfers.

4. Two identifications are required.

   a. An approved eartag acceptable to BDI;

   b. Either a tattoo No. or an ear notching system that positively identifies each individual animal.

REGISTRATION RULES:

1. The application of registration is the responsibility of the owner of animal at time of application.

2. Eligibility:

FEMALES:

a. Must have D.H.I.A. 305 day records on Dam, Grand Dam, and Great-grand Dam, on the Dam's side.

b. Must have three immediate generations of Registered or approved Red Danish Sires. (Red Danish Bulls leased from the U. S. D. A. are approved or accepted as registered Sires. Bulls imported from Denmark must be individually approved by the American Red Danish Cattle Association board of directors or executive committee, for registration!)

c. Must have been birth recorded under form No. 1 (see birth reporting rules.)

d. Must have one or more 305 day records as indicated on BDI 718 report.

e. All Females accepted for final Registry after the third cross must have a registered Dam and Sire in addition to being birth reported on Form No. 1.

MALES:

a. Must be sired by registered or approved Red Danish sire.

b. Dam must be registered in American Red Danish Cattle Association.

c. Must have been birth recorded on Form No. 1.

3. It shall be the responsibility of the Breeder in correlation with the D. H. I. A. supervisor to see that the 305-day Production Records are reported to the Secretary of the A.R.D.C.A. as soon as they are completed, using the special 305-day card provided by the A.R.D.C.A.

4. There will be a registration fee of $2 to members and $3 to non-members for females and $3 to members and $4 to non-members for males.

5. A fee of 50c will be charged to post complete and up to date production records on registration certificates.

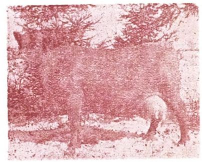
6. All calves which are or will become eligible for registration are eligible to be shown at cattle shows as registered animals if birth reported on Form No. 1.

7. These rules and fees are subject to change by ARDCA.

Introductory Information

CONCERNING

Red Danish Cattle



PREPARED BY

THE AMERICAN RED DANISH CATTLE ASSOCIATION

CLIFFORD SHANTZ, Secretary
FAIRVIEW, MICHIGAN

EXHIBIT A

THE BREED

The American Red Danish Cattle Association, through selective Breeding by using approved Red Danish Sires and by following a continuous D. H. I. A. testing program, has developed an outstanding breed of red dairy cattle of high butterfat producing ability.

This herd of Red Danish Cattle will rival all other herds of registered dairy cattle kept under similar conditions. The type will be uniform, Milk and Butterfat production will be high. The beef market value of the animals will be good. Animals will have generally rugged constitutions. Conformation will be uniform. Udders will generally be compact and well attached. Mature cows in average condition will weigh 1300 to 1500 pounds.

The way to get a herd like this is to use registered American Red Danish bulls under the rules prescribed by the Association.

The original cow used in establishing any family must be recorded with the Association, and must be D. H. I. A. tested for at least one year. Her production record will become a permanent record of the Association, as will production records of all females. She is bred to a Red Danish bull.

The resulting calf, if a female, will be recorded with the Association, and known as a "First Cross." Production records are kept, and the process is repeated for the "Second Cross", "Third Cross", and "Fourth Cross."

Third Cross females are considered purebred. Fourth Cross males are considered purebred.

Please note that every lactation of every female animal on record with the Association must be reported by the D. H. I. A. It becomes a part of the pedigree of that animal.

Blank forms for making all reports are available through the Association.

HISTORY

The breed of American Red Danish Cattle has been established through the joint effort of the United States Department of Agriculture, working farmers in three Michigan Counties, and Michigan State College. The breed is now becoming quite widely spread throughout North America because it is proving its worth.

The U. S. D. A. asked E. L. Anthony, now Dean of Agriculture, Michigan State College, to go to Denmark and get a few good Red Danish Cattle. He selected twenty females and two males, shipping them to the U. S. D. A. Experimental Farm at Beltsville, Md.

As the herd prospered, a group of farmers in Sanilac County, Michigan, accepted the offer of the U. S. D. A. to prove the bulls. The results of crossing the bulls on native cattle were so satisfying, that it was decided to develop a new breed.

Enthusiasm grew as the farmers saw their herds improve generation after generation until now a 500 lb. butterfat Red Danish cow on two-time milking is no novelty.

With the assistance of Michigan State College, the farmers established, in January 1948, the American Red Danish Cattle Association, with nominal headquarters at East Lansing, Michigan. However, business is usually transacted at the office of the Secretary.

NOTES

Because of heavy demand, Red Danish breeding stock is selling at a premium when it can be purchased.

Red Danish semen is available through the Michigan Artificial Breeders Association.

Altho the characteristic deep red color is firmly established in the third cross, first and second cross animals may vary in color.

EXHIBIT B

INSTRUCTIONS FOR FILLING OUT COW WORK SHEET

1. Please do not write above the starred line.

2. If you have a cow or cows in your herd for which you do not receive a work sheet in either of the two groups of work sheets which you will receive, then use one of the blank sheets found in the last group for these animals. It will be necessary for you to indicate her ear-tag number and birth date in the female box, the number of her sire in the sire box and the ear-tag number of her dam in the dam box. The other information above the starred line will be filled in by us after the sheets are returned to us.

   If this is a purchased cow indicate at the bottom of the sheet from who purchased. If you receive a work sheet for a cow which you have sold please indicate to whom sold at bottom of sheet.

3. Please fill in the columns below the "starred line" as follows:

Column 1. Enter here the lactation number corresponding to the information filled out for each line across the page. Example: 1 for first lact. - 2 for second and etc. (for each calf)

" 2. Enter the freshening date in the order shown at top of column. Year first, then month and then date. Example: 47-2-24.

" 3. Enter the age at freshening. This must be shown as year and month. Example how to calculate freshening age.

If cow calved 46-2-25 assume the date of birth from above starred line under female is 44-1-23. By substracting the birth date from the calving date the age at freshening can be found.

<u>Example</u>:	46-2-25	(calving date)
	44-1-23	(birth date of cow)
	2-1-2	This is the age at freshening written as 2-1, dropping the day since it's less than 15 days.

<u>Another Example</u>:

46-7-10	(calving date)
43-7-11	(birth date of cow)
2-11-29	This is the age at freshening and since the days are over 15 the age would be entered as 2-12.

As you notice in subtracting the birth date of cow from the freshening date in the last example, 11 from 10 wouldn't work therefore a month of 30 days was borrowed from 7 to make the days 40. Therefore 40 minus 11 = 29 days. This leaves 6 then as the months, 6 minus 7 wouldn't work. Therefore it is necessary to borrow 1 year or 12 months from 46. This makes the month 12 + 6 = 18, then 18 minus 7 = 11 months. In subtracting the year dates since a year was borrowed from 46 the procedure would be 45 minus 43 = 2 yrs.

4. Enter the length of time between calves. This should be entered by months.

5. Enter the time milked daily. Example: 2,3 or etc.

6. In this column enter the <u>exact number of days for which production is shown in columns in 7 and 8</u>. <u>This must be accurate or errors will result in analysis.</u>

Column 7. Enter here the production record made by the cow that is nearest 305 days. If a 305 day record is shown in the herd book use it. If you have to get the records from the "total-to-date" column in your herd book take the sub-total that is 305 days or the nearest one over 305 days. Do not cut a record off below 305 days. If a cow produced 270 days show her record then for 270 days. Be sure this is the same length of record as number of days milked in column six. Use only whole numbers. No fraction of pounds. Any partial records should be shown.

" 8. The fat production which goes in this column is figured exactly like the milk production for column seven and for the same number of days. Use only whole numbers. No fraction of pounds.

" 9. The disposal of the cow should be entered by one of the code numbers appearing opposite the reasons of disposal shown below. For example, if a cow died from "hardware" number 15 would be entered. If none of the below are appropriate leave column blank.

1. Sold - Commercial dairy purposes
2. Sold - Breeding stock
3. Sold - Poor type
4. Sold - Low production
5. Sold - Unthrifty, poorfeeder
6. Sold - Hard milker
7. Sold - Udder physically injured
8. Sold - Sterility - bred 4 times or more, normal heats, still open.
9. Sold - Sterility, lack of heat periods
10. Sold - Sterility, apparently settled, showed signs of heat three months later or more.
11. Sold - Bang(s reactor
12. Sold - T. B.
13. Died - Cause unknown
14. Died - Milk fever
15. Died - Hardware
16. Died - Difficult calving

" 10. This column pertains to abnormal conditions during a lactation. A code number is entered here, selected from one of the conditions below. If none are appropriate leave blank.

1. Physical injury to cow - serious enough to affect production for several weeks.
2. Sickness - unknown, off feed for several weeks.
3. Milk fever.
4. Ketosis or acetonemia - not serious enough to affect production
5. Ketosis or acetonemia - serious enough to affect production.
6. Mastitis - serious enough to affect production.
7. Mastitis - not serious enough to affect production.
8. Abortion - 152 days or less after breeding.
9. Abortion - 152 days or more after breeding.
10. Calving trouble.
11. Retained afterbirth.
12. Loss of one or more quarters.

Column 11. Sex of calf for each calving is shown here also by code number selected from below.

1. Male
2. Female
3. Twins, male and female
4. Twins, both male
5. Twins, both female

" 12. If calf was born alive check this column. Example: (✓)

" 13. If calf was born dead check this column. Example: (✓). If cow had twins and one was dead and one alive check both columns.

" 14. If calf was abnormal indicate this by entering one of the code numbers selected from below. If calf had an abnormality not appearing below describe this on line in remarks section.

1. Mummified
2. Paralyzed hind-quarters
3. Born blind
4. Raw areas on skin
5. Hairless in spots
6. Pasterns were flexed, calf couldn't stand - later recovered
7. Nervous, twitched all over when frightened.
8. Real small for age - dwarfed

" 15. Color of the calf is entered in this column also by code number selected from below.

1. Red
2. Black
3. Red and white spotted
4. Black and white spotted
5. Roan

" 16. Enter the number of the sire of the calf. Example: D556

" 17. Please leave blank - It is for our use in analyzing the data.

Remarks Section: This should be used for any additional information you feel we should have that is not shown in the columns.

Please return all work sheets regardless of whether you were able to fill it out completely or not. The information above the starred line is needed by us for certain studies.