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SWETT, W.W., MATTHEWS, C.A., FOHRMAN, M.H. 1 OF 1

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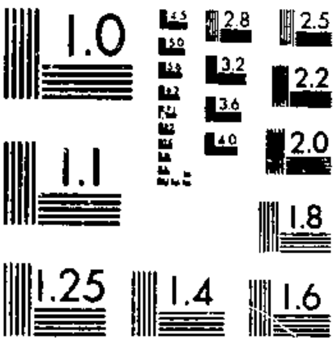

MICROCOPY RESOLUTION TEST CHART
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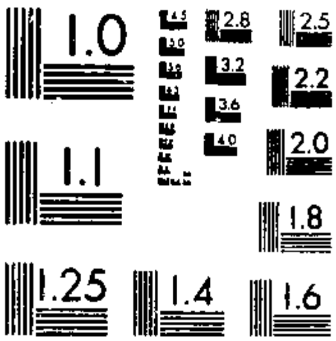

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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Effect of Inbreeding on Body Size, Anatomy, and Producing Capacity of Grade Holstein Cows [1]

By W. W. SWETT, *senior dairy husbandman*, C. A. MATTHEWS, *dairy husbandman*, *and* M. H. FOHRMAN, *head, Division of Dairy Cattle Breeding, Feeding, and Management, Bureau of Dairy Industry, Agricultural Research Administration* [2]

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INTRODUCTION

The study on which this report is based was undertaken in an attempt to measure the differences, in animal form and internal anatomy, between outbred dairy cows and cows representing various intensities of inbreeding, and if possible to determine the significance of such differences from the standpoint of functional ability.

REVIEW OF LITERATURE

Numerous attempts have been made by other investigators to measure the specific effects of inbreeding in various species of animals. Much of the available information pertaining to the effects of inbreeding on the size and structure of the animals has been obtained through studies of laboratory animals. A long-time, well controlled study of

[1] Submitted for publication March 1949.

[2] T. E. Woodward, formerly senior dairy husbandman, who retired July 31, 1944, calculated all of the coefficients of inbreeding used in this study. R. R. Graves, who retired March 30, 1946, was head of the Division of Dairy Cattle Breeding, Feeding, and Management while most of the experimental work was in progress.

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close inbreeding in guinea pigs, conducted by the Bureau of Animal Industry, United States Department of Agriculture, provided an abundance of valuable fundamental data. Various analyses of these data, which included control animals of a strain maintained without inbreeding and animals of highly inbred families and their crosses, showed "size and weight differences which constitute the principal differentiating characteristics between them" (*3*).[3]

In order to determine the extent to which anatomical differences contribute to the weight differences noted, and also whether or not anatomical differences are inherited, Eaton (*3*) subjected some 600 guinea pigs to an exhaustive anatomical study which involved the weighing or measuring of nearly all of the internal organs of the body. The 600 animals included representatives of the various inbred families and their hybrids as well as of the control group, which was not inbred. At the beginning of the anatomical study, three inbred families were in the twenty-sixth to thirtieth generations of brother-sister matings.

From the weights reported by Eaton, it appears that the animals in the three inbred families were definitely smaller (about 20 percent on the average) than those in the control group. He concluded that organs such as the lungs and liver were definitely proportional to live weight; that the heart, spleen, kidneys, adrenals, and testicles were more nearly uniform in weight regardless of body weights; that the adrenals were inversely proportional to live weight; and that there was a remarkable degree of uniformity in intestine length. Eaton found that the weight of pituitary body followed, in general, the live weight. The weights of lungs, thyroid, and adrenals showed the greatest variability; weights of blood, heart, liver, kidneys, spleen, pituitary, and testicles showed medium variability; and the length of intestines and spleen measurements were the least variable. The degree of variability in organ size was about 15 percent lower in the inbred animals than in those in the control group. In general, the organs were relatively larger—in proportion to body weight—in the lines having the smaller live weight.

In a later report Eaton (*4*) showed that, despite large differences in live weight between the inbred families, there was very little difference in the weights or lengths of the leg bones. However, the leg bones were definitely longer and heavier in the control animals (noninbred) than in the inbred animals. Variability was much less for length than for weight of bones, was low for all bone measurements, and was not materially different in the inbred strains than in the control stock. Correlation with live weight was higher for weight than for length of leg bones. These results appear to indicate that inbreeding affects body weight to a much greater extent than it does skeletal size.

The effect of inbreeding must not be confused with that of faulty nutrition, yet Eaton's findings are interesting in view of the observation made by Waters (*8*) more than 30 years ago. Waters observed that a growing animal kept under extremely adverse circumstances, with reference to nutrition, would remain underweight but would be-

[3] Italic numbers in parentheses refer to Literature Cited, p. 34.

come tall and narrow—signifying that the impulse to make skeletal growth is stronger than the impulse to increase in weight.

Many breeders of cattle and other livestock have practiced inbreeding to a limited extent and have drawn various conclusions with regard to its desirability. In most cases, interpretation of the results with cattle has been based on small numbers of animals and short periods of time. This probably is because few breeders have had the facilities for carrying on intensive inbreeding practices over the length of time required to obtain results involving numerous successive generations.

A few reports giving the results of organized inbreeding experiments with cattle have appeared. Woodward and Graves (*9*) found that birth weight was lowered and that rate of growth and mature size appeared to be reduced by inbreeding. Dickerson (*2*) reported that birth weight was lowered by inbreeding, but that the difference in size decreased with age. Bartlett, Reece, and Lepard (*1*) concluded that neither birth weight nor rate of growth was depressed by inbreeding in a family of Holsteins and that type was unaffected. The results of a more complete analysis by Woodward and Graves (*10*) confirm in general those previously reported by the same authors. They indicate that intensive inbreeding lowered breeding efficiency; lowered the birth weight of calves and tended to reduce their vigor; and resulted in smaller mature cows, though the effect was not as marked, relatively, at maturity as at birth. The results showed marked reductions in both milk and butterfat production in the fifth and sixth generations of highly inbred cows, although in the earlier generations level of production had been well maintained.

EXPERIMENTAL PROCEDURE AND DATA USED

The Beltsville inbreeding experiment on which the reports of Woodward and Graves (*9, 10*) were based was begun in 1913 and continued until 1943. During the last 20 years of this period it was carried on concurrently with a study of the interrelationships between body form, internal anatomy, and producing ability in dairy cattle.

In the latter study, which is still under way at Beltsville, cows that have demonstrated their producing capacity and are to be removed from the herd are first measured in detail in order to record body conformation in terms of body dimensions and proportions. Then they are slaughtered and all of their internal organs, endocrine glands, and body parts are weighed or measured. The same plan is carried on at a number of State experiment stations that are cooperating in the study. A summary (*6*) of the breed averages for body weight and dimensions, and for the size of the internal organs and body parts—based on the first 593 cows studied that had records of production—affords a basis for comparing the body form and anatomy of cows representing different breeds and families, and of cows kept under various environmental conditions.

As the cows in the inbreeding experiment—both inbred and outbred—were removed from the herd, they were handled according to the above-described plan by which ante-mortem and post-mortem data were obtained. Some of the cows went out of the herd during the 10-year period before the conformation-anatomy-production relationship study was begun. In fact, no body-form and internal-anatomy data were obtained on any of the foundation cows in the inbreeding experiment, nor on some of the other cows in the earlier generations. Subsequently, it became regular practice to include the cows from the inbreeding experiment in the anatomical study and a high percentage of the individual cows were studied.

In order to avoid, so far as possible, variations which might result from the inclusion of animals representing too great a mixture of breed ancestry, the anatomical study was limited to grade Holsteins; and only those cows were included that had at least 50 percent of Holstein ancestry and less than 50 percent of the ancestry of any other breed. Ante-mortem and post-mortem data were obtained for 71 grade Holsteins, of which 22 were outbred and 49 were inbred. The latter had inbreeding coefficients ranging from 12.5 to 64.6 percent as calculated by the Wright formula (*11*).

The 71 grade Holsteins were divided into 4 groups on the basis of intensity of inbreeding. One group contained all of the 22 outbred cows. For convenience in tabulating the data, these animals were given a value of "0" for inbreeding and were grouped under the heading "outbred." The second group contained 15 inbred cows with inbreeding coefficients of 10 to 29 percent; the third group contained 27 cows with inbreeding coefficients of 30 to 49 percent; and the fourth group included 7 cows with inbreeding coefficients of 50 to 69 percent.

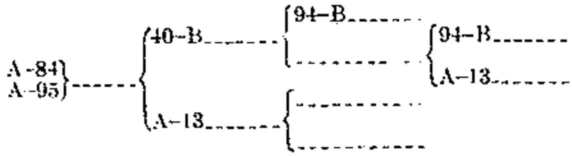
The lowest individual coefficient among the 49 inbred cows was 12.5 percent and only 2 had coefficients below 21.1 percent. In the 3 groups arbitrarily set up to show degrees of inbreeding among the inbred cows (10–29, 30–49, and 50–69), the coefficients of inbreeding for the various groups of items studied increased in increments of approximately 15 from one inbred group to the next.

The group of outbred cows included 12 by registered Holstein sires out of grade Holstein dams; 6 by registered Holstein sires out of grade Guernsey or grade Jersey dams; 2 by grade Holstein sires out of grade Holstein dams, and 2 others of unknown ancestry that were judged to be three-quarters Holstein. Although the sire and dam of each outbred cow were unrelated, there was some linebreeding in the sire of 2 of the cows and a varied amount of linebreeding and inbreeding in the dams of several of the cows.

Pedigrees Showing Character of Inbreeding

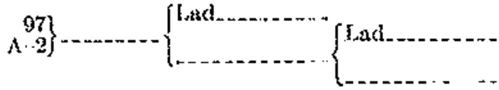
Several examples of pedigrees are included here to illustrate the character of some of the matings that produced various degrees of inbreeding. These simplified pedigrees show only those ancestors involved in calculations for the coefficient of inbreeding. Many of the inbred animals trace to the Holstein sire, Johan Woodcrest Lad 11th 103987, the first sire used in the inbreeding experiment. In the following pedigree examples, this sire will be referred to as Lad.

EXAMPLE A



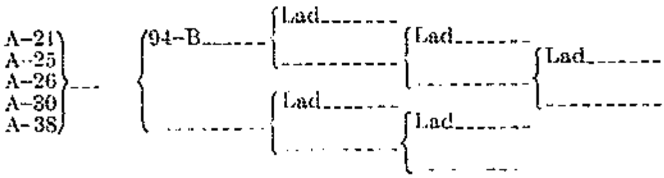
Example A is the pedigree of 2 cows (A–84 and A–95) with 12.5 percent as the coefficient of inbreeding, the lowest among the 49 inbred cows. The inbreeding was through cow A–13. Although the sire 40–B was an inbred son of 94–B, this did not affect the inbreeding coefficients of the daughters of A–13 because there was no relationship between 94–B and A–13.

EXAMPLE B



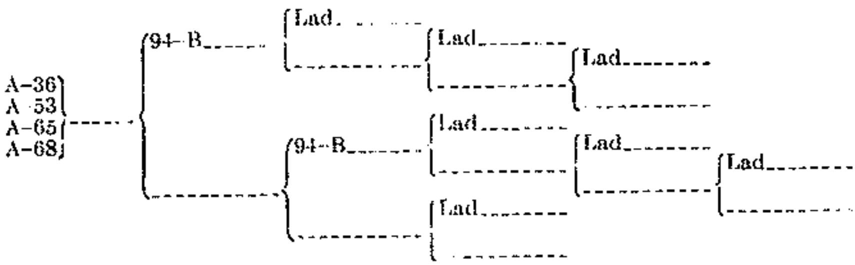
Example B is a simple illustration of a sire-to-daughter mating which gives an inbreeding coefficient of 25.0 percent.

EXAMPLE C



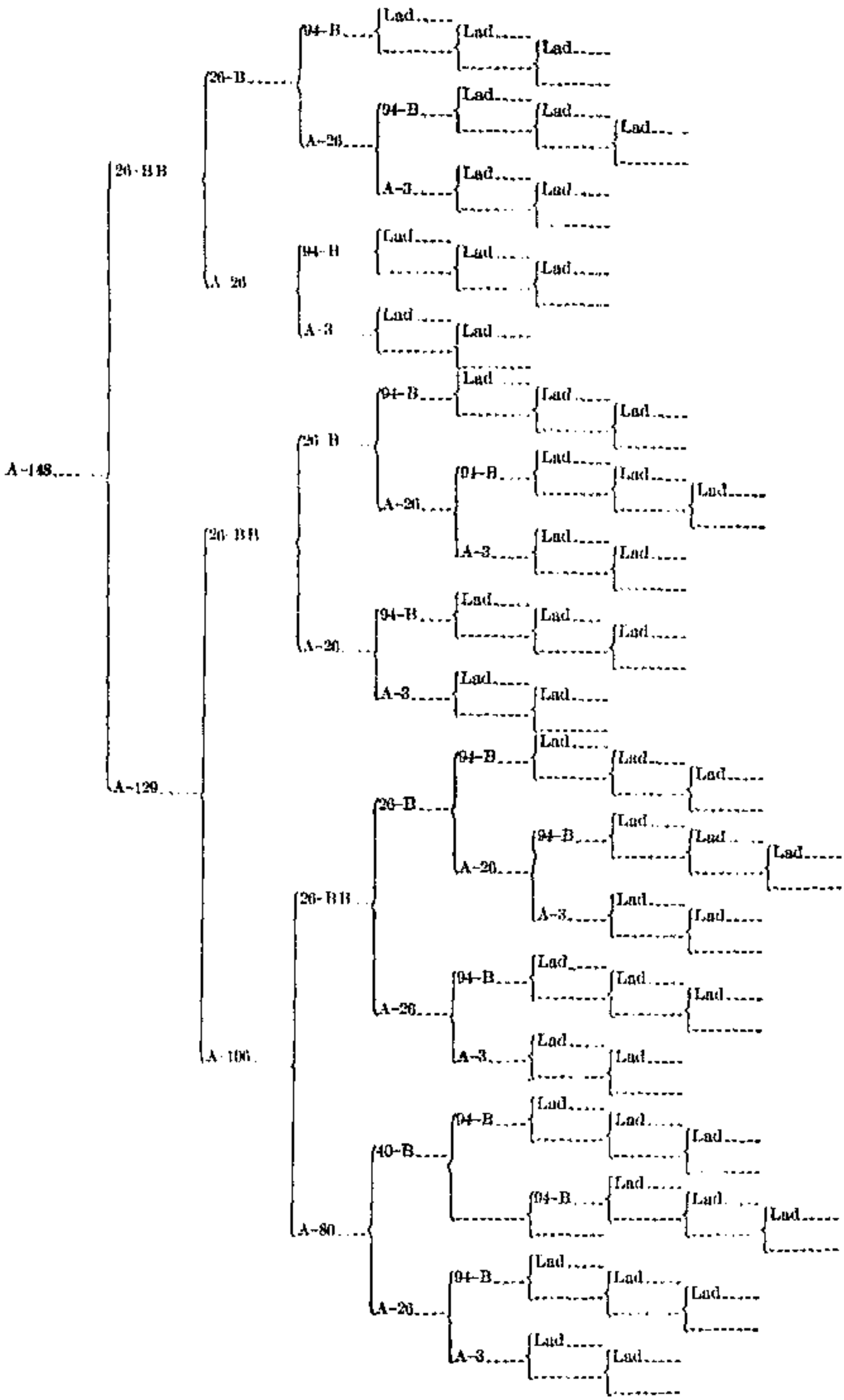
Example C is a simplified pedigree of five cows with an inbreeding coefficient of 32.8 percent. The dams of all five cows had inbreeding coefficients of 25.0 percent.

EXAMPLE D



Example D is a simplified pedigree of four cows that had inbreeding coefficients of 45.3 percent.

EXAMPLE E



Example E shows the pedigree of the cow A–148 that had an inbreeding coefficient of 64.6 percent. This was the highest in the group, and the inbreeding coefficient of 58.1 percent for her dam was next to the highest for the cows included in this study. Coefficients for other female ancestors of A–148 were 50.4 percent for cow A–106, 37.9 percent for cow A–80, 32.8 percent for cow A–26, and 25.0 percent for cow A–3.

Age and Number of Cows in the Inbred Groups

Thirty-four of the 71 cows in this study were under 5 years of age (average 3 years 10 months) and 37 were over 5 years (average 8 years 6 months) at the time of slaughter. In the outbred group there were 10 under 5 years (average 3 years 8 months) and 12 over 5 years (average 9 years 4 months). In the group with the lowest inbreeding coefficients (below 30), there were 6 cows under 5 years (average 4 years) and 9 cows over 5 years (average 8 years 9 months). The middle inbred group (coefficients between 30 and 49) contained 14 cows under 5 years (average 3 years 11 months) and 13 cows over 5 years (average 8 years). The highly inbred group (coefficients between 50 and 69) contained 4 cows under 5 years (average 3 years 6 months) and 3 cows over 5 years of age (average 6 years 3 months). The uniformity of distribution in number of cows with respect to age in the 4 groups indicates that age differences were not a serious disturbing factor in interpreting the effects of inbreeding in this study.

Weights and Measurements Used in Analysis

Thirty-one different weights or measurements for each animal were used in this analysis. They include 3 body measurements taken just prior to slaughter; live weights taken at 3 different periods of life; and 25 weights and measurements of organs and body parts obtained after slaughter.

Although 35 external body measurements were obtained prior to slaughter, in order to minimize detail only 3 (height at withers, width of hips, and length from withers to pinbone) were selected to represent the 3 body dimensions, height, width, and length. The live weights used were taken at 18 months of age, at approximately 3 months after first calving, and again when the animal was measured prior to slaughter. Udder capacity was determined by filling the secretory system with fluid and measuring the quantity held.

Records of milk and butterfat production also were used. Since most of the production records were made during the first lactation and commenced at ages ranging from 2 to 2½ years, those that were made at other ages were adjusted to the basis of the average age of first calving, which was 2 years 2 months and 10 days. The various items were divided into six groups as follows: (1) Those representing body weight or mass, (2) those which indicate skeletal size, (3) the internal organs, (4) the endocrine glands, (5) the udder, and (6) milk and butterfat production records. Average values were used as a basis for comparison.

PRESENTATION AND DISCUSSION OF RESULTS

The data have been tabulated in four groups (table 1), according to the intensity of inbreeding of the cows included in the study. Averages for each item of weight and measurement are given for the outbred group and for each of the three inbred groups. The average coefficient of inbreeding is shown in each case for the number of cows represented in each item of weight or measurement. Percentages, calculated on the basis of 100 percent for the outbred group, are given to show the changes in size of each item of weight or measurement as inbreeding was intensified.

Comparable data showing the relative rather than the actual magnitude of the various items of weight or measurement are given in table 2, in which the data are arranged in the same manner as in table 1. The values given represent the number of units of weight or measurement for each 100 pounds of empty body weight of the animal. "Empty body weight" is the difference between the live weight of the animal immediately before slaughter and the weight of the contents of the digestive tract. Several items given in table 1 were omitted from table 2 as they were not affected by empty body weight at slaughter. The number of animals representing some items in table 2 was smaller than in table 1 because empty body weight was not determined for all cows.

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TABLE 1.—*Effect of inbreeding on size of body and its parts, and on records of milk and butterfat production, expressed in actual units of weight or measurement*

Weight or measurement	Outbred group		Inbred groups with inbreeding coefficients of—						Relation of weight or measurement for each inbred group to that of the outbred group		
			10 to 29 percent		30 to 49 percent		50 to 69 percent				
	Cows	Average weight or measurement	Cows [1]	Average weight or measurement	Cows [1]	Average weight or measurement	Cows [1]	Average weight or measurement	First inbred group (10–29)	Second inbred group (30–49)	Third inbred group (50–69)
Body weight or mass:	*Number*	*Pounds*	*Number*	*Pounds*	*Number*	*Pounds*	*Number*	*Pounds*	*Percent*	*Percent*	*Percent*
Live weight at 18 months	15	863.00	15 (23.5)	765.00	27 (39.2)	771.00	7 (54.5)	744.00	88.6	89.3	86.2
Live weight about 3 months after 1st calf	18	1,030.00	14 (23.0)	987.00	26 (38.9)	970.00	7 (54.5)	935.00	95.8	94.2	90.8
Live weight at slaughter	22	1,238.00	15 (23.5)	1,167.00	27 (39.2)	1,139.00	7 (54.5)	1,104.00	94.3	92.0	89.2
Empty body weight	20	1,035.77	15 (23.5)	949.57	27 (39.2)	887.03	7 (54.5)	884.60	91.7	85.6	85.4
Weight of carcass	22	619.45	15 (23.5)	571.02	27 (39.2)	538.62	7 (54.5)	524.72	92.2	87.0	84.7
Average									92.5	89.6	87.3
Skeletal size:		*Centimeters*		*Centimeters*		*Centimeters*		*Centimeters*			
Height at withers	22	133.77	15 (23.5)	131.48	27 (39.2)	132.47	7 (54.5)	132.86	98.3	99.0	99.3
Width of hips	22	54.95	15 (23.5)	53.62	27 (39.2)	54.91	7 (54.5)	54.50	97.6	99.9	99.2
Length, withers to pinbones	20	141.85	14 (23.3)	138.46	27 (39.2)	139.53	7 (54.5)	141.46	97.6	98.4	99.7
Depth of thoracic cavity (maximum)	22	49.49	15 (23.5)	47.38	27 (39.2)	47.59	7 (54.5)	48.25	95.7	96.2	97.5
Width of thoracic cavity (7th rib)	22	35.37	15 (23.5)	35.17	27 (39.2)	34.83	7 (54.5)	34.50	99.4	98.5	97.5

See footnote at end of table

TABLE 1.—*Effect of inbreeding on size of body and its parts, and on records of milk and butterfat production, expressed in actual units of weight or measurement*—Continued

Weight or measurement	Outbred group		Inbred groups with inbreeding coefficients of—						Relation of weight or measurement for each inbred group to that of the outbred group		
			10 to 29 percent		30 to 49 percent		50 to 69 percent				
	Cows	Average weight or measurement	Cows [1]	Average weight or measurement	Cows [1]	Average weight or measurement	Cows [1]	Average weight or measurement	First inbred group (10–29)	Second inbred group (30–49)	Third inbred group (50–69)
	Number	*Pounds*	*Number*	*Pounds*	*Number*	*Pounds*	*Number*	*Pounds*	*Percent*	*Percent*	*Percent*
Length of thoracic cavity (maximum)	22	80. 82	15 (23. 5)	82. 13	27 (39. 2)	81. 62	7 (54. 5)	81. 64	101. 6	101. 0	101. 0
Average									98. 4	98. 8	99. 1
Internal organs:		*Pounds*		*Pounds*		*Pounds*		*Pounds*			
Weight of heart	21	4. 33	15 (23. 5)	4. 16	27 (39. 2)	3. 74	7 (54. 5)	3. 66	96. 1	86. 4	84. 5
Weight of lungs	21	8. 31	15 (23. 5)	9. 53	27 (39. 2)	9. 63	7 (54. 5)	9. 46	114. 7	115. 9	113. 8
Weight of liver	20	15. 01	15 (23. 5)	15. 44	27 (39. 2)	14. 77	7 (54. 5)	14. 31	102. 9	98. 4	95. 3
Weight of stomachs	21	36. 27	15 (23. 5)	35. 33	27 (39. 2)	34. 32	7 (54. 5)	33. 03	97. 4	94. 6	91. 1
		Grams		*Grams*		*Grams*		*Grams*			
Weight of brain	22	428. 5	15 (23. 5)	425. 5	27 (39. 2)	407. 8	7 (54. 5)	385. 3	99. 3	95. 2	89. 9
Weight of spleen	21	864. 2	15 (23. 5)	875. 3	27 (39. 2)	824. 2	7 (54. 5)	820. 2	101. 3	95. 4	94. 9
Weight of kidneys	22	1,246. 0	14 (23. 3)	1, 213. 2	26 (39. 2)	1, 180. 4	7 (54. 5)	1, 196. 1	97. 4	94. 7	96. 0
		Meters		*Meters*		*Meters*		*Meters*			
Length of intestines	21	58. 84	15 (23. 5)	58. 06	27 (39. 2)	57. 86	7 (54. 5)	60. 83	98. 7	98. 3	103. 4
Average									101. 0	97. 4	96. 1

Endocrine glands:		*Grams*		*Grams*		*Grams*		*Grams*			
Weight of pituitary	22	3. 59	15 (23. 5)	3. 47	26 (39. 3)	3. 31	7 (54. 5)	2. 88	96. 7	92. 2	80. 2
Weight of pineal	12	. 2517	11 (23. 7)	. 2473	18 (38. 9)	. 2494	4 (55. 4)	. 2500	98. 3	99. 1	99. 3
Weight of thyroid	20	34. 7	14 (24. 2)	38. 5	26 (38. 9)	35. 4	7 (54. 5)	46. 3	111. 0	102. 0	133. 4
Weight of parathyroids	11	. 1318	7 (25. 9)	. 1629	18 (40. 0)	. 1111	5 (55. 9)	. 0760	123. 6	84. 3	57. 7
Weight of pancreas	21	445. 5	14 (23. 0)	386. 4	27 (39. 2)	364. 1	7 (54. 5)	355. 0	86. 7	81. 7	79. 7
Weight of adrenals	22	28. 5	14 (23. 3)	30. 0	27 (39. 2)	29. 7	7 (54. 5)	28. 8	105. 3	104. 2	101. 1
Average									103. 6	93. 9	91. 9
Udder:											
Weight of udder (lactating)	9	*Pounds* 42. 16	7 (19. 8)	*Pounds* 31. 13	8 (35. 8)	*Pounds* 35. 33	3 (50. 7)	*Pounds* 22. 82	73. 8	83. 8	54. 1
Weight of udder (dry)	13	27. 83	8 (26. 7)	26. 48	18 (40. 3)	22. 54	3 (54. 9)	19. 23	95. 1	81. 0	69. 1
Average									84. 5	82. 4	61. 6
Capacity of udder (lactating)	4	54. 14	6 (18. 9)	52. 67	5 (36. 2)	57. 15	3 (50. 7)	38. 15	97. 3	105. 6	70. 5
Capacity of udder (dry)	9	38. 02	7 (26. 9)	30. 74	14 (41. 2)	32. 43	2 (53. 3)	47. 82	80. 9	85. 3	125. 8
Average									89. 1	95. 5	98. 2
Ratio of capacity to weight (lactating)	4	*Percent* 145. 97	6 (18. 9)	*Percent* 167. 72	5 (36. 2)	*Percent* 180. 74	3 (50. 7)	*Percent* 165. 95	114. 9	123. 8	113. 7
Ratio of capacity to weight (dry)	9	132. 14	7 (26. 9)	122. 92	14 (41. 2)	135. 29	2 (53. 3)	226. 72	93. 0	102. 4	171. 6
Average									104. 0	113. 1	142. 7
Production records:		*Pounds*		*Pounds*		*Pounds*		*Pounds*			
Milk	21	12, 306	15 (23. 5)	13, 202	24 (39. 2)	12, 635	6 (52. 8)	11, 343	107. 3	102. 7	92. 2
Butterfat	21	459	15 (23. 5)	466	24 (39. 2)	427	6 (52. 8)	379	101. 5	93. 0	82. 6
Average									104. 4	97. 9	87. 4

[1] Figures in parentheses show the average inbreeding coefficient of the cows represented.

TABLE 2.—*Effect of inbreeding on size of body and its parts, expressed in units of weight or measurement per 100 pounds of empty body weight*

Weight or measurement	Outbred group		Inbred groups with inbreeding coefficients of— 10 to 29 percent		30 to 49 percent		50 to 69 percent		Relation of weight or measurement for each inbred group to that of the outbred group		
	Cows	Average per 100 pounds empty body weight	Cows [1]	Average per 100 pounds empty body weight	Cows [1]	Average per 100 pounds empty body weight	Cows [1]	Average per 100 pounds empty body weight	First inbred group (10–29)	Second inbred group (30–49)	Third inbred group (50–69)
Body weight or mass:	*Number*	*Pounds*	*Number*	*Pounds*	*Number*	*Pounds*	*Number*	*Pounds*	*Percent*	*Percent*	*Percent*
Live weight at slaughter	20	121.09	15 (23.5)	123.20	27 (39.2)	128.61	7 (54.5)	124.85	101.7	106.2	103.1
Weight of carcass	20	61.00	15 (23.5)	60.10	27 (39.2)	60.59	7 (54.5)	59.46	98.5	99.3	97.5
Average									100.1	102.8	100.3
Skeletal size:		*Centimeters*		*Centimeters*		*Centimeters*		*Centimeters*			
Height at withers	20	13.02	15 (23.5)	13.98	27 (39.2)	15.07	7 (54.5)	15.15	107.4	115.7	116.4
Width of hips	20	5.35	15 (23.5)	5.68	27 (39.2)	6.23	7 (54.5)	6.20	106.2	116.4	115.9
Length, withers to pinbones	20	13.76	14 (23.3)	14.81	27 (39.2)	15.85	7 (54.5)	16.10	107.6	115.2	117.0
Depth of thoracic cavity (maximum)	20	4.79	15 (23.5)	5.05	27 (39.2)	5.41	7 (54.5)	6.34	105.4	112.9	132.4
Width of thoracic cavity (7th rib)	20	3.45	15 (23.5)	3.73	27 (39.2)	3.96	7 (54.5)	3.93	108.1	114.8	113.9
Length of thoracic cavity (maximum)	20	7.85	15 (23.5)	8.73	27 (39.2)	9.23	7 (54.5)	9.28	111.2	117.6	118.2
Average									107.7	115.4	119.0

Internal organs:		*Pounds*		*Pounds*		*Pounds*		*Pounds*			
Weight of heart	20	. 42	15 (23. 5)	. 44	27 (39. 2)	. 42	7 (54. 5)	. 41	104. 8	100. 0	97. 6
Weight of lungs	20	. 81	15 (23. 5)	1. 01	27 (39. 2)	1. 09	7 (54. 5)	1. 08	124. 7	134. 6	133. 3
Weight of liver	19	1. 46	15 (23. 5)	1. 63	27 (39. 2)	1. 67	7 (54. 5)	1. 63	111. 6	114. 4	111. 6
Weight of stomachs	19	3. 48	15 (23. 5)	3. 73	27 (39. 2)	3. 89	7 (54. 5)	3. 74	107. 2	111. 8	107. 5
		Grams		*Grams*		*Grams*		*Grams*			
Weight of brain	20	41. 74	15 (23. 5)	45. 24	27 (39. 2)	46. 41	7 (54. 5)	43. 81	108. 4	111. 2	105. 0
Weight of spleen	20	82. 69	15 (23. 5)	92. 71	27 (39. 2)	93. 05	7 (54. 5)	93. 18	112. 1	112. 5	112. 7
Weight of kidneys	20	120. 16	14 (23. 3)	127. 57	26 (39. 2)	133. 03	7 (54. 5)	135. 94	106. 2	110. 7	113. 1
		Meters		*Meters*		*Meters*		*Meters*			
Length of intestines	20	5. 76	15 (23. 5)	6. 17	27 (39. 2)	6. 59	7 (54. 5)	6. 93	107. 1	114. 4	120. 3
Average									110. 3	113. 7	112. 5
Endocrine glands:		*Grams*		*Grams*		*Grams*		*Grams*			
Weight of pituitary	20	. 35	15 (23. 5)	. 37	26 (39. 3)	. 37	7 (54. 5)	. 33	105. 7	105. 7	94. 3
Weight of pineal	12	. 0250	11 (23. 7)	. 0267	18 (38. 9)	. 0291	4 (55. 4)	. 0289	106. 8	116. 4	115. 6
Weight of thyroid	19	3. 35	14 (24. 2)	4. 00	26 (38. 9)	4. 01	7 (54. 5)	5. 31	119. 4	119. 7	158. 5
Weight of parathyroids	11	. 0130	7 (25. 9)	. 0178	18 (40. 0)	. 0123	5 (55. 9)	. 0086	136. 9	94. 6	66. 2
Weight of pancreas	20	42. 89	14 (23. 0)	41. 04	27 (39. 2)	41. 23	7 (54. 5)	40. 05	95. 7	96. 1	93. 4
Weight of adrenals	20	2. 68	14 (23. 3)	3. 15	27 (39. 2)	3. 34	7 (54. 5)	3. 24	117. 5	124. 6	120. 9
Average									113. 7	109. 5	108. 2
Udder:		*Pounds*		*Pounds*		*Pounds*		*Pounds*			
Weight of udder (lactating)	7	4. 46	7 (19. 8)	3. 24	8 (35. 8)	4. 19	3 (50. 7)	2. 51	72. 6	93. 9	56. 3
Weight of udder (dry)	13	2. 69	8 (26. 7)	2. 82	18 (40. 3)	2. 46	3 (54. 9)	2. 12	104. 8	91. 4	78. 8
Average									88. 7	92. 7	67. 6
Capacity of udder (lactating)	4	5. 20	6 (18. 9)	5. 56	5 (36. 2)	6. 85	3 (50. 7)	4. 15	106. 9	131. 7	79. 8
Capacity of udder (dry)	9	3. 61	7 (26. 9)	3. 21	14 (41. 2)	3. 52	2 (53. 3)	5. 28	88. 9	97. 5	146. 3
Average									97. 9	114. 6	113. 1

[1] Figures in parentheses show the average inbreeding coefficient for the cows represented.

EFFECT OF INBREEDING ON SIZE OF COW AND HER BODY PARTS

For the items representing body mass, a definite decline in the percentages based on actual units accompanied an increase in the coefficient of inbreeding (table 1). Averages of the percentages for the five items representing body mass for the three inbred groups are 92.5, 89.6, and 87.3, respectively, showing that as inbreeding became more intense the size of the animal decreased. On an average, the animals having the highest degree of inbreeding were nearly 13 percent below the outbred animals in size. This is somewhat less than the 20 percent decline in guinea pigs reported by Eaton (*3*), where inbreeding was carried on for many generations. In this connection it should be stated that the data on inbreeding of dairy cows were compiled entirely on the basis of coefficient of inbreeding without regard to the generation, despite the fact that in some cases high coefficients occurred in the early generations.

Empty body weight is a basic value representing body weight unaffected by "fill"; thus, it is significant that the downward trend in percentages was nearly the same for empty body weight as for the other items representing body weight. That is, the empty body weight was 85.4 percent as great in the group of cows having the highest inbreeding coefficients (50–69) as in the outbred group, whereas the average of all items representing body size was 87.3 percent as great. It is noteworthy also that the decline in weights taken after first calving is almost the same as the decline in weights taken at time of slaughter, which shows that the effect of inbreeding was essentially as great in early life as at the time of slaughter. The question of whether or not the inbred animals were in relatively poorer condition may be raised. It is difficult to obtain an accurate measure of the degree of flesh or fatness, but such differences did not appear to have been a seriously disturbing factor.

In view of the marked downward trend in percentages for body weight with intensified inbreeding, a tabulation was made to determine whether or not the period during which the cows in the various groups were present in the herd had any influence on their body size at time of slaughter. It was found that 11 of the outbred cows were slaughtered prior to the end of 1934 and 11 at later dates; in the first inbred group (10–29), 7 were slaughtered before and 8 after the end of 1934; in the second inbred group (30–49), 12 were slaughtered before and 15 after that date; and in the most highly inbred group (50–69), 2 were slaughtered before and 5 after the end of 1934. Therefore, in view of the fact that the outbred animals were so well distributed throughout the period of time covered by the experiment, there is no reason to believe that as a class they had any advantage over the inbred animals with respect to any changes in environmental conditions that may have occurred. Both the outbred and the inbred cows were kept in the same herd. Thus, if the inbred animals were smaller than the outbred animals, it would appear that the difference was the result of inbreeding rather than of any differences in environment.

The trends in percentages based on units of weight or measurement per 100 pounds of empty body weight may be expected to differ considerably from those based on actual units, as they have a somewhat different significance. In general, so long as the size of the body or of any of its parts declines or increases in the same proportion as the animal's empty body weight, the percentages showing the relative size (last 3 columns in table 2) will all be approximately 100. If an organ or part declines regularly with inbreeding to a greater relative degree than empty body weight, the percentages will be below 100 and will have a downward trend. Similarly, if the organs or body parts decline more slowly than empty body weight, remain stationary, or increase in size with increased intensity of inbreeding while the empty body weight declines, they will represent a higher proportion of the total animal structure; and the percentages will be above 100. Under these circumstances an upward trend in percentages will occur if the organ weights remain stationary or if their increases are progressive.

It has been noted that the downward trend in percentages based on actual units was nearly the same, on an average, for empty body weight as for the other items representing body size. However, the percentages based on units per 100 pounds of empty body weight were all near 100—the averages for the three inbred groups being 100.1, 102.8, and 100.3, respectively (table 2)—indicating again that live weight and weight of carcass declined in almost the same proportion as empty body weight.

Of the six items representing skeletal size, three are body dimensions (height, width, and length) measured before slaughter and three are dimensions of the thoracic cavity (depth, width, and length) obtained by measuring the dressed carcass. In the case of every item, the percentages based on actual units are all close to 100 and there is no significant trend with increase in inbreeding. The averages of the percentages for the six items are 98.4, 98.8, and 99.1, respectively, for the three inbred groups (table 1), which shows that inbreeding had no appreciable effect on skeletal size, as indicated by the measurements selected, regardless of whether they were external body measurements of the living animal or of the thoracic cavity obtained after slaughter. As explained previously, when any body part remains unchanged by inbreeding while the empty body weight declines, the percentages based on empty body weight that show proportional size are above 100 and show an upward trend. In this case, the averages of the percentages for the six measured items are 107.7, 115.4, and 119.0, respectively (table 2). The actual skeletal size of the animals was not affected to any appreciable extent by inbreeding, but the relation of size of body frame to mass was definitely increased.

For the internal organs the results were less consistent. Some of the organs increased and some decreased in size with inbreeding. The brain showed an actual decline of about 10 percent but became larger in relation to body mass. The heart (auricles attached) decreased in size in almost the same proportion as the body mass items (including empty body weight); consequently, the relative size of the heart remained essentially unchanged. It is not surprising that size of heart closely follows the body mass in view of the fact that the heart is related to functional demands and consequently to body mass since it serves all of the tissues of the body.

The actual weight of the lungs was substantially greater in the inbred groups than in the outbred group, but the weight did not change appreciably as the coefficient of inbreeding increased. The relative weight of lungs, however, was definitely greater in the inbred groups and showed a tendency to increase with intensity of inbreeding. The percentages were 124.7, 134.6, and 133.3, respectively, in the three inbred groups as compared with the outbred group (table 2).

The weight of liver remained more stable than some of the other organs. In the first inbred group the liver was slightly heavier than in the outbred group, but the weight decreased slightly as inbreeding became more intense. However, the weight of liver did not decline as rapidly as the net weight of the animal, with the result that the liver represented a considerably higher proportion of the total animal structure in all inbred groups than in the outbred group. Changes in the weight of spleen followed nearly the same course as the changes in the weight of liver.

There was a steady decline in weight of stomachs (total for rumen, reticulum, omasum, and abomasum) as the coefficient of inbreeding increased, but the decline did not keep pace with the decline in body mass. The stomachs, therefore, represented a higher proportion of the total body in the inbred groups, though there was no definite trend as intensity of inbreeding increased.

Length of intestines was not significantly affected by inbreeding. In two inbred groups the length was almost the same as in the outbred group, and in one inbred group it was slightly greater than in the outbred group. In relation to net or empty body weight, the length of intestines increased progressively with inbreeding to become 107.1, 114.4, and 120.3 percent, respectively, as compared with 100 percent for the outbred group (table 2).

Weight of kidneys was slightly lower in all of the inbred groups, though the weight did not decline appreciably as intensity of inbreeding increased. The kidneys were relatively larger in all of the inbred groups than in the outbred group, and the percentages based on empty body weight showed an upward trend (table 2).

In view of the mixed results for the eight items representing internal organs, too much significance should not be attached to averages. However, there was a very slight tendency for the organs to be smaller in the cows in the two most highly inbred groups, as indicated by percentages of 101.0, 97.4, and 96.1, respectively, for the three groups (table 1). In relation to total animal structure, however, the organs averaged about 12 percent greater in the inbred groups than in the outbred group, but there was no appreciable trend in percentages among the three inbred groups (table 2).

It has been implied (*7*) that inheritance for any given quality or function may depend to a very great extent on the inheritance of an endocrine balance. More and more attention, therefore, is being paid to the endocrine glands in studies of physiology and anatomy. The possible effect of intense inbreeding on the endocrine glands obviously is of much interest. The pituitary body is considered to be, in a sense, the control center of the endocrine system; and it directly affects various physiological functions such as growth, reproduction, and lactation. For this reason the possible effect of inbreeding on this gland is of particular interest. The weight of the pituitary body declined progressively as the intensity of inbreeding increased.

In the first two inbred groups, which include coefficients up to 49 percent, the decline coincided closely with the decline for live weight, but in the third or most highly inbred group the pituitary body was reduced in size to 80.2 percent of its size in the outbred group (table 1).

This is a greater reduction than that of live weight, empty body weight, weight of carcass, or weight of heart which, of all items discussed up to this point, have shown the most pronounced reduction. Pituitary weight not only showed the most marked reduction in actual weight, but it became smaller in relation to empty body weight in animals that were greatly reduced in body size. The reduction in size of pituitary body was greater than the reduction in milk production and slightly greater than the reduction in butterfat production.

Of course, it is not possible, without extensive assay work, to determine whether or not the functional activity of the pituitary body was reduced to the same degree as its weight. An accurate appraisal of the significance of the reduced size of pituitary with respect to reductions in body size and in milk and butterfat production is not possible in view of the marked increase in thyroid size in the highly inbred cows and the fact that the adrenals were essentially unaffected. The great variability in size of the endocrine glands suggests the possibility of some endocrine dysfunction or unbalance.

No appreciable change occurred in the actual weight of the pineal body as a result of inbreeding. This means, of course, that the pineal was somewhat heavier in relation to empty body weight in the inbred groups than in the outbred group.

The weight of thyroid was considerably greater in the inbred groups than in the outbred group. The thyroid was by far the largest in the most highly inbred group, but the increase in size was not entirely consistent with the increase in intensity of inbreeding. The thyroid was actually one-third larger in the most highly inbred group (50–69) than in the outbred group (table 1). In relation to empty body weight the thyroid increased greatly, although not entirely regularly with inbreeding, as the percentages of 119.4, 119.7, and 158.5 indicate (table 2).

The parathyroids were larger in the first inbred group than in the outbred group, but as inbreeding increased in intensity the weight of the parathyroids decreased with extreme rapidity to reach a minimum of 57.7 percent of the weight of parathyroids recorded for the outbred group (table 1). This decline was so much more rapid than the decline in empty body weight that the relative size also reached a minimum of 66.2 percent of the size in the outbred group (table 2).

The pancreas might with logic be included either with the internal organs or with the endocrine glands. It is included with the endocrine glands because it has been included in this group in previous studies. The pancreas appears to have undergone a marked reduction in size with inbreeding. The pancreas was small in all the inbred groups; and the reduction in weight was progressive, although the difference between the outbred group and the first inbred group was particularly striking. The fact that the pancreas was relatively smaller in all of the inbred groups than in the outbred group is indicated by percentages of 95.7, 96.1, and 93.4 (table 2). This is the only item so far discussed, except weight of carcass, for which the relative size was consistently lower in all inbred groups than in the outbred group.

The size of the adrenals apparently was not affected materially by inbreeding. There was a very slight decline in actual weight as inbreeding became more intense, but the weight was higher in every inbred group than in the outbred group. The adrenals represented a substantially greater proportion of the total animal structure in all of the inbred groups than in the outbred group.

Taken as a whole, the endocrine glands show a wide variety of changes. In actual weight the pineal body and adrenals underwent only slight changes, the thyroid showed a substantial increase, and the pituitary body, parathyroids, and pancreas were reduced in size to such an extent that they became not only actually smaller, but also smaller in relation to total animal structure, as the coefficient of inbreeding became greater. Here again group averages lose some of their meaning in view of the wide individual variations. However, averages of the percentages indicate that the endocrine glands became actually smaller in the higher inbred groups, although they were from 8 to 13 percent higher in relation to total animal structure in the inbred groups than in the outbred group.

One organ for which information was desired particularly was the udder. Unfortunately, this was the one for which it was most difficult to obtain comparable data because of the great changes that occur in the mammary glands as a result of changes in lactating activity. Not only was it necessary to obtain the data when cows were in various stages of lactation, but many were slaughtered when the udders were entirely inactive. The number of cows was not large enough to justify a classification on the basis of stage of lactation, but the cows were divided into two groups—those that were lactating and those that were dry at the time of slaughter. Data are available for 27 lactating and for 42 nonlactating udders.

The results indicate that the effect of inbreeding on the size of the udder was greater than on any of the other internal organs, endocrine glands, or other body parts—with the possible exception of the parathyroids. The lactating udders reached a weight in the most highly inbred group that was little more than half the udder weight in the outbred group. The reduction of weight in the dry udders was more regular and somewhat less extreme. On an average, the size of the udder reached a level in the most highly inbred group that was less than two-thirds the actual weight and approximately two-thirds the relative weight of the udder in the outbred group.

Capacity of the udder (cisterns, ducts, and secreting elements) was determined by measuring the amount of fluid it would hold. The possible effect of inbreeding on udder capacity is not evaluated easily. In the lactating udders the capacity seems to have been reduced in the highly inbred cows, whereas in the nonlactating udders it was low in the first two inbred groups, but increased to 125 percent in the third inbred group. On an average, the capacity seems to have been affected to only a limited extent by inbreeding and the results are inconsistent.

The relation of capacity to weight, that is, the number of pounds of fluid held for each pound of udder, is expressed in percentage. The percentage gives an idea of the porosity of the udder tissue. Porosity is affected to a considerable degree by the secreting activity of the gland, lactating udders usually having a higher capacity in relation to weight—other things being equal—than dry udders. The individual percentages for the cows in this study range from 61 to 252, which means that some udders held only little more than half their own weight of injected fluid, while others held 2½ times their weight. The percentage of capacity to weight was generally higher in the inbred than in the outbred cows, and the value tended to be progressively greater with the more intense inbreeding—especially in the dry cows.

The milk production records were very slightly higher in the first two inbred groups than in the outbred group but were lower in the most highly inbred group, which produced 92.2 percent as much milk as the outbred group. Butterfat production was almost the same in the first inbred group as in the outbred group but decreased regularly and markedly to 82.6 percent with increased inbreeding. The percentage of butterfat in the milk showed a decline with increased inbreeding which was more marked than the decline in milk production but less pronounced than the decline in total butterfat production.

Attention is called to the fact that, while this study is based on the animals used in the inbreeding experiments on which Woodward and Graves (*10*) have reported, the make-up of the various groups was different. This came about as a result of the fact that this study included only the animals for which detailed post mortem and anatomical data were available, and also the fact that only those cows were included which had at least 50 percent Holstein ancestry and less than 50 percent of the ancestry of any other breed. The results here reported, therefore, are based on a considerably smaller number of animals. They are for that reason particularly significant, as they so closely confirm the general findings of the other study with regard to milk and butterfat production.

The difference between the results of the two analyses is almost entirely one of degree. The total decline from the outbred cows to those having inbreeding coefficients of 50 or above is 7.8 percent for milk and 17.4 for butterfat in this study as compared with 12.2 and 20.6 percent, respectively, for the study based on the larger number of cows.

There are a number of observations about the results obtained that seem worthy of discussion and speculation, although conclusions are not warranted. Comment already has been made on the possible significance of the fact that the pituitary body—which supposedly is a highly important factor in controlling body growth and the development and functioning of the mammary glands—was only 80.2 percent as large in the highly inbred as in the outbred cows, while body mass and udder development were among the items showing marked decline as inbreeding was intensified. Milk production was not proportionately reduced with inbreeding, but butterfat production declined to almost the same extent as weight of pituitary.

The higher capacities of udders in the highly inbred cows may indicate differences in the structure of the mammary tissues and may have offset to some extent the marked reduction in udder weight. There is something of a suggestion here that the more porous type of tissue may be conducive to greater production per unit of udder size. On the other hand, there is a possibility that capacity may have been affected somewhat by changes in the technique of measuring udder capacity, which occurred in the course of the study. It is likely, also, that the irregularity of results can be attributed in part to the small number of animals represented, both in the lactating and in the nonlactating groups.

Anatomy of the Grade Holstein Cows in This Experiment as Compared With That of Registered Holstein Cows

The foregoing tabulations and discussions have shown the most noteworthy differences in body size and anatomy between outbred cows and those representing various intensities of inbreeding. All cows in this study were grade Holsteins—that is, cows with 50 percent or more of Holstein ancestry and with less than 50 percent of the ancestry of any other breed. Such a discussion would be lacking in completeness if it did not show the extent to which these grade animals differed in size and anatomy from a population of registered Holstein cows.

In a previous study of body form, anatomy, and producing capacity of 593 cows (*6*), data were included for 75 registered Holsteins from the Beltsville herd. The averages for these registered Holsteins were used as a basis for comparison with the grade Holsteins in the present study. Averages for items showing size of body and body parts, and percentages showing the relation of size in the outbred and the inbred grade Holsteins to that in registered Holsteins, are given in table 3.

The chief point of interest in this comparison is the degree of difference between the outbred grade Holsteins and the registered Holsteins, since the changes in size of body and body parts that occurred with inbreeding already have been discussed.

In body mass the outbred grade Holsteins were about 6 percent smaller than the registered Holsteins. They differed even less, on an average, in measurements of skeletal size.

The differences were much less consistent for the items listed under "internal organs" and the average difference was greater than for either body mass or skeletal size. The brain was of almost the same size in the outbred grade Holsteins as in the registered Holsteins, but all of the other items were smaller. The greatest differences occurred in connection with weights of kidneys, heart, and lungs.

The endocrine glands also showed some marked individual differences and averaged 12.2 percent smaller in the outbred grade Holsteins. All of the endocrine glands were smaller in the outbred grade Holsteins; the greatest difference being in weight of adrenals which averaged about 27 percent smaller.

The trends in average percentages for the various groups of items are similar to those shown in table 1. In table 3, however, the percentages for the three inbred groups are all smaller because they were calculated on the basis of the larger registered Holsteins rather than on the smaller outbred grade Holsteins.

Approximately one-third of the cows in the outbred group were sired by registered Holstein bulls and were out of grade Jersey or grade Guernsey cows. It would seem logical to assume that if they had had a higher percentage of Holstein instead of Jersey or Guernsey ancestry the cows in the outbred group would have been larger, on an average, and the effects of inbreeding would have been more pronounced.

TABLE 3.—*Anatomy of outbred and inbred grade Holstein cows compared with that of registered Holstein cows*

Weight or measurement	Average weight or measurement					Relation of weight or measurement for the outbred group and the inbred groups to that of the registered group			
	Registered Holstein group [1]	Outbred group	Inbred groups having inbreeding coefficients of— 10 to 29 percent	30 to 49 percent	50 to 69 percent	Outbred group	First inbred group (10–29)	Second inbred group (30–49)	Third inbred group (50–69)
Body weight or mass:	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Percent*	*Percent*	*Percent*	*Percent*
Live weight at slaughter	1, 339	1, 238	1, 167	1, 139	1, 104	92. 5	87. 2	85. 1	82. 4
Empty body weight	1, 090. 30	1, 035. 77	949. 57	887. 03	884. 60	95. 0	87. 1	81. 4	81. 1
Weight of carcass	655. 90	619. 45	571. 02	538. 62	524. 72	94. 4	87. 1	82. 1	80. 0
Average						94. 0	87. 1	82. 9	81. 2
Skeletal size:	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*				
Height at withers	137. 58	133. 77	131. 48	132. 47	132. 86	97. 2	95. 6	96. 3	96. 6
Width of hips	57. 05	54. 95	53. 62	54. 91	54. 50	96. 3	94. 0	96. 2	95. 5
Length, withers to pinbones	144. 31	141. 85	138. 46	139. 53	141. 46	98. 3	95. 9	96. 7	98. 0
Depth of thoracic cavity (maximum)	50. 48	49. 49	47. 38	47. 59	48. 25	98. 0	93. 9	94. 3	95. 6
Width of thoracic cavity (7th rib)	38. 33	35. 37	35. 17	34. 83	34. 50	92. 2	91. 8	90. 9	90. 0
Length of thoracic cavity (maximum)	82. 07	80. 82	82. 13	81. 62	81. 64	98. 5	100. 1	99. 5	99. 5
Average						96. 8	95. 2	95. 7	95. 9

See footnote at end of table

TABLE 3.—*Anatomy of outbred and inbred grade Holstein cows compared with that of registered Holstein cows*—Continued

Weight or measurement	Average weight or measurement					Relation of weight or measurement for the outbred group and the inbred groups to that of the registered group			
	Registered Holstein group [1]	Outbred group	Inbred groups having inbreeding coefficients of—			Outbred group	First inbred group (10–29)	Second inbred group (30–49)	Third inbred group (50–69)
			10 to 29 percent	30 to 49 percent	50 to 69 percent				
Internal organs:	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Percent*	*Percent*	*Percent*	*Percent*
Weight of heart	4. 90	4. 33	4. 16	3. 74	3. 66	88. 4	84. 9	76. 3	74. 7
Weight of lungs	9. 44	8. 31	9. 53	9. 63	9. 46	88. 0	101. 0	102. 0	100. 2
Weight of liver	15. 62	15. 01	15. 44	14. 77	14. 31	96. 1	98. 8	94. 6	91. 6
Weight of stomachs	38. 57	36. 27	35. 33	34. 32	33. 03	94. 0	91. 6	89. 0	85. 6
	Grams	*Grams*	*Grams*	*Grams*	*Grams*				
Weight of brain	431. 5	428. 5	425. 5	407. 8	385. 3	99. 3	98. 6	94. 5	89. 3
Weight of spleen	945. 4	864. 2	875. 3	824. 2	820. 2	91. 4	92. 6	87. 2	86. 7
Weight of kidneys	1, 429. 4	1, 246. 0	1, 213. 2	1, 180. 4	1, 196. 1	87. 2	84. 9	82. 6	83. 7
	Meters	*Meters*	*Meters*	*Meters*	*Meters*				
Length of intestines	60. 87	58. 84	58. 06	57. 86	60. 83	96. 7	95. 4	95. 1	99. 9
Average						92. 6	93. 5	90. 2	89. 0

Endocrine glands:	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*				
Weight of pituitary	3. 84	3. 59	3. 47	3. 31	2. 88	93. 5	90. 4	86. 2	75. 0
Weight of pineal	. 28	. 2517	. 2473	. 2494	. 2500	89. 9	88. 3	89. 1	89. 3
Weight of thyroid	39. 6	34. 7	38. 5	35. 4	46. 3	87. 6	97. 2	89. 4	117. 0
Weight of parathyroids	. 14	. 1318	. 1629	. 1111	. 0760	94. 1	116. 4	79. 4	54. 3
Weight of pancreas	503. 7	445. 5	386. 4	364. 1	355. 0	88. 4	76. 7	72. 3	70. 5
Weight of adrenals	39. 0	28. 5	30. 0	29. 7	28. 8	73. 1	76. 9	76. 2	73. 8
Average						87. 8	91. 0	82. 1	80. 0

[1] Averages for the registered Holstein group were based on data obtained from 75 cows slaughtered at Beltsville prior to June 30, 1936. See Literature Cited (*6*).

Statistical Analysis of Correlation Between Coefficients of Inbreeding and Form, Anatomy, and Production

Correlation coefficients were calculated between the degree of inbreeding and measures of body size, organ and gland size, and producing ability in the data from 49 cows with various degrees of inbreeding. The results of this analysis, as shown in table 4, indicate definite relationships in relatively few of the items studied.

Table 4.—*Correlation between intensity of inbreeding and form, anatomy, and production* [1]

Weight or measurement	Number of cows	Coefficient of correlation
Body weight or mass:		
Live weight at 18 months	49	−0.0449±0.0962
Live weight about 3 months after 1st calf	47	−.1174± .0970
Live weight at slaughter	49	.0000± .0000
Empty body weight	49	−.1945± .0927
Weight of carcass	49	−.1843± .0931
Skeletal size:		
Height at withers	49	+.0393± .0962
Width of hips	49	+.1278± .0948
Length, withers to pinbones	48	+.1464± .0953
Depth of thoracic cavity (maximum)	49	+.0446± .0962
Width of thoracic cavity (7th rib)	49	−.1039± .0953
Length of thoracic cavity (maximum)	49	−.0924± .0955
Internal organs:		
Weight of heart	49	−.2886± .0883
Weight of lungs	49	−.0420± .0962
Weight of liver	49	−.3217± .0864
Weight of stomachs	49	−.1625± .0938
Weight of brain	49	−.2740± .0891
Weight of spleen	49	−.0642± .0960
Weight of kidneys	47	−.0261± .0983
Length of intestines	49	+.0961± .0955
Endocrine glands:		
Weight of pituitary	48	−.1461± .0953
Weight of pineal	33	−.0488± .1171
Weight of thyroid	47	−.0889± .0976
Weight of parathyroids	32	−.2165± .1136
Weight of pancreas	48	−.1635± .0948
Weight of adrenals	48	−.0256± .0973
Udder:		
Weight of udder (lactating)	18	−.1217± .1566
Weight of udder (dry)	29	−.2066± .1199
Capacity of udder (lactating)	14	−.3249± .1612
Capacity of udder (dry)	23	+.2409± .1326
Ratio of capacity to weight (lactating)	14	.0000± .0000
Ratio of capacity to weight (dry)	23	+.4113± .1168
Production:		
Milk	45	−.2610± .0937
Butterfat	45	−.3394± .0890
Percentage of butterfat in milk	45	−.3141± .0906

[1] The outbred cows are not included in these correlation studies.

The correlations showed that measures of producing ability were more definitely affected by intensive inbreeding than measures of body size or organ and gland size. The negative correlation coefficient showing decreases in milk production with increases in degree of inbreeding was slightly below the level of significance. However, the negative correlation coefficients with butterfat percentage in the milk and with total butterfat production were significant. Probably these coefficients underestimate the adverse effects of inbreeding. For example, the cow with the highest coefficient of inbreeding (A–148) had such a small udder and so little milk secretion that no attempt was made to milk her during the 30 days between the time of first calving and the time of slaughter.

Most of the correlation coefficients between the degree of inbreeding and measures of body or skeletal size and the size of internal organs and glands were negative but not significantly so. The correlations with some of the measures of skeletal size, udder capacity, and the ratio of capacity to weight were positive. The only significant or nearly significant negative relationships were between degree of inbreeding and the weights of the brain, heart, and liver. No significant relationships were found between intensity of inbreeding and the size of any of the endocrine glands.

Variability in Size of Body and Its Parts in Outbred and Inbred Cows

According to Wright (*11*) "the principal effect of inbreeding . . . is in automatically making homozygous some combinations of the factors which were heterozygous in the original random-bred stock." His statement implies a resulting increase in uniformity in the inbred stock. This was borne out by the analytical studies of Eaton (*3*), which showed for guinea pigs that the degree of variability in organ size was about 15 percent lower in the inbred animals than in the control group.

Coefficients of variation were determined for the various items representing size of the body and its parts. for the outbred cows and for those representing different intensities (coefficients) of inbreeding. The results are given in table 5.

TABLE 5.—*Variability in size of body and its parts in outbred and inbred cows, expressed as coefficients of variation*

Weight or measurement	Outbred group		Inbred groups with inbreeding coefficients of—					
			10 to 29 percent		30 to 49 percent		50 to 69 percent	
	Cows	Coefficient of variation	Cows	Coefficient of variation	Cows	Coefficient of variation	Cows	Coefficient of variation
Body weight or mass:	*Number*		*Number*		*Number*		*Number*	
Live weight at 18 months	15	9. 50	15	10. 02	27	6. 70	7	11. 34
Live weight about 3 months after 1st calf	18	10. 73	14	8. 82	26	8. 57	7	8. 53
Live weight at slaughter	22	8. 79	15	9. 46	27	9. 49	7	10. 29
Empty body weight	20	7. 58	15	10. 77	27	9. 83	7	10. 51
Weight of carcass	22	11. 19	15	12. 11	27	13. 16	7	10. 79
Average		9. 56		10. 24		9. 55		10. 29
Skeletal size:								
Height at withers	22	2. 50	15	2. 59	27	1. 84	7	1. 97
Width of hips	22	3. 60	15	5. 80	27	4. 17	7	4. 68
Length, withers to pinbones	20	2. 80	14	3. 23	27	3. 36	7	4. 15
Depth of thoracic cavity (maximum)	22	3. 53	15	5. 53	27	4. 39	7	5. 52
Width of thoracic cavity (7th rib)	22	4. 26	15	5. 51	27	3. 88	7	4. 88
Length of thoracic cavity (maximum)	22	2. 77	15	3. 85	27	4. 19	7	5. 36
Average		3. 24		4. 42		3. 64		4. 43

Internal organs:								
Weight of heart	21	11. 18	15	12. 12	27	11. 50	7	11. 54
Weight of lungs	21	15. 42	15	21. 17	27	17. 61	7	12. 33
Weight of liver	20	15. 10	15	19. 38	27	12. 76	7	8. 70
Weight of stomachs	21	13. 90	15	19. 16	27	16. 77	7	12. 48
Weight of brain	22	7. 94	15	9. 07	27	10. 35	7	7. 01
Weight of spleen	21	17. 11	15	11. 97.	27	18. 75	7	22. 08
Weight of kidneys	22	15. 37	14	15. 90	26	15. 43	7	14. 23
Length of intestines	21	8. 55	15	10. 84	27	5. 58	7	8. 97
Average	--------	13. 08	--------	14. 95	--------	13. 59	--------	12. 17
Endocrine glands:								
Weight of pituitary	22	19. 98	15	19. 57	26	20. 14	7	18. 54
Weight of pineal	12	29. 87	11	31. 90	18	29. 45	4	14. 97
Weight of thyroid	20	23. 52	14	30. 24	26	21. 32	7	25. 04
Weight of parathyroids	11	38. 21	7	61. 57	18	37. 67	5	23. 91
Weight of pancreas	21	14. 24	14	19. 08	27	15. 11	7	15. 48
Weight of adrenals	22	29. 36	14	24. 21	27	26. 23	7	22. 23
Average	--------	25. 86	--------	31. 10	--------	24. 99	--------	20. 03
Udder:								
Weight of udder (lactating)	9	58. 83	7	30. 27	8	44. 62	3	7. 07
Weight of udder (dry)	13	31. 26.	8	28. 77	18	40. 85	3	17. 26
Capacity of udder (lactating)	4	33. 79	6	24. 16	5	27. 98	3	37. 21
Capacity of udder (dry)	9	53. 55	7	40. 31	14	53. 29	2	5. 38
Ratio of capacity to weight (lactating)	4	30. 89	6	28. 73	5	28. 47	3	34. 52
Ratio of capacity to weight (dry)	9	51. 77	7	32. 43	14	33. 52	2	9. 04
Average	--------	43. 35	--------	30. 78	--------	38. 12	--------	18. 41
Production:								
Milk	21	20. 15	15	16. 44	24	19. 33	6	18. 08
Butterfat	21	20. 96	15	15. 89	24	19. 97	6	17. 40
Percentage of butterfat in milk	21	7. 97	15	6. 72	24	5. 15	6	9. 03
Average	--------	16. 36	--------	13. 02	--------	14. 82	--------	14. 84

Individual items differ greatly with regard to variability in size. For example, the coefficients of variation for height at withers for the outbred group and the three inbred groups were 2.50, 2.59, 1.84, and 1.97, respectively, while the corresponding coefficients for weight of parathyroids were 38.21, 61.57, 37.67, and 23.91. Probably there are at least two reasons for the high variability in the latter case: (1) The extreme smallness of the glands makes accurate dissection difficult, and (2) a smaller number of animals is represented. In addition, differences in the amount of accessory parathyroid tissue might also affect variability. On the other hand, weight of adrenals, which is obtained with comparatively great uniformity and accuracy, is represented by essentially the same number of animals as height at withers and has the comparatively high coefficients of 29.36, 24.21, 26.23, and 22.23, respectively, for the same four groups.

It is regrettable that some of the items—particularly those pertaining to weight and capacity of udder—are represented by so few animals. In such instances the coefficients of variation between various small groups may be largely a matter of chance. Furthermore, there is a tendency for coefficients calculated for very small groups to be somewhat lower than those calculated for larger groups. The reasons for dividing the data on udders into those that were lactating and those that were dry should require no further explanation.

Variability among the items representing body mass was relatively uniform. There was little difference among the items. There was a very slight tendency for variability to be greater in the inbred groups than in the outbred group, but no significant trend can be detected—either in individual items or in group averages of variation coefficients—as the degree of inbreeding increased.

Among the items selected to represent skeletal size, the variation was very low in every case—much lower than in any other group of items. There was a slight tendency, also, for variability to be greater in the inbred groups than in the outbred group. The variation is slightly greater in the measurements of thoracic cavity than in the measurements of height, width, and length in the living animal.

Among the eight items representing internal organs, the variation was much less uniform. On an average, weights of spleen and of lungs showed the greatest variation; length of intestines the least. Variation was high also for weights of stomachs and kidneys. On the whole, variation was substantially greater for the internal organs than for the items of body size, and much greater than for the items representing skeletal size. There was a tendency for the variation to be lower in the most highly inbred group than in the outbred group and the less intensely inbred groups, but the variation was slightly higher—on an average and in some of the individual items—for the groups with inbreeding coefficients of 10 to 29 percent and 30 to 49 percent than in the outbred group. Weight of heart and weight of kidneys showed little change with inbreeding. Weight of liver fluctuated but declined markedly. The reason for the lower coefficient of variation for weight of spleen in the group of cows with inbreeding coefficients of 10 to 29 percent is not known.

The coefficients of variation were almost twice as great on an average for the endocrine glands as for "internal organs." For the endocrine glands as a whole, the group of cows with inbreeding coefficients of 10 to 29 percent showed greater variation than the outbred group, but as inbreeding increased the coefficient of variation declined progressively to a point considerably below the average for the outbred group. In this respect the averages follow much the same pattern as those for the "internal organ" items, although the trend is magnified considerably by the high coefficients for parathyroids. The items represented by the smaller number of cows tend to show the highest coefficients of variation, yet even those items with close to maximum numbers showed greater variability in most cases than items in any of the groups previously discussed.

Although the weight of pituitary was definitely reduced by inbreeding it did not become markedly less variable. The thyroid, on the other hand, was much larger in the highly inbred group than in the outbred group, and its variability was not greatly changed. The weights of pineal and of adrenals, which showed little change in weight as a result of inbreeding, were considerably less variable in the highly inbred group than in the outbred group or in the less highly inbred groups.

In view of the small number of cows represented and the great variation in stage of lactation—even among lactating cows—a very high degree of variation for items pertaining to weight and capacity of udder is to be expected and little significance can be attached to any but the most marked differences in results. Weight was more variable in the lactating udders except in the most highly inbred group. Capacity of udder was much more variable in the dry cows, except in the most highly inbred group. Trends in variability with increase in intensity of inbreeding are not definite for weight or capacity of udder. However, both were less variable in the low inbred (10–29) group than in the outbred or in the middle inbred (30–49) group, and lower on an average in the highly inbred (50–69) group than in any of the other groups.

Milk and butterfat production varied to essentially the same extent in each group of cows, that is, inbreeding affected variability in these items to only a slight extent. Percentage of butterfat varied much less than milk and butterfat production, and there was no clear-cut trend with inbreeding. In fact, the highest variation was in the most highly inbred group.

A comparison of the averages for the various groups of items shows that there is a tendency—particularly for internal organs and endocrine glands—for the low inbred group to be more variable than the outbred group but for variability to decline as inbreeding was further intensified. Combined averages for all of the 34 items in table 5 show that the coefficient of variation was only 86.95 percent as high for all inbred groups and only 70.82 percent as high for the most highly inbred group as for the outbred group. Corresponding averages for the 31 items pertaining to the animals' anatomy—omitting the 3 items relating to producing capacity—are 86.96 and 69.16 percent.

These results are in close accord with those reported by Eaton (*3*), which show that the degree of variability was about 15 percent lower in the inbred animals than in the controls.

General Discussion

It is not to be expected that the results of this study will be identical for body size and production with those reported by Woodward and

Graves (*10*) because this study includes only cows having at least 50 percent of Holstein ancestry and less than 50 percent of the ancestry of any other breed, and also because this study includes only the cows for which post-mortem data were available. In view of the smaller numbers of cows represented in this study, it is surprising that the results agree so well.

This study shows that inbreeding affected live weight at 18 months almost as much as it affected live weight at time of slaughter, and empty body weight and carcass weight. Live weight at 18 months was about 14 percent lower for the highly inbred group than for the outbred group. The study by Woodward and Graves (*10*) indicated that the highly inbred animals were about 25 percent below the weight of the outbred animals at birth and up to 6 months, about 17 percent below from 12 to 24 months, and that they tended to catch up with advance in age.

In discussing the effect of inbreeding on body size and production records, the possible influence of a breed factor must not be overlooked. About one-third of the cows in the outbred group were sired by registered Holstein bulls and were out of grade Jersey or grade Guernsey cows. The use of Holstein sires undoubtedly tended to increase the size of the offspring, particularly in the early generations, and to counteract the effects that inbreeding may have had in reducing body size. Similarly, the Holstein characteristics for higher milk production and lower butterfat tests may have minimized the tendency for inbreeding to reduce the milk production but accelerated the decline in butterfat test. Any improvements that may have occurred in feeding practices probably had no significant effect on the results, in view of the fact that the cows in all except the most highly inbred groups were fairly well distributed, with respect to time, throughout the long period covered by the experiment.

Another point that cannot be evaluated but should not be overlooked is the fact that essentially all of the inbreeding traces to the one sire, Johan Woodcrest Lad 11th 103987.

It has been noted that skeletal size was not appreciably affected by inbreeding and that variability for all of the various skeletal dimensions was very much lower than for any other group of items. As previously stated, Waters (*8*) concluded some 30 years ago that the impulse was stronger for skeletal growth than for increase in weight. On the other hand, a difference between weight and skeletal growth probably should be expected in view of the fact that from birth to maturity cattle seldom, if ever, double their height at withers, whereas body weight increases some 15 to 20 times during the same period. This basis of reasoning, however, does not explain why width of hips, which normally increases to nearly 3½ times the measurement at birth (*5*), was not reduced to a greater extent.

The marked decline in body weight with inbreeding, while skeletal dimensions remained practically unchanged, raises a number of questions. There is reason to believe that the inbred animals were as well fed as the outbred ones. That being the case, what was the cause of the decline in body size? Apparently it was not the result of deficiency in size of the digestive organs as the size of stomachs declined less than body size, the length of intestines remained virtually unchanged, and both became larger in relation to empty body weight as inbreeding increased. Perhaps it was due to some inherited characteristic that resulted in less efficient utilization of feed. A look at the changes in size of endocrine glands shows that the thyroid was markedly heavier and the pancreas was much lighter in the highly inbred cows than in the outbred ones. In view of the thyroid's control over rate of oxidation and the digestive functions of the pancreatic fluid, the changes noted in these glands possibly may be of some significance.

The question might also be raised as to whether the increased size of the thyroid might indicate a goitrous condition. The marked decrease in size of pituitary is, of course, suggestive of a decrease in elaboration of the growth-stimulating hormone, though it is not clear why this would not affect skeletal growth as well as increase in body weight. Again there comes to mind the question: Why was there not a reduction in the adrenals and thyroids if the pituitaries had been deficient. There is much in the data to suggest the occurrence of a dysfunction in the endocrine system resulting from inbreeding which may have been at least partly responsible for the smaller body size in inbred cows. Definite proof, however, is lacking as assays of the endocrine glands were not made.

The results obtained with cows were in fairly close agreement with those reported by Eaton for guinea pigs in a number of respects. For example, there was a substantial decline in body weight with inbreeding, the organs in the smaller animals were larger in proportion to body weight, and skeletal size was affected to a smaller degree than body weight. Also, the weights of pituitary and heart declined in much the same manner as live weight, and the length of intestines and weight of spleen were not affected materially. Trends for other organs were not in such close agreement. In both species the variability in organ size was high in the case of weight of lungs, thyroid, and adrenals and low for intestine length. Eaton showed that variability, on an average, was about 15 percent lower in the inbred animals than in controls. Averages of the coefficients of variation for all of the items listed in table 5 are about 13 percent lower for all three inbred groups than for the outbred group and about 29 percent lower for the most highly inbred group (50–69) than for the outbred group.

SUMMARY AND CONCLUSIONS

Seventy-one grade Holstein cows, for which measurements of body size, anatomy, and producing capacity were available, were divided into 4 groups on the basis of the intensities (coefficients) of inbreeding. An outbred group contained 22 cows. The 49 inbred cows included 27 with inbreeding coefficients of 29 percent or less, 15 with coefficients between 30 and 49 percent inclusive, and 7 with coefficients of 50 percent or above. Analyses of available data were made to determine the effect of inbreeding on (1) the magnitude, and (2) the variability of more than 30 items representing measurements of body weight and skeletal size, size of organs and endocrine glands, and milk and butterfat production.

Inbreeding resulted in a decline of approximately 15 percent in body weight or mass, but did not affect skeletal size to any significant extent.

Some of the internal organs—notably the weight of heart—were reduced in the most intensely inbred cows, almost to the same extent as body mass. Weight of brain and weight of empty stomachs were reduced about 10 percent. Weight of lungs was definitely greater in the inbred cows and length of intestines was only slightly affected.

The endocrine glands, on an average, were reduced in size. Greatest reductions were in weights of parathyroids, pituitary, and pancreas; no significant change occurred in weights of pineal or adrenals: and the heaviest thyroids were found in the most intensely inbred group.

Weight of udder was greatly reduced in the more intensely inbred cows, but changes in udder capacity were not consistent. However, the relation of capacity to weight (porosity) of udder increased with inbreeding. Milk production was substantially lowered (7.8 percent) in the highly inbred cows, and butterfat production showed an even greater decrease (17.4 percent).

It is of interest that the pituitary body, which supposedly is closely tied up with the physiology of growth and lactation, declined in weight to 80.2 percent in the most highly inbred group: that milk and butterfat production declined to 92.2 and 82.6 percent, respectively; and that the items representing body mass declined to 87.3 percent of the values represented by the outbred group. Weight of udder decreased to an even greater extent (to nearly 60 percent), but this may have been compensated for to some extent in the matter of producing ability, by a greater degree of porosity in the mammary tissue which is indicated by the high relation of capacity to weight of udder in the more highly inbred groups. The different effects of inbreeding on size of various endocrine glands (pituitary, thyroid, and adrenals) suggest the possibility that a lack of endocrine balance might have existed.

It would seem logical to assume that, if the outbred cows had had a higher percentage of Holstein instead of Jersey and Guernsey ancestry, some of these effects of inbreeding would have been more pronounced.

As inbreeding increased and the size of the cows became smaller, the organs and body parts, on an average, came to represent a larger proportion of the total animal structure. They did not decline as much as did empty body weight. To just what extent this tendency can be attributed to inbreeding cannot be determined accurately as it occurs to some degree in most cases when cows are grouped on the basis of live weight. Most notable exceptions were weights of parathyroids, pancreas, and the weight and capacity of the udder. These glands were reduced in size relatively more than empty body weight.

The outbred grade Holstein cows included in this study were only slightly smaller in weight and skeletal size than 75 registered Holstein cows slaughtered at Beltsville in studies of conformation and anatomy in relation to producing capacity, but their internal organs and especially their endocrine glands differed to a greater extent. Percentages showing the relation of outbred grade cows to registered cows average 94.0 for body weight or mass, 96.8 for skeletal size, 92.6 for internal organs, and 87.8 for endocrine glands. Size was smaller in the outbred grade cows than in the registered cows for every item compared.

Correlation coefficients showed that producing ability was more adversely affected by intensive inbreeding than measures of body or skeletal size and internal organs or gland size, although most of the items under these headings indicated some decrease in size with intensity of inbreeding.

Variability, expressed as coefficients of variation, differed greatly for the various items. For example, the coefficients of variation for weight of adrenals were approximately 10 times as great as those for height at withers, both in the outbred group and in the three inbred groups. Coefficients for some of the other endocrine glands and for weight and capacity of udder were even higher than those for weight of adrenals.

Inbreeding apparently did not decrease variability in body mass or skeletal dimensions; in fact, there is some indication that variability increased slightly for some of these items as inbreeding became more intense. Inbreeding did not substantially reduce variability in the internal organs except that the average was lower in the most highly inbred group than in the outbred or the other two inbred groups. The spleen was most variable in the highly inbred group. In the endocrine gland items variability was nearly twice as high as in the internal organ items, and the average for the most highly inbred group was less than for any other group. Individual items differed greatly in variability.

The high variability in items pertaining to weight and capacity of udder is probably due in large measure to differences in stage of lactation at slaughter and to the small numbers of cows represented in each group. Weight of udder was least variable in the most highly inbred group. The same was true for capacity of dry udders but not for capacity of lactating udders.

Variability in milk and butterfat production or in percentage of butterfat did not decrease significantly with inbreeding.

Changes in variability with intensity of inbreeding also differed greatly for individual items. The body mass and skeletal size items were not greatly affected. Among the internal organs, weight of heart, weight of kidneys, and length of intestines showed little change while weight of liver declined markedly.

Among the endocrine glands, variability in weights of pituitary, thyroid, and pancreas was not significantly affected by inbreeding despite the fact that the pituitary was reduced and the thyroid was increased in weight. Weights of pineal, adrenals, and parathyroids were definitely less variable in the highly inbred group despite the fact that the actual weights of pineal and adrenals were not appreciably affected.

Weight of udder showed a very much lowered variability in the most highly inbred group.

In a number of cases there was a decline in variability within the three inbred groups, but little if any when the inbred groups were compared with the outbred group. This resulted from the tendency for variability to be high in the group of cows having inbreeding coefficients ranging from 10 to 29 percent.

Combined averages for all of the 34 items studied show that the coefficient of variation was approximately 13 percent less for all inbred groups, and approximately 29 percent less for the most highly inbred group than for the outbred group.

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