A GENETIC STUDY OF THE HEREFORD CATTLE AS BRED BY ROBERT H. HAZLETT

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1. Introduction

Most of the modern breeders have borrowed their methods from predecessors in the field of animal improvement. It seems, therefore, that it would be of value to study the methods used in the development of some of the most successful herds, and attempt to express in terms of modern genetics, what these methods have accomplished. The dissemination of the methods which have given the most satisfactory results may add much to the wide-spread improvement of livestock.

The general principle in livestock breeding that "like begets like" has been known to some practically as far back as records of domestic herds are known.

Just how early shepherds and herdsmen came to a realization of the great fact of heredity for the conscious molding of animal forms and functions toward their needs is unknown. Fortunately, livestock breeders did not have to wait for the development of a science of breeding to make improvement in the wild types which they domesticated.

Jones, 1921, (7) states that the improvement of livestock by controlling the parentage undoubtedly goes beyond the time of Prince Mehenwetre of Egypt, who reigned about 2100 B. C. In 1919 a chamber, previously overlooked, in the tomb of this prince, was discovered a census which disclosed that he owned 835 long-horn cattle, 224 polled cattle, 750 donkeys, 974 sheep, and 2,234 goats. Apparently the Egyptians at this early date were fairly well versed in the art of animal breeding, as one of several models found in the tomb showed the difference between the cattle which they had improved and those unimproved.

From about 1800 B. C. comes the story of Jacob and Laban as recorded in the 30th chapter of Genesis. Laban, it is said, engaged Jacob to

manage his flocks of sheep and goats and as his hire was to receive all the spotted, striped, black or ringstreaked born in the flock. To increase his wage, Jacob mated the females in the flock with males that were spotted, striped, black or ringstreaked.

Among the early peoples who took great pride in their breeding operations were the Arabs. Jones, 1921, (7). It is known that about 1635 B. C. Shiek Salaman owned five famous mares from which most of the fine Arabian horses have descended. The early Arabs fully realized the great advantages they enjoyed in the superiority of their horses, and thus enshrouded their breeding operations in an atmosphere of mystery, so as to guard against the dissemination of the methods and thus retain for themselves a monopoly of the art.

At a somewhat later date we find the Romans taking great pride in their horses and even later the French and the English promoting the improvement of horses so that their armies might be better equipped.

The development of modern breeding, however, dates from 1760 A. D. when Robert Bakewell assumed the management of the estate on which both his father and grandfather had resided at Dishley Grange, in Leicestershire, England. He became known as the "Father of Livestock Husbandry" through his achievements as a breeder and improver of Shire horses, Longhorn cattle, and Leicester sheep. He gave more careful and serious study to livestock breeding and improvement than anyone who had preceeded him and established certain principles and methods of breeding which became very popular in England and paved the way for the development of most of our modern breeds of livestock.

According to Vaughan, 1931, (11), Bakewell's success seems to revolve about the practice of mating close relatives. He inbred

extensively and demonstrated that inbreeding accompanied by careful selection is a great power for good in livestock improvement.

It was not until the latter part of the century--1865, when Gregor Mendel, an Austrian monk, experimenting with peas discovered some definite principles of heredity, that a scientific basis for animal breeding was known. The Mendelian principles were ignored, however, until Correns of Germany, DeVries of Holland, and Tschermak of Austria, working independently, re-discovered the Mendelian principles and established them among men of science. The Mendelian principles may generally be accepted as the regular mode of inheritance of all characteristics in all organisms.

With accurate knowledge of heredity much new interest in the field of breeding was inspired. Extensive research in the fields of histology, cytology, physiology and other related sciences have added much additional information to that supplied by Mendel. Rather extensive experimental breeding, carried on primarily with smaller forms of life because of the time element involved, has added materially to the practical application of Mendelian principles.

The application of statistical methods to the Mendelian theory of closebreeding and crossbreeding has given a definite measuring stick for interpreting and evaluating the methods used in the development of the modern breeds and herds of livestock.

The herd selected for this study was that developed by the late Robert H. Hazlett of ElDorado, Kansas, whose achievements as a Hereford breeder, based on the exhibition record, was probably unexcelled by any contemporary in America.

The main objects of this study were: first, to find what part

inbreeding has played in the development of the Hazlett herd of Herefords; second, to see whether the herd was developed as a somewhat homogeneous unit of related animals or whether there was a tendency for the herd to split into definite families or groups; third, to find which animals were most widely used in the founding of the herd; fourth, to see which sires have contributed most to the herd up to and including 1936.

II. REVIEW OF LITERATURE

A. The Duchess Family of Shorthorns as Bred by Thomas Bates

Several breeds or parts of breeds of livestock have been analyzed by similar methods as are being used in this study. Wright and McPhee, 1923, (16), have analyzed the Duchess Family of Shorthorns as bred by Thomas Bates. This is, within the knowledge of this writer, the only single herd, or flock, to be so analyzed. Thus, for obvious reasons, it should be of value to review briefly the history of the Bates herd and the results obtained by Wright in his genetic analysis of it.

The herd started with the purchase of Duchess I, by Bates, from Charles Colling. Duchess I was a descendant of a Duchess cow purchased by Charles Colling in 1784. She was highly related to Favorite 252. Bates developed a Duchess family from Duchess I. Up to the time of his death in 1849, he had bred 63 cows in the family which he named Duchess 2 to Duchess 64. Forty-five males are recorded as dropped by Duchess cows. The family was not a prolific one. They won, however, an extraordinary reputation in both England and America. After Bates' death, a line of Duchesses was maintained without outcrossing. These became the aristocrats of the cattle world. Their lack of fertility, instead of being a detriment, enhanced the value of the family due to scarcity. The climax came in a sale at New York Mills, New York in 1873. The "pure" line of Duchesses had become extinct in England and all in America had come into the hands of one man. There was international competition for the "pure" Duchesses. One cow sold for $40,600. The average for the 11 Duchess cows was $21,705; that for three bulls $7,866.

Wright used complete pedigrees in his study of the herd, and traced

them all to the beginning of the Coates' herd books. It should be noted here that Thomas Bates started with Colling-bred stock which was already about 40 per cent inbred. This means they were 40 per cent less heterozygous than the original Shorthorns. Through the practice of closemating he maintained substantially the same level of inbreeding through a period of about 40 years or eight generations. The relationship of his herd to the bull, Favorite, starting at 76 per cent, gradually fell through the eight generations to 57 per cent. These figures can be compared to a coefficient of 50 per cent between random bred brothers and sisters, or parent and offspring. Thus, for eight generations, Bates maintained in his herd a closer resemblance to Favorite than exists between parent and offspring in random bred stock. Bates pursued a steady policy of maintaining a relationship of nearly 60 per cent between the animals he mated. He used bulls, whether his own or other breeding, which averaged about 40 per cent inbred.

A striking feature of his actual practices is their uniformity throughout his whole career. He did not inbreed at the closest possible rate for a few generations and then make violent outcrosses. Neither did he concentrate the blood of one bull for a few generations and then turn to a wholly different line.

The outcrosses which were used occasionally, to restore vigor and add new blood, were themselves inbred, and most of them bore a rather high genetic relationship to Duchess or Favorite. So it is not a surprising result to find that Bates maintained a strain for 40 years after the death of Favorite, in which there was a distinctly closer relationship to the latter and hence presumably a closer resemblance than between ordinary parent and offspring, or brother and sister.

Before leaving the Bates herd it is important to mention that selection is accredited with having played a most indispensable part in the improvement program followed by Bates.

B. BRIEF HISTORY OF THE HEREFORD BREED

The ancestorial home of the Hereford breed is the country of Hereford, located on the western border and a little below the middle of England. This little county of Hereford only thirty-eight miles long and thirty-five miles wide, is bounded on the west by Wales and on the north by Shropshire. The section adjoining Wales is quite hilly, but the majority of the land is gently rolling with wide flat valleys. The small farms, eighty-four per cent of which are less than ten acres in size, are well managed and superior grazing generally prevails. Although Herefordshire is the chief apple producing area in England, it is celebrated throughout all Britain for its grass and cattle, and upon animal husbandry most of its agriculture depends.

The lack of sufficiently complete and accurate records and the prevalence of several rather conflicting opinions leaves the exact origin of the Hereford breed somewhat obscure. In 1788 William Marshall, a well known English judge of cattle, expressed his belief that the Hereford may be regarded as the first breed in England. Sanders, 1914, (10), Youatt, T. Duckham, and others maintain that the Hereford has descended from the aboriginal cattle. The original cattle of that locality as well as the cattle of the neighboring counties of Devon and Sussex were solid reds with wide-spread horns. From whence has come the white face, now characteristic of the Hereford breed, no one can be sure. The white face may have come from one or more of the three or four sources suggested by various authors. It is definitely known that Hereford color varied considerably with respect to the white markings during the early history of the breed. According to Vaughan, 1931, (11), one explanation for the white face is that a red bull with a white face and rather wide horns was

brought into Herefordshire from Yorkshire sometime between 1750 and 1760. Some of the early authorities have explained that the color is the result of the mating of the white cattle of Wales on the red cattle of Herefordshire. Other writers emphasize the importance of a bull calf with a white face dropped about the middle of the eighteenth century in the herd of one of the Tullys of Huntington which later sired many white faced calves. Most authors agree that there was an importation of some red-bodied, white-faced cattle from Holland prior to 1771. These cattle were well accepted in England, and it is certain that they left their impression on the native cattle.

The first noted breeders of Hereford cattle were Benjamin Tomkins, William Galliers, the Tully family, the Skyrme family, and John Haywood. These first breeders made considerable progress in improving the beef qualities of their cattle but added little, if any, uniformity to the breed with respect to type and color. Of these early breeders considered fathers of the Hereford breed, seniority is accorded to Benjamin Tomkins, according to Sanders, 1914, (10). The Tomkins family maintained a valuable "breed" for at least a century. They paid very little attention to color; form and flesh were the objects sought, and by resort to inbreeding, the desired qualities were ultimately well established.

John Price of Ryall (1776-1843), who secured his foundation stock from the Tomkins herd, produced breeding cattle which were an important source in the improvement of many herds in Herefordshire. Like the Tomkins family, as well as many other early breeders, Price was unable to secure bulls of sufficient quality outside his own herd. Therefore, for nearly forty years, he produced his own sires. Some contemporary

breeders insisted that closebreeding as practiced by Tomkins and Price was injurious, but records of their sales indicate that prices which they received were among the highest paid for cattle of any breed.

After John Price, John and William Hewer were the next to obtain positions of eminence for their contribution to Hereford improvement. To them goes most of the credit for fixing the modern type of the breed in color markings, form and quality. The Hewers were located in Glocestershire adjoining Herefordshire on the southeast. They established the red bodies with white face and white marking and improved the scale and weight. They also selected for improved quality and symmetry. It is known that they practiced inbreeding quite extensively but were careful to preserve constitution and vigor. According to Sanders, 1914, (10), the Hewers were said to have maintained five different families or strains within their herd, and by so doing were able to breed a closed herd with no ill effects. The fact that their cattle were considered superior in quality in and about Herefordshire and that they rented many bulls to other breeders, accounts for the wide influence their herd had upon the breed as a whole.

Thomas Jefferies the younger (1796-1843), although contributing less than some former breeders to the establishment of Hereford characteristics, according to Plum, 1920, (8), is accredited with having obtained remarkable success through the crossing of the Hereford stock developed by his family and that produced by John Hewer.

There were many other men who contributed to the founding of the breed, but these reviewed herein are among the most important, and their methods shed about as much light as is available on breeding practices

responsible for the founding of Herefords.

The importation by Henry Clay in 1817 of a young bull, a cow and a heifer to his home at Lexington, Kentucky, is considered by Sanders, 1914, (10), to be the first introduction of Herefords to America.

Subsequent minor importations were made following that of Henry Clay. The first major importation was made by W. H. Sotham who, in 1840, brought twenty-one cows and heifers and a two-year-old bull to Albany, New York, in partnership with Erastus Corning, Jr.

In 1852 John Humphries and Thomas Aston came over from England and settled at Elyria, Ohio. They brought a number of Herefords with them and made a second importation in 1860. Several other small importations were made to the New England states. By this time there was quite a nucleus of Hereford interest and activity in Maine and in Ohio from which came the foundation stock that established herds in many sections of the central and middle west.

During the Civil War period from 1860 to 1864, very few cattle were imported; however, in the seventies and early eighties a real start was made in the breeding of Hereford cattle in the United States. According to Vaughan, 1931, (11), there were probably not more than two hundred head of Hereford cattle imported to the United States prior to 1880, while 3,550 head were imported between 1880-1889. Much credit for the great expansion of Herefords at this time should go to T. L. Miller who established his herd in 1872 at Beecher, Illinois, and exhibited them quite extensively. His influence did much to popularize the Hereford among the cattlemen in the western range territory.

By this time the general need for united action was felt by many of the Hereford breeders and consequently a call was issued for a meeting

to be held in Chicago, January 22, 1881. From this gathering the American Hereford Cattle Breeders' Association was evolved. Due to a ruling adopted in 1886 by the Association imposing a fee of $100 for the registration of an imported animal, there were no cattle imported between 1886 and 1893. According to Anderson, 1932, (1), no importations have been made since 1918.

It should be of value here to discuss briefly a few American herds which have made major contributions to the popularity and excellence now enjoyed by Herefords in the United States. Such a discussion certainly should include the herd of Frederick William Stone which was established in 1860 at Guelph, Ontario, Canada. According to Sanders, 1914, (10), there was scarcely a herd established in the Northern United States in the seventies or eighties that did not owe something to the Stone herd. His foundation stock was purchased principally from the herds of Lord Berwick and Lord Bateman of England. G. S. Burleigh bought cattle from Stone at the time he was founding his herd in the state of Iowa. Sir Charles was one of the most important bulls produced on this Ontario farm. A number of his sons headed herds in the United States. When Sir Charles was five years old he was sold to T. L. Miller of Beecher, Illinois, who already had a good many cattle by him. Thus, the blood was passed on to the western range.

One of the earliest introductions in the state of Michigan was that made in 1866 by Governor W. W. Crapo of Flint, who started some experiments with Shorthorn, Devon and Herefords, for the purpose of determining to his own satisfaction which breed was most worthy. After giving the three breeds the same feed and care for 12 years, he decided in favor of the Herefords. He was convinced that for farmers in general

Herefords were more profitable than the others because they were more hardy, less liable to disease and better feeders and grazers as well as better killers. According to Hazelton, 1935, (5), the herd contains about 150 breeding cows and is still being increased in size. Most of the important bulls used in this herd trace to Anxiety 4th.

At this time the breed needed resourceful leadership, and this was found in T. L. Miller who established his herd at Beecher, Illinois, in 1872 and became the leading advocate of the breed in this country. His original cattle came from the herds in and around Elyria, Ohio. At the same time he bought Sir Charles from Stone of Canada for $1,000. Up to this time few Herefords had found their way into the range country and the majority of those were grade bulls. The possibilities of the Southwest for cattle growing were just then beginning to be realized, railways were being pushed into the range country and cattle were selling for prices theretofore undreamed of. Not satisfied with the best he could buy from the existing Canadian and American herds, Miller imported 114 head in 1880, and 108 head in 1883. Among these imported were some of the most noted show animals in England. In order to secure a fair and adequate hearing for the "White-faces" he established the Breeders' Journal which he published monthly from 1880 to 1887.

The center of Hereford activity had now been transferred from Elyria, Ohio, to Beecher, Illinois. One of the many men who saw the T. L. Miller Hereford exhibit at the World's Fair Centennial Exposition at Philadelphia in 1876 and later became a breeder, was C. M. Culbertson, a retired Chicago packer who bought five head that were among the Philadelphia exhibit and moved them to his 2,300 acre tract of land near Newman, Illinois. This purchase made in 1877, together

with several other purchases made later from the same herd, accredit Mr. Miller with furnishing the first cows to the Culbertson herd. Culbertson imported thirteen head in 1879, and in 1880 imported over one hundred of the choicest quality and breeding. Included in his first importation was the bull Anxiety 2238, which was selected from the herd of T. J. Carwardine of Stocktonburg, England. Ansiety was a sensation at livestock shows both in England and in the United States, having been first at the English Royal in 1877, and was undefeated in the United States in 1879 and 1880. Unfortunately, he died after his second year of showing in America. He left only one crop of twelve calves. In 1883 Culbertson imported the noted sire, The Grove 3d. 2490. In Culbertson's herd was mingled the blood of Anxiety, Lord Wilton, and The Grove3d.These three sires, according to Hazelton, 1935, (5), did more than any other three to improve American Herefords. Many great animals were produced in the Culbertson herd, but Hazelton, 1935, (5), suggests that even greater ones may have been produced had there been more concentration and less mixing of blood. Attention should be called here to the fact that Anxiety 2238 was got by Longhorns and that his two greatest sons, Anxiety 3d and Anxiety 4th, and his greatest daughter, Pretty Face, were all out of cows sired by Longhorns.

Three other firms who made important contributions around the later part of the nineteenth century were Thomas Clark, Earl and Stuart, and Fowler and Van Natta. Thomas Clark started breeding Herefords at Elyria, Ohio, in the early seventies. He imported Anxiety 3d in 1880 and assisted Earl and Stuart in making one of the most notable importations ever made to the United States. Earl and Stuart of Lafayette, Indiana, in 1882 imported one hundred twenty-five very good cattle, including two

outstanding sons of Lord Wilton, and also the bull Garfield 7015 which sired all the famous Earls of Shadeland. Fowler and Van Natta, later Van Natta and Son, formed a partnership and laid the foundation of their herd at Fowler, Indiana, in 1878, with females secured from J. L. Miller.

We come now to the most important breeding herd in America up to this time. The foundation of the Gudgell and Simpson herd, at Independence, Missouri, was laid in 1877 by Charles Gudgell who bought for his brother James R. Gudgell three cows, four two-year-old heifers, and a bull from the herd of F. W. Stone, Guelph, Ontario. In 1878 a second heifer and the imported bull, Governor 4th 1293, which had been used two or three years in the Stone herd. About twelve young bulls were also purchased and sold at auction in Kansas City. This was the first public sale of registered Hereford cattle ever held west of the Mississippi River. The Gudgell herd was the first in the state of Missouri and the second herd of Herefords west of the Mississippi. A business partnership was formed with T. A. Simpson in 1880, and immediately they imported sixty head, including one bull and 59 heifers, cows, and calves. A second importation by the Gudgell and Simpson firm was made in 1881. Among the 100 head comprising this importation were 25 bulls which were sent to a Colorado ranch, also the bulls Anxiety 4th 9904, and North Pole 8946. The former, a son of old Anxiety, was purchased from T. J. Carwardine, and the latter from Aaron Rogers. Animals from both of these herds had been conspicuous in English shows. A third importation of about 100 head, most of which were females, was made in 1882. Practically all the females purchased up to that date had been added to the breeding herd at Independence.

Inasmuch as Anxiety 4th and North Pole have figured so greatly in

the development of the Gudgell-Simpson herd, it might be well to deal with them a bit more thoroughly. Anxiety 4th was the result of inbreeding. Both his sire and dam were sired by Longhorns and out of cows sired by De Cote 2243, and both his sire and dam trace to great-grandams sired by Counsellor 2264. In other words, the sire and dam of Anxiety 4th had over 75 per cent of blood in common, being more than three-fourths brother and sister. Anxiety 4th is described in literature as low set, blocky, and thick with heavy bone. His outstanding characteristic seems to have been his thick, heavy hindquarters. His greatest weakness, according to most writers, was his heart-girth. North Pole came from a herd known for their size and great constitution. As an individual he was larger than Anxiety 4th and somewhat longer in his legs. He was very deep in his heart, but not so good in the thighs. He never proved a success as a sire of bulls, but his heifers were very acceptable and crossed well with Anxiety 4th and his sons.

At the outset inbreeding was avoided in this herd, the evident intention being to mate sons of the Anxiety line on daughters of the North Pole line and vice versa, but this could not continue long without close mating. Since early American Hereford breeders did not favor the practice of inbreeding, several outcrosses were tried. All of these resulted in lowering rather than raising the excellence of the herd, so it was decided to concentrate the blood of Anxiety 4th. Perhaps this decision was made partially because Anxiety 4th himself was the product of inbreeding.

Very little new blood was introduced into the Gudgell and Simpson herd after the last importation. Most of the females were bred in the herd, and were the descendants of the original imported cows, and

Anxiety 4th and North Pole. Some of the outstanding sires produced in the herd were Don Carlos 33734, Lamplighter 51834, Beau Brummel 51817, Beau Donald 58996, Beau President 171349, Domino 264259, and Prince Domino 499611.

The superiority of the Gudgell and Simpson herd and the popularity which it enjoyed can partially be appreciated by the fact that in 1930 Beau Brummel 51817 maintained a coefficient of relationship of nearly 25 per cent to the entire Hereford breed--Willham, 1937, (12). Willham's figures show that Anxiety 4th 9904 was eighteen and five-tenths per cent related to the breed in 1930. Further evidence of the acceptance of the Gudgell and Simpson bred cattle was shown at their dispersion sale in 1916 when 175 head sold at an average price of $544.

Even after the breed had become well established in England, efforts to establish a Hereford herd book were met with some difficulty due to the unwillingness of breeders to divulge their breeding methods, and to the controversies arising from attempts to standardize the breed characteristics. The first volume, however, appeared in 1846 as the private enterprise of T. C. Eyton, of Shropshire.

To T. L. Miller is due the credit for the establishment of the American Hereford Record. He began his compilation of the first volume in 1877. It was off the press in 1880 and by 1882 a second volume containing 6,419 entries was printed.

The growth of the pure bred Hereford business in America is indicated in the following table which gives, at five year intervals, the entries from 1897 to 1937, and the transfers from 1907 to 1937.

TABLE I

Year	Entries	Transfers
1897	7,800	--
1902	20,000	--
1907	29,008	21,350
1912	24,660	17,635
1917	70,202	70,369
1922	108,430	69,800
1927	88,875	60,140
1932	89,209	48,134
1937	134,679	95,338

Soon after the World War there developed, in the Texas Panhandle, a demand for "straight bred" Herefords. Breeders defined "straight bred" as any animal in which all the top lines of its pedigree traced to Anxiety 4th, or North Pole. This movement was responsible for the further concentration of the blood of the Gudgell and Simpson herd which itself was the product of many years inbreeding.

The herds reviewed thus far include many of the families which were instrumental in the development of the American Hereford, and afford a fair estimate of the genetic background upon which our more recent herds were built. With the exception of the Robert H. Hazlett herd, which furnishes the basis of this study and a discussion of which is now at hand, it will not be possible here to deal further with other breeders.

C. A Brief History of the Hereford Herd as Bred by Robert H. Hazlett

Among the several men who have carried on the Gudgell and Simpson breeding is Robert H. Hazlett of El Dorado, Kansas. His interest in Herefords was aroused when T. L. Miller, C. M. Culbertson, and others were trying to introduce them in Illinois through the State Fair. What attracted his attention, especially, was the fact that the State Board of Agriculture refused to make classification for Herefords. He believed these men were not getting fair treatment, and the fact that his sympathies were with them in their fight, undoubtedly, had something to do with his decision to buy Herefords.

When he moved from Illinois to Kansas in 1885, there was a small herd of Herefords near El Dorado owned by H. H. Grover. Having been raised on an ordinary farm in Illinois, where there were only a few milk cows, he knew little about cattle of any breed, but often went out to see this little herd. Their markings and general appearance appealed to him and strengthened the sympathetic interest he already had in their favor. When he learned that Mr. Grover was offering to sell the herd, he incidentally met him and bought the herd--sixteen in all--that same afternoon. This was in February, 1898. About the first of May they were moved to his farm which he later called "Hazford Place."

Of the sixteen head, fourteen were cows and heifers, the majority of which were too young to breed. There were two bull calves, both sired by Wild Beau 56099, a full brother to Wild Tom, the bull that made the Cross herd famous. Wild Beau was sired by Beau Real, by Anxiety 4th. The dam of one of these calves, Major Beau Real, was Lou 2d, then in the herd. Lou 2d was sired by Stone Mason, by Beau Real ~~by~~

by Anxiety 4th. This made a strong concentration of Anxiety 4th blood in the calf, Major Beau Real.

Within a short time after getting the herd, Mr. Hazlett became a member of the American Hereford Cattle Breeders' Association, and began attending Fairs, and other Live Stock Shows; and became particulary interested in good Herefords, pedigrees, blood lines, etc. It may be mentioned incidentally that he never missed an annual meeting of the stockholders of this Association from the time he became a member until his death in 1936.

Having Lou 2d, the dam of Major Beau Real, in the herd, he bought another bull--a good individual, Bernadotte 2d--soon after getting the herd. For two years, more or less, he used the bulls, Major Beau Real, bred by Mr. Grover, and Bernadotte 2d, bred by Gudgell and Simpson. Bernadotte 2d, except as to this grandsire, was of close Anxiety 4th breeding.

By this time he had become quite interested and enthusiastic in the matter of breeding, but as he had never made a study of the subject, and had little thought of the science of breeding, he was naturally influenced largely by what many older breeders said. He thought it would not be safe to continue such close line breeding further; that it was necessary to have an out-cross. The statement was frequently made that Gudgell and Simpson were in a dilemna because they could not safely continue close breeding.

With this in mind, he bought, at a sale in Kansas City in 1903, a young bull (a very good individual) that was sixth in class at the American Royal in 1902. He was a half brother to a many times grand champion. At the American Royal the next year, Mr. Hazlett won fourth place

with him. He bought and tried two others, straight out-crosses (good individuals, and of very popular breeding) all with the same disappointing results. From all the heifers sired by the three bulls, only one was kept in the herd.

In the meantime, he had done some investigating and thinking on the subject, or science of breeding. The results from such close breeding, as he had followed before trying the experiments with out-crosses, had been very satisfactory. He had a greater percent of good, outstanding calves. With this experience, he decided to go back to the Anxiety blood lines and use, as far as possible, nothing but sons of Beau Brummel for the immediate future, and follow that line of breeding indefinitely unless he learned, from experience, that close breeding would injure or destroy the usefulness of the herd.

In his Private Herd Catalogue, Hazlett, 1925, (6), shows that he used after that, Beau Brummel 10th, Beau Beauty, Printer and Beau Santos, all good sons of Beau Brummel. Following these sons of Beau Brummel, he used Caldo 2d by Printer; Beau Baltimore by Beau Beauty; Paragon 12th, a very close Anxiety 4th bred bull; Publican, by Paladin, by Lamplighter, by Don Carlos. As Beau Brummel was by Don Carlos, all the herd bulls he has used, except Major Beau Real, trace to Don Carlos. From conversations with Mr. Gudgell, he formed the conclusion that Don Carlos has not received his share of credit for the excellence of the Gudgell and Simpson herd.

He felt that the matter of selection was at least as important as blood lines, whether a herd was composed of close bred cows, or cows promiscuously bred. Through the years he disposed of cows and heifers, in the yards for beef because of some defects or weaknesses in conformation,

quality or character that should not be perpetuated. It was a fundamental with him that no animal of any line of breeding, of either sex, having any serious fault or weakness in conformation, quality, or breed character, should be used for breeding purposes in a purebred herd.

Before his first crop of calves were dropped he resolved that he would never sell a bull calf at less than $100 which at that time seemed a good price. In order that he might be able to sell his bulls for that sum or more, he kept as bulls only the better ones, castrating quite a large per cent every year. From the beginning, all those that he did not believe would give good results as sires, wherever they might go, whether as range bulls or herd bulls, were sent to market. This practice was continued to the end, believing it was not only good business, but the right thing for the good of the breed. He, for many years, culled the heifers very freely, retaining only those he considered the good ones to put in the herd or to sell for breeding.

The value of Mr. Hazlett's system of breeding and rigid selection has been passed on by most every prominent Hereford judge in America. He started showing at major fairs and shows about 1915, and every breeder who entered the show ring during the last 20 years realized at once that Hazlett Herefords were to be reckoned with. Since 1915 the herd has won 757 firsts; 418 seconds; 294 thirds, and 208 championships in the largest and strongest shows on this continent. Five times they won the ten-head award at the American Royal. At the International,Chicago, four bulls bred and showed by Mr. Hazlett were grand champions, Bocaldo 6th in 1916, Bocaldo Tone in 1926, Zato Rupert in 1933, and Hazford Rupert 81st in 1936. The 1936 International was his last,

and the same year a Hazlett cow, Bonita Zato, was named grand champion female. Anon, 1937, (2)

In the Hereford Register of Merit there are four bulls produced at Hazford Place. (To achieve that rating they must have sired five or more winners with 100 or more points.)* Of the eighty cows in this Register, 12 of them were produced at Hazford Place. One Izatone, is the highest ranking female in the entire register.

Mr. Hazlett began his work at the age of 51 and in the next 38 years produced what many people believe to be the greatest herd of Hereford cattle in the world. In his later years he was known as the Premier Hereford Breeder of the United States.

Following Mr. Hazlett's death, the entire herd was dispersed at Hazford Place in an auction sale on June 15, 16 and 17, 1937. The attendance of the sale was estimated at approximately 8,000. Six hundred and four lots were sold to 133 buyers from 26 states and three provinces in Canada at an average of $505. Table II gives a summary of the prices paid in the sale. Anon, 1937, (3)

Ten head which were being fitted for the 1937 shows were sold as a group to Harper and Turner of Sulphur, Oklahoma, for the consideration of $18,000. The same firm bought Hazford Tone 76th, one of the chief Hazford Place sires, at a new record price for a Hereford bull since 1923--$6,800.

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*The Register of Merit was authorized at the annual meeting of the Hereford Association in 1927. Points are awarded to sires on their prize winning get, and to dams on their prize winning produce on the following basis: first prizes, ten points; second prizes, eight points; third prizes, six points; fourth prizes, four points; and fifth prizes, two points. To become eligible to a place in the Register of Merit, a bull must have sired at least five winners and have at least 100 points to his credit; a cow must have been the dam of at least two, and have at least 25 points.

TABLE II

SUMMARY OF THE SALE OF HAZLETT HEREFORDS

113 Bulls	$ 78,460:	Average.....	$ 694
491 Females.....	226,790:	Average.....	462
604 Lots.....	305,250:	Average.....	505
Top 50 Head.....	86,845:	Average.....	1,737
Top 100 Head.....	122,210:	Average.....	1,222
Top 150 Head.....	151,895:	Average.....	1,012
Top 200 Head.....	177,875:	Average.....	889
Top 450 Head.....	271,645:	Average.....	604
18 bulls sold at $1,000 or more...	$46,775:	Average..	2,598
20 females sold at $1,000 or more.	29,685:	Average..	1,484
38 head sold at $1,000 or more....	76,460:	Average..	2,012

Bonita Zato, the undefeated grand champion of the 1936 season established a new seven-year record price for Hereford females, when Robert T. Wilson of Prescott, Arizona, bought her at $3,100.

A four-year-old bull, Hazford Tone 74th, formerly one of the Hazlett show bulls and later becoming one of the most popular of the Hazlett herd sires sold on the second day of the auction at $3,850. to Harper and Turner.

The Harper and Turner firm was the heaviest buyer at the sale. In addition to the show group of 10 head, they secured 46 other cattle, their purchases totaling $52,530 or an average of $938 per head.

III. THE INVESTIGATION

A. Method of Procedure

1. Coefficient of inbreeding.

The methods used in this study were developed by Wright, 1922, (13) and Wright and McPhee, 1925, (15). The following breeds of livestock have been analyzed by these methods: British Shorthorn Cattle, Clydesdale horses in Scotland, Jersey cattle in England, Ayrshire cattle in Scotland, Rambouillet sheep in the United States, Holstein-Friesian cattle in the United States, Brown Swiss cattle in the United States, Poland China hogs in the United States, Hereford cattle in the United States, and the British Dairy Shorthorns.

The coefficient of inbreeding developed by Wright, 1922, (13), measures the approximate percentage of genes that have changed from a heterozygous state in the foundation stock to a homozygous state in the offspring as a result of inbreeding. Since it is based upon the statistical laws of probability, it is subject to the errors inherent therein. Therefore, it is not an absolute, but a relative measure of the inbreeding of an animal. It measures the probable similarity between the egg and sperm cells which unite to form the individual in question, relative to the similarity of random germ cells from the foundation stock. Inbreeding may be defined insofar as Mendelian factors are involved, as the bringing together of similar germ cells. As experiments with different kinds of animals and plants have indicated that the effects generally obtained by inbreeding, such as decline in vigor, decrease in fertility, fixation of type, and prepotency in crosses, vary directly with the increase in homozygosis, the coefficient seems adequate from a physiological standpoint.

A pedigree to show inbreeding must have the same animal appearing

in one or more lines back of both the sire and dam. The closer the ancestor responsible for the inbreeding, is to the sire and dam, the greater will be his contribution to the inbreeding of the animal. Likewise, greater will be the probability that the genes contributed through the sire and through the dam will be similar, thus establishing a state of homozygosity in the offspring for the characters in question. In the event the animal responsible for inbreeding in a pedigree is himself inbred, even greater will be the probability that the genes he transmits to an offspring, through the sire and dam, will be similar. Thus, a method for computing inbreeding must attach a value to such a common ancestor proportionate to his degree of inbreeding.

The formula for computing the coefficients of inbreeding developed by Wright is as follows:

$$F_x = \Sigma\left[\left(\frac{1}{2}\right)^{n+n'+1}\left(1 + F_a\right)\right]$$

In this formula, F_x is the required coefficient, and F_a is a similar coefficient for any common ancestor that makes the closest connecting link between a line of ancestry tracing back from the sire and one tracing back from the dam. The factor $(1 + F_a)$ takes care of the contribution made by any common ancestor which is himself inbred. The Greek letter Σ means "the sum of." The "n" is the number of generations back from the sire to the common ancestor, and "n'" is the number of generations back from the dam to the common ancestor. A particular tie between the pedigrees of a sire and dam contributes $(\frac{1}{2})^{n+n'+1}(1+F_a)$. The factor $\frac{1}{2}$ represents a 50-50 chance which occurs at each Mendelian segregation. In other words, the physiology of animal reproduction is such that two sex cells are formed from one original, and the chances

are even that any specific gene may be in either one or the other. Of course, the new individual formed is the product of only one sex cell from each parent. The $\frac{1}{2}$ is multiplied by $n+n'+1$ to take care of the comparative chance involved relative to n and n'. It is evident that with every segregation or generation that a common ancestor is removed from the sire and dam, the probability that a particular gene will reach the offspring is halved. The total coefficient F_x is simply the sum of the contributions made by each common ancestor.

The coefficient of inbreeding is based on two major assumptions: first, that inheritance is Mendelian; and second, that sire and dam contribute equally to the offspring. There is little question about the first, but the latter may be modified slightly by characters which are sex-linked. Only a slight discrepancy may be expected to arise from sex-linked characters in farm animals due to the large number of chromosomes which farm animals have, and the likelihood of only a few genes being sex-linked. The effects of sex-linked characters would tend to cancel since sires have no influence on their sons, but transmit these characters to their daughters as though they were homozygous. Inbreeding in a female's pedigree has no effect on her sex-linked genes when the line of descent is from sire to son, but when the line of descent is from sire to daughter, a higher degree of homozygosis for the sex-linked characters results. As the result of mother-son or father-daughter matings, there is expected a decrease of 29.3 per cent in the heterozygosis in sex-linked genes, and 19.1 per cent in autosomal genes.

2. Coefficient of relationship.

Closely related to the coefficient of inbreeding is the coefficient of relationship which measures the degree of correlation to be expected between two individuals in characters which are wholly genetic and without dominance. Since this coefficient is based on the assumption that correlation between parent and offspring or between brothers in a random bred stock is 50 per cent, its interpretation, therefore, depends upon the genetic status of the foundation stock.

The following formula has been prepared by Wright, 1923, (14):

$$Rxy = \frac{\sum\left[\left(\frac{1}{2}\right)^{n-n'} \quad (1+Fa)\right]}{\sqrt{(1+F_x) \quad (1+F_y)}}$$

In this formula F_x and F_y are coefficients of inbreeding for the two animals in question. X and Y are used to represent the two animals being correlated. F_a is the inbreeding coefficient for the closest common ancestor connecting a pair of ancestral lines in their pedigrees. The factors n and n' are the number of generations from x and y to this common ancestor along the lines in question. R_{xy} is the required coefficient and may vary from 0 per cent to 100 per cent. This is a more accurate measure than would be obtained on the basis of the percentage of common blood in the two animals. Full brothers and sisters have 100 per cent common blood. The percentage of common blood measures dirrect relationship where there is no inbreeding, but fails to measure collateral relationship as exists between double cousins, for instance. Full brother and sister mating, according to the above formula, would yield a relationship of 50 per cent. The factor $(1+F_a)$ weights the contribution made by a common ancestor. For further details of this formula, the reader is referred to Wright, 1923, (14).

3. Approximate method of calculating coefficients of inbreeding and relationship from livestock pedigrees.

If these coefficients were to be secured for a large group of animals and all the paths from the sire and dam to each common ancestor evaluated, the amount of work involved would become very cumbersome. Even the matter of tracing complete pedigrees back as many as five or six generations is almost prohibitive if many animals are involved. Wright used complete pedigrees in his analysis of the Bates' Shorthorns. This was possible, however, due to relatively short pedigrees and the fact that relatively few animals were involved. The making of a single complete pedigree for 10 generations back, of the animal in question, would involve the tabulation of 2,047 animals.

Wright and McPhee, 1925, (15) have developed an approximate method of calculating coefficients of inbreeding and relationship from livestock pedigrees. The approximate method depends on the tabulation of random lines back through the pedigrees of the sire and dam. The standard error involved can be calculated from the ordinary theory of sampling. A two-line random pedigree is therefore not at all complete as it consists of only a single line of ancestry back from each sire and dam. It is necessary that the sample lines be chosen wholly at random. Obviously, most of the common ancestors involved will be males; therefore, straight male or straight female lines would not be a fair sample. Fairly accurate results can be obtained by alternating males and females but the accuracy of such a system cannot be tested by theory of sampling.

Table III shows a pedigree taken from the 1936 sample used in this study.

Note the tie between the two lines in which Bocaldo 6th 464826 becomes the common ancestor. Of course, a second sample of the same

TABLE III

HAZFORD BOAZ 2d 2496179 Calved 5-3-1936

SIRE Hazford Tone 74th 2127386		DAM Boza Tone 1567367	
MALE	FEMALE	MALE	FEMALE
1652680		1093542	
	1456760	464826	
1093527			372147
	720832	192235	
464826		51817	
	372147		24629
192235		8946	
	46811		
	37167		
8946			

pedigree would not show the same sequence of sires and dams and hence Bocaldo 6th 464826 may not have appeared as a common ancestor. It is well to make clear that a single sample of this sort is practically worthless as an indication of the inbreeding of one individual. The average, however, obtained from a large group of pedigrees should not vary appreciably from the actual inbreeding of the group. Two-line samples of this kind fall immediately into two groups; those which show an ancestral connection, as does the one shown in Table III, and those which have no common ancestor. In the latter case the coefficient is zero as far as this sample is concerned. In the former case a contribution of $(\frac{1}{2})^{n + n' + 1}(1 + Fa)$ is indicated if the common ancestor is n generations back of the sire and n' generations back of the dam. In a complete pedigree, the number of ancestral lines doubles with each generation from the offspring. Thus, in a random sample pedigree, the chance of non-occurrence of a specific ancestor doubles

with each generation from the offspring. The sire has 2^n ancestors in the nth generation, and the dam $2^{n'}$ in the n'th generation. The sample pair of lines is only one among the $2^{n + n'}$ possible pairs going back as far as the common ancestor. Therefore, if the sample pair of lines is a fair sample of the total, its contribution must be multiplied by $2^{n + n'}$ to obtain a fair estimate of the inbreeding of the whole pedigree. Upon multiplication, the coefficient takes the simple form $\frac{1}{2}(1 + Fa)$. In a two-column pedigree, therefore, it is not necessary to count the generations to the closest tie, but merely to note whether or not one exists and what animal is responsible for it. The coefficient of inbreeding for a group of animals is the sum of all such contributions divided by the number of animals in the group.

To secure a fairly dependable coefficient for the various common ancestors involved, it will be necessary to resort to a more complete pedigree. A rather accurate figure can be obtained by the random method, however, providing a number of such lines as tabulated from each pedigree. The more satisfactory method which is being used in this paper includes a complete pedigree for the first four generations and each of the lines then randsomed to the foundation stock. A tie occuring in the random portion of the pedigree is worth approximately the same as one in the fourth generation, and may be considered so in computing the coefficient. The formula $F_x = \sum \left[(\frac{1}{2})^{n + n' + 1} (1 + Fa)\right]$ has previously been explained in this paper. A coefficient of inbreeding that is rather highly reliable should be secured for those common ancestors responsible for the large number of ties.

The standard error of the percentage of ties occuring can be

calculated by the formula, $\sqrt{\frac{pq}{n}}$ where n is the number of cases, p is the observed chance of occurrence of a tie, and q, (1 - p), is the chance of non-occurrence. The standard error of $F_x = \sqrt{\frac{pq}{n}} \cdot \left(\frac{F_x}{p}\right)$. The factor $\frac{F_x}{p}$ is used to rate the standard error for the percentage of ties down so that it will apply to the coefficient of inbreeding.

The standard error for the percentage of ties measures the error which may result in sampling due to the use of incomplete pedigrees.

The standard error of the coefficient of inbreeding does not measure the chance involved at the time of segregation.

The calculation of coefficients of relationship presents no special difficulty.

The presence of a tie between single random lines back of two animals considered (x,y) indicates a coefficient of relationship = to $\frac{1 + F_a}{\sqrt{(1 + F_x)(1 + F_y)}}$. The standard error is calculated from the proportion of ties and is rated up by the ratio of the coefficient to this proportion as in the case of the inbreeding coefficient.

4. Analysis of the Hazlett herd.

In the present study samples were taken from the American Hereford Record and include all the animals recorded by Mr. Hazlett as born in the following years: 1900, 1908, 1915, 1922, 1929 and 1936. There were 13 pedigrees in the 1900 group, 68 in 1908, 67 in 1915, 121 in 1922, 89 in 1929, and 227 in 1936. It was felt that samples taken at about seven year intervals would be a sufficiently accurate index of the herd through the different stages of its progress.

Two line pedigrees were used. The date selected as the base to which all of the pedigrees would be traced was 1880. This would include all of the breeding activities of Mr. Hazlett and would give a fair estimate of the foundation stocks used. In finding the coefficient of inbreeding for all animals responsible for a total of two or more ties, considering both inbreeding and inter se, pedigrees were completed for four generations and then randomed to the base date. For animals responsible for only one tie a coefficient was ascribed equal to the average for the Hazlett herd at the time the animal in question was born. In case an animal with only one tie was born prior to the establishment of the herd, the average coefficient for the Hereford breed as a whole (12) at about that time was used.

The sequence of sires and dams which was used in the random lines was determined by the tossing of a coin. "Heads" was let to represent a male and "tails" represented a female.

The same samples were used in determining the inter se relationship.

The pedigrees in each group were thoroughly mixed so that any two picked up together for matching represented pure random choice.

A coin was tossed for each pedigree to determine whether the sire's line or the dam's line would be matched first. The lines thus selected were compared and the ties marked. After the entire group were thus compared, they were again mixed. Again they were picked up in pairs and the lines not used before were compared and the ties were marked. All the ties were then tabulated according to the common ancestors.

In computing the coefficient of relationship between important sires and the 1936 sample, only direct relationship was considered. This was determined by tabulating from all the 1936 pedigrees the numbers of times each animal appeared in the random lines. The direct relationship = $\frac{\text{total number of appearances}}{\text{Maximum possible appearances}}$.

No particular study was made of the foundation animals in the Hazlett herd. The original source of these animals was merely noted.

B. Results

1. Inbreeding and Inter se relationship.

The average coefficients of inbreeding and relationship for the Hazlett herd for the six years in which samples were taken is presented in Table IV and in Figure A. The coefficient of inbreeding measures the percentage of genes fixed for the various years which were fixable but not yet fixed in the foundation animals of the herd.

For example, the coefficient of inbreeding 15 $\pm$ 0.5 found in the 1936 sample means that the average animal included in that sample was 15 per cent less hetrozygous than the average animal in the foundation stock of 1880.

The base date to which the pedigrees were traced was 1880. It is obvious, however, that all of the lines would not end with an animal born exactly on that date. In this study no animal which was dropped before 1880 was used, and many of the lines ended with animals born shortly after 1880. Therefore, the actual base date would be somewhere about 1882 or 1883. There was an increase in the coefficient of inbreeding from 1900 to 1936 of 7.29 per cent. The average length of generation was not considered in this study. However, if the average generation interval found by Willham to be 5.4 years for the breed as a whole can be applied to the Hazlett herd, an increase of 1.1 per cent in the gene homozygosity of the herd would be indicated per generation. Again supposing that Willham's figure would be about correct for the Hazlett herd, the first eight years show an increase in the inbreeding coefficient of 3.34 per cent or about 2.6 per cent per generation. The following fourteen years between 1908 and 1922 show an increase of only

TABLE IV

Inbreeding and Inter se Relationships

Year	Pedigrees Sampled	INBREEDING COEFFICIENTS: Actually Found	Expected from inter se relationship	Excess of Expected	Inter se Relationship
1900	13	7.7%±1.6	30.4	22.7	46.1 ± 2.9
1908	68	11. %±0.8	13.5	2.5	23.5 ± 3.3
1915	67	9.7%±0.8	19.9	10.2	32.8 ± 3.8
1922	121	11.2%±0.6	17.1	5.9	28.9 ± 2.7
1929	89	14.6%±0.8	18.9	4.3	31.5 ± 4.0
1936	227	15. %±0.5	17.2	2.2	29.1 ± 2.0

.13% which, considering the standard error involved, is not significant. Within the next interval of seven years the total increase jumped 4.45%--probably about 3.4% per generation. The increase which occured between 1929 and 1936, .37% is insignificant.

The coefficient of relationship, also shown in Table IV is a measure of the approximate relationship existing between animals in the herd selected at random. The significance of these figures is dependent upon the inbreeding coefficients. McPhee and Wright, 1925, (8) have shown that the percentage of inbreeding expected from the purely random mating among the sires and dams of a group of any size may be calculated by the formula $F_x = \frac{R}{2-R}$ where F_x is the desired coefficient and R represents the coefficient of inter se relationship.

In column four of Table IV is presented the inbreeding coefficients of each sample which would be expected from purely random mating in the herd. This figure in comparison with the coefficient of inbreeding observed reveals at once whether the herd at a particular time tended to be divided into rather distinct groups or whether the members of the herd were rather highly interrelated. Throughout most of the period, the expected inbreeding has been considerably above that observed, indicating no appreciable segregation or grouping. The fact that the expected coefficient was higher than the observed, shows also that there existed a closer relationship between parents matched at random than between the sires and dams.

The very high inter se relationship found for the 1900 sample is due to the fact that one bull sired 12 of the 13 animals in that sample.

The 1900 sample represented the highest inter se relationship and the 1908 sample represents the lowest. Excepting for the high relationship

in 1900, little change in the relationship coefficient is indicated. The 1900 sample is hardly comparable due to the smallness of the sample.

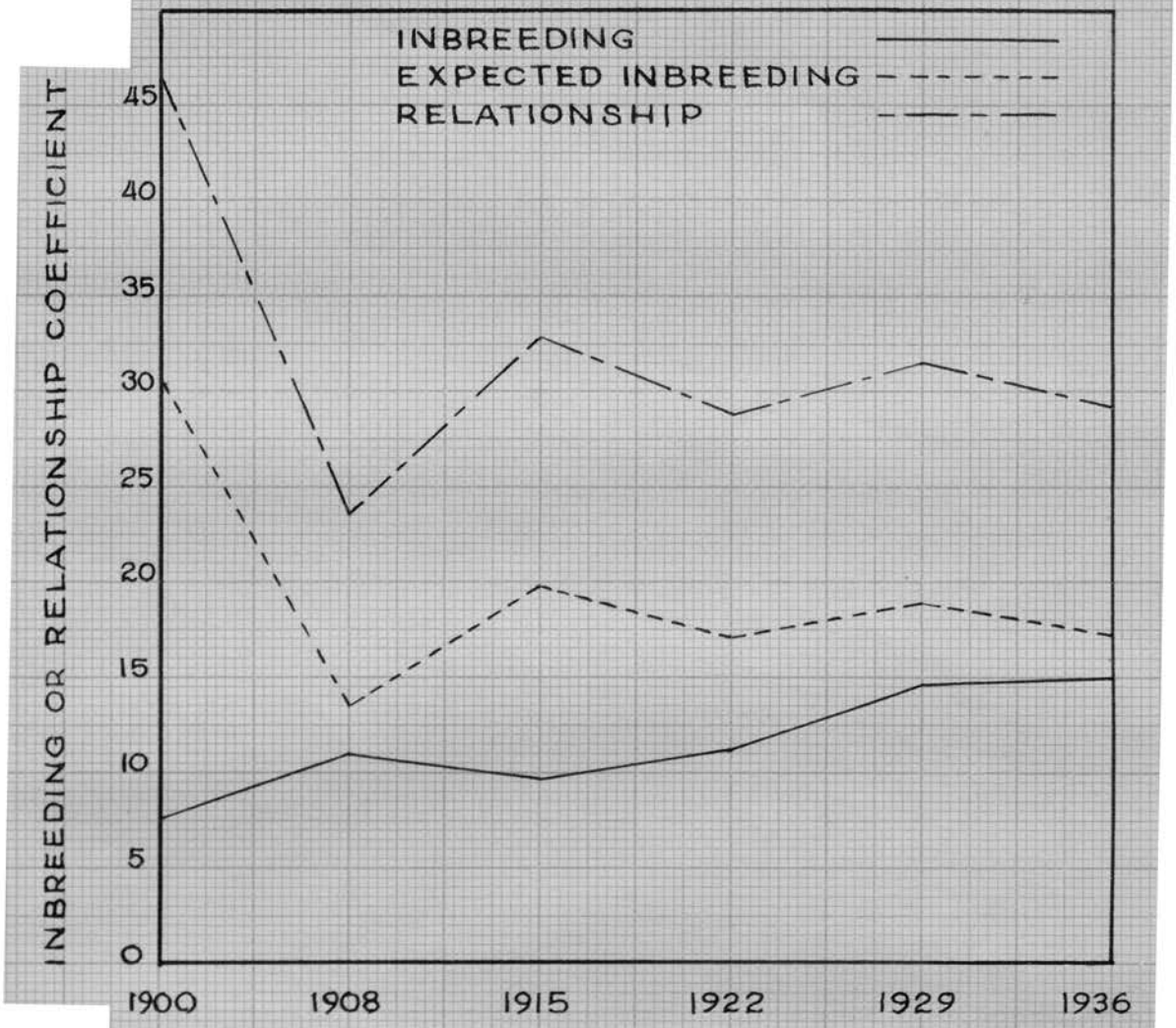
2. Animals used as foundation stock.

The foundation animals of the Hazlett herd as they relate to this study will be dealt with later in the discussion. Briefly, the foundation stock came from rather close bred herds and were line bred to Anxiety 4th 9904. With the exception of a few individuals, the foundation animals came from the Gudgell and Simpson herd.

3. Sires contributing most to the herd.

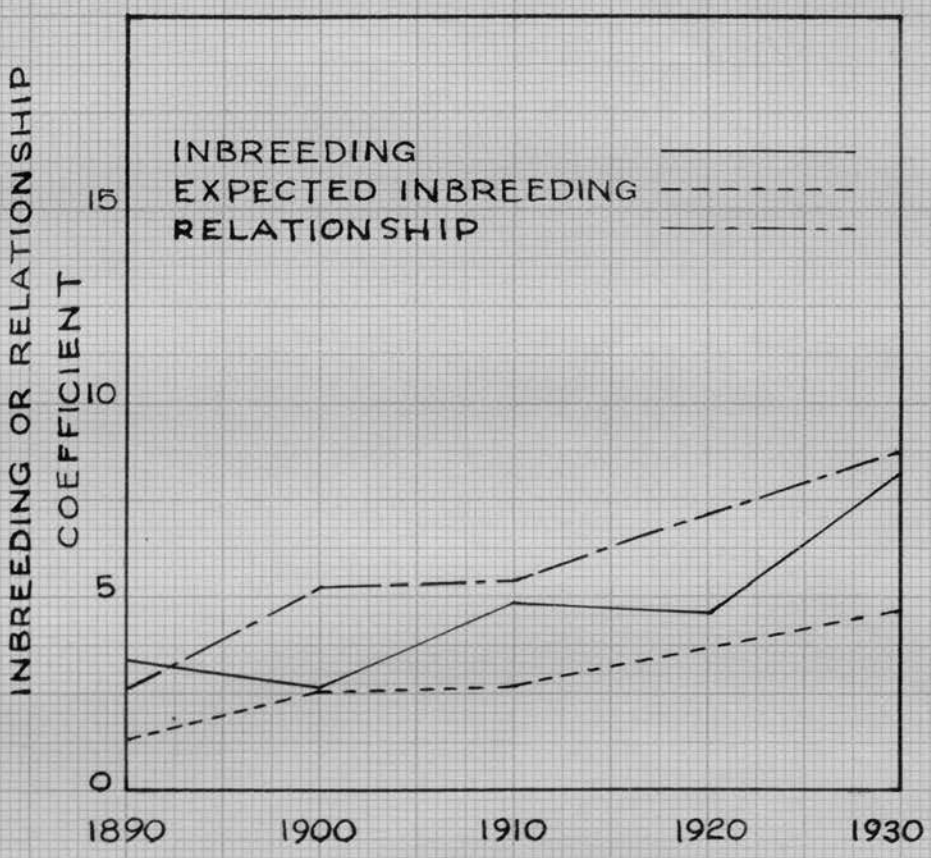
Table V shows the coefficients of inbreeding and relationship of important sires. The percentage of inbreeding shown in column six of the table is important in that it is a measure of prepotency of this group of the most widely used sires. Column five in the table shows the percentage direct relationship existing between these sires and the 1936 sample. This indicates the concentration of the blood of these sires within the herd at that time. The date each sire was calved is shown. Bocaldo 6th 464826 and Beau Brummel 51817 have a direct relationship of about 25 per cent to the 1936 sample.

FIGURE A



COEFFICIENTSOF INBREEDING AND INTER SE RELATIONSHIP FROM 1900 TO 1936

FIGURE B



COEFFICIENTS OF INBREEDING AND INTER SE RELATIONSHIP FROM 1890 TO 1930 FOR HEREFORD BREED.

WILLHAM, 1937, (12)

TABLE V

Coefficients of Inbreeding and Relationship of Important Sires

NAME	Registry Number	Date Calved	Number of Appearances	% Related to 1936 Sample	Coefficient of Inbreeding
Hazford Tone 74th	2127386	1-2-'33	65	14.31	.218
Hazford Rupert 25th	1209734	2-19-'23	53	11.67	.032
Hazford Tone	1093542	7-9-'21	80	17.62	.103
Beauty's Bocaldo	1093508	1-6-'22	37	8.15	.032
Hazford Rupert	634535	1-24-'17	40	8.81	.025
Bocaldo 6th	464826	3-20-'14	113	24.89	.157
Beau Brummel	51817	10-5-'90	114	25.11	.013
Don Carlos	33734	11-18-'86	79	17.40	.012
Anxiety 4th	9904	5-23-'80	78	17.18	.158
Possible Appearance			454		

TABLE VI a

NUMBER OF SIRES USED

Name	Number	Number of Calves Sired 1900	1908	1915	1922	1929	1936
Major Beau Real	71621	12					
Bernadotte 2d	71634	1					
Beau Brummel 10th	167719		20				
Protocol 2d	91715		15				
Beau Beauty	192235		13				
Builder	234716		9				
Tophon	223688		5				
Printer	66684		3				
Security	254544		1				
Typesetter	254548		1				
Caldo 2d	260444		1	16			
Beau Baltimore 15th	388453			25			
Zelpho	316637			15			
Publican 3d	429761			3			
Beau Blanco	415826			2			
Maple Lad	397603			2			
Hazford Santos 3d	415856			2			
Beau Sturgess 2d	316605			1			
Beau Bradford 7th	328052			1			
Bocaldo 6th	464826				36		
Hazford Rupert	634535				25		
Bocaldo 17th	685018				18		
Hazford Donald 2d	788744				15		

TABLE VI a (Cont'd)

Name	Number	1900	1908	1915	1922	1929	1936
Hazford Anxiety	885727				8		
Beau Gudgell	668298				5		
Hazford Bocaldo 3d	786771				4		
Beau Blanchard 54th	623115				4		
Hazford Bocaldo 8th	885728				2		
Beau Baltimore 28th	722109				2		
Governor Simpson	819685				1		
Maple Lad 82d	567909				1		
Hazford Rupert 25th	1209734					21	
Hazford Lad 11th	1093527					18	
Beauty's Bocaldo	1093508					14	
Hazford Bocaldo 9th	885729					11	
Hazford Tone	1093542					8	
Bocaldo Tone	1456773					5	
Hazford Tone 8th	1456786					5	
Prince Domino A.	1480308					4	
Hazford Bocaldo 8th	885728					1	
Hazford Credit	1456777					1	
Hazford Tone 10th	1456788					1	
Hazford Tone 74th	2127386						64
Hazford Bocaldo 97th	2040530						34
Lassie's Tone	1759101						27
Bocaldo Rupert 3d	1855665						20
Bocaldo Tone 19th	2207430						16
Hazford Tone 77th	2148658						16

TABLE VI a (Cont'd)

Name	Number	1900	1908	1915	1922	1929	1936
Beauty's Bocaldo 16th	1855661						16
Bocaldo Tone 3d	1733232						12
Hazford Tone 76th	2127388						7
Rupert Tone 12th	2237641						6
Hazford Rupert 25th	1209734						6
Bocaldo Lad	21[illegible]8635						1
Rupert Tone 13th	2244522						1
Hazford Rupert 71st	2150793						1
Total Animals in Sample		13	68	67	121	89	227

TABLE VI b

NUMBER OF SIRES USED

YEAR	NUMBER OF DIFFERENT SIRES USED	NUMBER IN SAMPLE	AVERAGE NUMBER OF CALVES SIRED PER BULL
1900	2	13	6.5
1908	9	68	7.5
1915	9	67	7.4
1922	12	121	10.1
1929	11	89	8.1
1936	14	227	16.2

Table VI a shows the number of different sires used in each of the samples. It also shows the number of animals in any particular sample that were sired by each of the bulls.

Table VI b shows the number of different sires used in relation to the size of the sample. Thus, there the average number of calves got per sire is indicated. These figures can not be accepted as absolute, in that only calves which were registered were available for study. There likely were several calves each year which, for one reason or another, were not registered.

The above mentioned figures have some bearing on the coefficients of relationship and inbreeding found.

IV. DISCUSSION

Figure B shows the coefficients of inbreeding and relationship found by Willham for the Hereford breed as a whole at ten-year intervals from 1890 to 1930 (12). The figure of primary interest at this point is the coefficient of inbreeding for the breed as a whole, at about the time the Hazlett herd was established. This is of interest here as we attempt to estimate the genetic status of the foundation animals in this herd. The Hazlett herd was established in 1898 at which time, according to Willham, 1937, (12) the breed was as a whole nearly 3 per cent less heterozygous than it was in 1860.

Little was learned about the inbreeding of the first group of cows in the Hazlett herd, which were bought from H. H. Grover. It is known, however, that Major Beau Real, bought as a calf with the original cows, was highly related to Anxiety 4th, and was about 6 per cent inbred. It is possible, therefore, that the cows bought from the Grover herd were more highly inbred than the breed as a whole at that time, and that they also traced to Anxiety 4th.

Since some of the original cows were related to Major Beau Real, another sire Bernadotte 2d, was secured soon after the herd was founded. His coefficient of inbreeding was not ascertained; however, his pedigree reveals that he was highly related to Anxiety 4th.

The greater part of the Hazlett foundation herd was purchased from Gudgell and Simpson. Without knowing which animals were purchased, no accurate estimate as to their inbreeding could be made. At the time of this writing no data were available giving the coefficient of inbreeding for the Gudgell and Simpson herd at about 1900. It is quite generally known, however, that there was a concentration of the blood

of Anxiety 4th and North Pole in this herd. Thus, it is undoubtedly safe to assume that the cows which Hazlett bought from this firm were substantially more inbred than the average cows of the breed. It is of value to note further that practically all of the foundation stock of the Hazlett herd was not only rather highly inbred, compared with the herd average, but that there was a concentration of the blood of Anxiety 4th 9904.

All of the early attempts to secure successful outcrosses in the Hazlett herd were met with failure. Three sires of high quality were used, but they failed to give as satisfactory results as his own Anxiety bred bulls were giving. As the result of this experience, Hazlett made up his mind to stick to Anxiety blood lines and concentrate even further Anxiety blood in the herd.

By 1908 four sons of Beau Brummel 51817 were being used in the herd. With the exception of Hazford Rupert very little outside blood was introduced since 1908.

The fact, shown in Table IV, that the expected inbreeding remained well above the observed inbreeding tells something of the system of mating employed in the herd. There was no apparent attempt ever made to breed separate families within the herd. The wide difference in the expected inbreeding and that actually observed is evidence of the extent to which very close matings were avoided.

The results obtained in this study indicate that the improvement program followed by Hazlett with respect to breeding was primarily the concentration of the blood of outstanding sires without inbreeding individuals within the herd more closely than the achievement of this result compelled. This was accompanied by rigid selection.

Through the years from 1900 to 1936 the coefficients of inbreeding for the herd have been almost constantly on the increase. The coefficient for the 1936 sample practically doubles that of the 1900 sample. It is possible that this is an unsought result occuring from the continued heavy use of outstanding sires in an effort to spread their genes as widely as possible within the herd.

Attention should be called here to the fact that the results obtained in the 1900 sample probably represent more accurately the foundation stock as Hazlett found them than any breeding achievement in the herd. As has been mentioned previously in this paper, the very high coefficient of relationship indicated for the 1900 sample is due to the fact that only two sires were used on the 13 cows which calved in that year.

Table VIa throws some light on the use given outstanding sires. It was not possible in this study to determine the average tenure of service for these sires, but that would be of interest.

As shown in Table V, the Hazlett herd in 1936 bore a direct relationship of about 25 per cent to Beau Brummel and Bocaldo 6th. According to Willham, 1937, (12) the Hereford breed in 1930 bore a like relationship to Beau Brummel. This is equivalent to a grandsire. This study measured only the direct relationship existing between the herd in 1936 and these sires, but one can readily see that the addition of collateral relationship would increase these figures. It is probably safe to estimate that the herd in 1936 would be as much as 33 per cent related to Beau Brummel and Bocaldo 6th had their collateral relationship been included. The figure for Beau Brummel takes on increased significance when one considers that he was born 46 years before the

animals in the 1936 sample were calved.

The coefficient of relationship of Hazford Tone 74th to the 1936 sample was 14.3 per cent. This is a very high relationship considering that he was calved in 1933 and that there were 227 animals in the 1936 sample. He sired 64 calves in this sample.

It is interesting to note that Hazford Rupert 634535, which was bred by O. M. Wright of Vesper, Kansas, and outcrossed on the Hazlett herd about 1920, was only slightly inbred and that he made a major contribution to the herd.

The herd in 1936 was a little more than 17 per cent directly related to Anxiety 4th, Don Carlos, and Hazford Tone.

The using of an outstanding sire year after year in an effort to spread his genes as widely as possible within the herd may in some instances lead to rather close inbreeding, a practice generally to be avoided, but which, in the case of the Hazlett herd, was used rather extensively with good results. The more common practice with the average livestock breeder has been to select a sire not related to the majority of his females, use him until the first, second, or third crop of calves become of breeding age, and then discard him in favor of another sire practically unrelated to the females. Such a system of livestock improvement depends upon the effectiveness of the selection employed for its success and has at least four disadvantages. In the first place, the selection applied to non-related or remotely related animals is less effective than is possible among individuals of a more homogeneous group. Especially is this true when the factors involved are readily modified within the individual by environment or accidents of development; secondly, the effect of any sire starts being

diminished as soon as his use is discontinued. His contribution would be diluted one-half the first generation by the use of an unrelated sire. He would be responsible for only one-fourth of the genes in the second generation, one-eighth in the third, one-sixteenth in the fourth, etc.; thirdly, the depending upon superior individuality in out-cross males is a conservative breeding practice, but is also a slower route to blood concentration or the fixation of characters.

In fact, it is very doubtful if any fixation at all can be achieved through selection as practically all of the characteristics sought are the result of multiplicity of genes the individual identity of which cannot possibly be made by any of our present known methods of selection. A fourth inadequacy of the system is encountered as the successful breeder begins to approach his goal, for it is impossible to achieve as complete fixation through selection as it possible through inbreeding. Thus, further increase in the prepotency of the individual is halted; the attainment of maximum uniformity in the herd is limited; and the problem of securing sires which will 'nick' advantageously with the cows becomes increasingly difficult or impossible.

If the foregoing statements are true, it follows that breeders who are depending solely upon culling within the herd and the selection of unrelated sires for improvement could make more rapid and positive progress by securing and maintaining a rather high degree of relationship between the breeding herd and their most outstanding sires. This high degree of relationship can be achieved by the retention of superior sires until their blood has been rather highly concentrated within the herd. The maintenance of the effect of a superior sire can be accomplished through the concentrated use of relatives of the outstanding sire.

Let us compare a little more closely the methods followed by Bates, Gudgell and Simpson, and Hazlett, and Mendelian theory. In combining inbreeding and selection there are several methods which may logically be followed, depending on the genetic complexity of the characters, the importance of environmental variation and such factors as the extent of the operations and the risk to be undertaken.

The first step in any case should be selection of a vigorous foundation, approaching as closely as possible to the desired type. Knowing that most lines would inevitably deteriorate greatly, one could not expect to continuously practice very close matings. By crossing lines within a herd one may reasonably hope to recover more than the original vigor and retain those characteristics which had been fixed. This is probably not work for individuals. For the individual breeder, theory as well as practice indicates that a most constructive improvement program would be a combination of blood concentration and selection. The closeness of the breeding which should be practiced depends, naturally, on the homogeneity of the foundation animals and the breeder's skill as a judge of livestock. This conclusion seems to be in accord with one made by Dickson and Lush, 1933, (4) after having made a genetic study of Rambouillet sheep.

V. SUMMARY AND CONCLUSIONS

The breeding methods used by Robert H. Hazlett in developing his herd of Hereford cattle are analyzed.

An approximate method of calculating coefficients of inbreeding and relationship from livestock pedigrees developed by Wright and McPhee was used in this study. Two-line random sample pedigrees were used. The samples include all the animals recorded by Hazlett as calved in the following years: 1900, 1908, 1915, 1922, 1929, and 1936. The base date used in this study was 1880.

The coefficient of inbreeding for the 1900 group was 7.7 per cent which is about 5 per cent greater than for the breed as a whole at that time. This means that the foundation animals of the Hazlett herd were approximately 5 per cent less heterozygous than the average Hereford of the United States in 1900.

There was an increase in the coefficient of inbreeding from 1900 to 1936 of 7.3 per cent in the Hazlett herd. This represents a decrease in heterozygosis of about 1.15 per cent per generation. The coefficient of inbreeding for the Hereford breed as a whole in 1900 was only 2.7 per cent, and from 1900 to 1930 this increased to 8.1 per cent, representing about 1.0 per cent decrease in heterozygosis per generation. Thus, the rate of gene fixation which took place in the Hazlett herd was about the same or only slightly above that of the entire breed during these periods. The difference in the final percentages of inbreeding for the Hazlett herd and the Hereford breed during that period is due primarily to the difference in the inbreeding of the animals at the start.

The coefficient of inbreeding observed was well below that expected from the coefficient of inter se relationship which was maintained

rather constantly at about 29 per cent. This indicated that the herd was a somewhat homogenous unit of related animals rather than being divided into families or groups between which there was little relationship. The difference between the observed inbreeding and that expected indicated that inbreeding in general was avoided.

The foundation animals in the Hazlett herd were furnished in part by H. H. Grover and others, but predominantly by Gudgell and Simpson.

It was found that the herd in 1936 was about 25 per cent directly related to Beau Brummel 51817 and to Bocaldo 6th 464826. In other words, they are a little more closely related to this group than grandsires. The herd in 1936 was a little more than 17 per cent directly related to Hazford Tone 1093542, Don Carlos 33734 and Anxiety 4th 9904.

Mr. Hazlett demonstrated in his herd that the concentration of the characters of outstanding sires by means of selection and linebreeding is an excellent way to produce superior beef cattle.

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