THE PREDICTABILITY OF THE BUTTERFAT TRANSMITTING ABILITY OF DAIRY BULLS

By

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VITA

The author was born March 27, 1920 at Glassboro, New Jersey and spent his early life in a rural background. He received the B.S. degree from Rutgers University in 1941, majoring in dairy husbandry. The M.S. degree was obtained at Cornell University in 1943 while an assistant in animal breeding. The author then entered the New York State Veterinary College and received the D.V.M. degree in 1945. One year of this time was spent as a member of the Army veterinary training program. In November 1945 the author was appointed Assistant Professor of Anatomy at Michigan State College where he entered the Graduate School in 1946. He is the author or co-author of two laboratory textbooks and of four scientific articles in the field of endocrinology. He is currently employed as Associate Professor of Anatomy at Michigan State College.

INTRODUCTION

One of the most important problems facing the dairyman is the prediction of which of several prospective sires is most likely to transmit the highest level of butterfat production. That no accurate means is available is manifest from the meager progress in improvement of production, about one pound a year, as indicated by herd testing data* which have been compiled in the last two decades or longer. A large portion of the progress that has been made can be attributed to improvement in environment. Few of the studies made upon the inheritance of producing ability have been successful in distinguishing between hereditary and environmental factors involved. Still fewer of the techniques in common use for predicting butterfat production recognize the effects of environment other than correcting records for standard conditions of age, times milked daily and length of lactation.

It is generally recognized that an increase in the production of a herd can be achieved by altering one or both of two factors, i.e., by improving either the herd environment or the heredity of the individual animals. Effective as the former may be in many cases, there can be no doubt that improvments in environment are temporary and do not add to the genetic worth of the animals. The genetic worth of an animal is frequently obscured by environmental factors.

*HIR Green Book 1949 Holstein Friesian Association

Improvement in genetic worth, other than the doubtful possibility of seizing upon worthwhile mutations, is dependent upon selection to change gene frequency. The effectiveness of any method of selection for a character which can be identified depends primarily upon the variability present and the selection differential. The genetic variability present and the selection differential. The genetic variability of males and females in dairy herds is probably similar, but is obscured by environment. The ratio of breeding males to females, already wide, is being increased by the widespread use of artificial insemination. Thus while the greatest use of the selection differential can be made with males, it is also important that the best possible use of this be made. Inter-herd variations in environment make it essential to distinguish between genetic and environmental factors if real progress is to be made. Culling of the lowest producing cows is a useful technique regardless of the level of herd production even though the selection differential available in most herds makes progress by this means painfully slow. Improvement in management to enable a greater rate of culling of cows would increase the value of this technique.

The object of the present study is to consider the merits of several techniques in use or proposed for predicting the production of the daughters of a potential sire. An attempt will be made to analyze the utility of these methods and to suggest possible improvements in their application. It is obvious that the most valuable technique which can be used in the selection of a breeding animal is that which has the highest predictive value and at the same time is capable of widespread application. Even if those methods which impose the greatest number of restrictions upon the animal in question, in terms of individual or family merit, were the most accurate, their utility would be limited to the number of animals which could meet the specifications required. In other words, it is useless, except from an academic standpoint, to discover a number of superior animals if the method requires that they be dead before their worth can be established. Emphasis in the present work will be directed toward the applicability of the several methods considered as well as their predictability.

REVIEW OF LITERATURE

I. The heritability of butterfat production

The literature concerning predictability of milk and butterfat production can appropriately be divided into two major parts: one dealing primarily with genetic, the other with environmental factors. While many reports have dealt with the influence of various environmental factors upon production, much more attention has been focussed upon genetic factors in actually predicting production. Many of the papers dealing with correlations between the production records of related animals recognize environmental factors only to the extent of using the well established correction factors for age, number of times milked, and length of lactation to convert individual records to a mature equivalent basis. In most of these studies the comparison of the records of individual animals has been used. These data form the basis for the present study which concerns the correlation of related groups of animals, but because of the difference in average heritability of production of groups as compared with individuals, these papers will not be reviewed separately. Rather, attention is directed to the following authors whose work can be considered representative of this portion of the literature: Gowen, Copeland, Gifford, Lush, Turner. Excellent reviews of this work have been presented by Johansson and Hansson (1940), Lush and Straus (1942), Shrode and Lush (1947) and Eldridge (1948). Depending upon the sample studied the correlation values between the production of various relatives ranged from insignificance to 0.3-0.4 for close relatives with only few being higher than the latter value. While many of these values were significant at the 1% level of probability, they were for the most part not sufficiently high to be especially useful for prediction of production under the conditions studied. In most of these studies the effect of the common herd environment which usually exists in the case of dams and their daughters in particular was not ruled out. Lush (1945) has pointed out that there is a correlation of about 0.2-0.3 between cows in the same herd regardless of relationship.

The effect of averaging makes the correlation between the production of groups of related animals considerably higher than the values determined for individual comparisons. Thus the dam-daughter correlation for the daughter average of a sire was reported to be on the order of 0.60 for milk (Rice 1944) and 0.63-0.67 for butterfat (Lush and Schultz 1938, Eldridge 1948). These values are high enough to have practical significance, and in addition, it is these values in which the dairyman is primarily interested. That is, the dairy cattle breeder is more concerned with the average production of a group of daughters of a sire than with that for any individual daughter. This may not be quite so true for conditions under artificial insemination where a number of bulls may be used to inseminate cows in small herds with the result that some herds may contain a few single daughters of one or more bulls. This would appear to be a separate problem worthy of consideration. In one study relating to this problem the average production of artificially sired daughters of 32 bulls did not differ from the average of natural service daughters of the same sires regardless of the level of proof of the sire (Washbon 1950).

II. The prediction of transmitting ability

The observed correlation between the production of related animals has led to the formulation of a number of techniques for predicting the future production of the daughters of a sire through the formulation of sire indices. The pioneering work of Hansson, Yapp, Pearl, Turner, Gowen, Gifford, Heizer, Goodale, Wright and others has been amply reviewed by Lush (1933). This work has led to the widespread adoption of the "equal-parent" index which is based upon the supposition that the sire and dam contribute equally to the producing or transmitting ability of their offspring. The daughter-dam difference in production is added (algebraically) to the daughter average to secure an index of the bull's transmitting ability. The production of future daughters is predicted by averaging the original proof of the sire and the production of his mates, the only concessions to environment being to use the standard correction factors to convert records to a mature-equivalent basis. Other environmental factors are such however, as to make this technique most useful on an intra-herd basis.

The extensive program of proving bulls and of recording their proofs that has developed in the past two decades has been an important advance in dairy cattle breeding. However the applications of this information that have been made have not resulted in any marked improvement in production. Consequently a number of attempts to find an improved technique have been made. These have been directed toward making the records used in establishing the indices more truly representative of the probable transmitting ability. It is recognized that the production record (phenotype) of a cow may not accurately reflect her transmitting ability (genotype). With this in mind, Lush (1945) has advocated a formula based on the repeatability (r) of individual records and the number of records (N) constituting the dam's average: Probable transmitting level = Herd ave. + $\frac{Nr}{1-(N-1)r} \times$ (Cow ave. - Herd ave.) For an average repeatability of 0.4 this formula reduces to $\frac{2N}{2N-3} \times$ Cow's ave. + $\frac{3}{2N-3} \times$ Herd ave. Breed average may be substituted for herd average when the latter is unknown. Thus for N=1, reliance on the dam's record is reduced to 2/5, regression toward herd (breed) average accounting for the remainder. The method of intra-sire regression of offspring on dam has been advocated by Lush (1940) as the method of choice for estimating heritability of characteristics because of the reduction in environmental error.

The phenomenon of regression toward population average has long been established, yet only recently has its use been advocated in sire indexing. Rice (1944) has proposed a modification of the equal-parent index in which the records of both dams and daughters are averaged with breed average. Using this regression index, Dickey and Labarthe (1945) obtained a correlation of 0.61 between actual and predicted production of the daughters of 214 Holstein sires. The simple equal-parent index gave a correlation of 0.53 for the same data. The authors found the regression index to be most useful at high levels and the equal-parent index most useful at low levels of production. Lush (1944) has pointed out that since the regression index is the equal-parent index regressed half way toward breed average, it has half the variability but the same accuracy as the equal-parent index in determining transmitting ability. Allen (1944) has proposed that twice the deviation of the sire's daughters from the expected production* be added (algebraically) to the breed average to obtain a comparative rating of sires. This figure would represent the probable transmitting ability of the sire under average conditions of environment. For predicting the future production of daughters the index is not needed, the deviation of the sire's previous daughters being added to the expected production of future daughters.

From an analysis of the pedigrees of 207 Holstein sires proved in New York State DHIA, Eldridge (1948,1949) developed two multiple regression equations for predicting the production of the daughters of a sire. Depending upon the information available, the equations were:

$$Y_A = 29.6 + 0.75X_1 + 0.03X_2 + 0.01X_3 + 0.34X_4 - 0.21X_5$$

$$Y_B = 0.1 + 0.75X_1 + 0.01X_3 + 0.23X_4 - 0.22X_5 + 0.24X_6$$

Y_A, Y_B = predicted ave. M.E. prod. of daughters of the bull

*The expected production is based upon experience tables showing the average production of daughters of dams of varying levels of production under uniform testing conditions.

X_1 = ave. prod. of the mates of the bull

X_2 = ave. prod. of the maternal half sisters of the bull

X_3 = " " " " dam of the bull

X_4 = " " " " paternal half sisters of the bull

X_5 = " " " " dams of X_4

X_6 = " " " " daughters of maternal grandsire of bull

The multiple correlation coefficient between the actual and predicted production of the daughters of these bulls was 0.70 for Y_A and 0.69 for Y_B. Deletion of the mates' production (X_1) from the equations resulted in a correlation of 0.37 in either case. It was concluded that the most important information to consider in predicting the average production of the daughters of a bull is the average of the mates, and that the sire's index is the most important consideration in selecting a bull on the basis of pedigree.

The average production of the dam of the bull and/or that of her daughters contributed a negligible amount of information for predicting the transmitting ability of the bull. Tyler and Hyatt (1948a) have shown that one unselected record of a dam may be as important in predicting production of her future daughters as the average of her first 2 or 3 daughters in estimating production of future daughters, but correlation values were of a low order (0.18-0.38 for individual comparisons).

Beardsley and coworkers (1950) have suggested that a curvilinear regression might account for a greater portion of the variance in production inheritance studies than would simple linear regression. While their data did not show a significant difference between linear and curvilinear regression values, the latter method gave average heritability figures of 45, 31, 23, and 17% respectively for average production levels of 350, 450, 530 and 650 pounds of fat. These compared with an average figure of 27% for simple linear regression for all data and 28% determined by Eldridge (1948) for his data.

These relatively high correlation values, on the order of 0.6-0.7, between average production of the daughters and mates of a bull appear to be valid only for unselected data. Turner (1927b) and Gifford (1930) found that by grouping bulls according to mates' production, using 100 pound fat intervals, correlations of 0.25 and 0.20 respectively were obtained for dam-daughter averages. The latter work indicated that about 20% of the production of a bull's mates above breed average was inherited (Holstein data). Similar data for Jerseys gave a value of 15% (Gifford and Turner 1928).

The emphasis placed by Eldridge (1948) upon the production of the bull's mates was anticipated by Gowen, who in 1924a stated, "The record of the dam is one of the best pieces of evidence on which to base any estimate of the probable production of the daughter. In fact the close relationship between milk yield of daughter and dam makes it an open question if for the small breeder it is not better to purchase daughters from relatively high producing dams than it is to pay too much attention to and too much money for a supposedly high producing bull." Since much of the correlation between the production of dams and their daughters is undoubtedly due to intra-herd environment, the term "purchase" should probably be replaced by "select".

III. Environmental influences upon milk and butterfat production

As mentioned above, production records used in prediction of milk or butterfat production are now corrected for the influence of age, number of times milked and length of lactation, these influences being well established in the effect they exert upon lactation. In spite of correction for these environmental influences, correlations between actual and expected production still lack the accuracy desired. This lack of correspondence is generally attributed to "environmental" factors, but there has been no concerted effort to determine constants to correct for such errors.

The influence of body size upon milk production is recognized in the axiom that "within the breed, the big cows excel." In a summary of the effect of body size on lactation, Beck and Turk (1948) stated that while the larger cows of a breed do produce more milk, they may not necessarily do so more economically than smaller ones. That age factors automatically correct in part for size was shown by Brody and coworkers (1923). In over 15,000 Jersey ROM records with age constant there was an increase of 20 pounds of fat per 100 pounds increase in body weight. If age was not held constant, there was an increase of 104 pounds of fat per 100 pounds increase in body weight. In Guernsey AR records the increase was 16 pounds (or 14 pounds for DHIA records--Turner 1929). The correlation of body weight and milk production was found to be on the order of 0.6 and was highest at one month after calving (Davis and coworkers 1943) for records uncorrected for age. This value was reduced by one-half if age correction factors were used (Gowen 1936). Gaines and coworkers (1940) have gone so far as to advocate correlating production directly with body weight without regard for age using the formula FCM/body weight (FCM = fat corrected milk). This idea has been vigorously attacked by Kleiber and Mead (1941, 1945) who maintain that production is proportional to metabolic body size ($Kg^{0.75}$) in determining relative lactation capacity. Brody (1945)* pointed out that Gaines' formula would be valid only for cows of the same weight.

Misner (1939,1941) computed a size index for cattle using width of hips, length of rump andheight at hips, and found a correlation of 0.54 with FCM on 2747 Holsteins. Measurements of 100 cows in the Cornell herd gave a correlation of 0.49 between size index and the best age corrected record. For immature cows Davis and Willett (1938) found no correlation between gain in weight, increase in height or chest girth from birth to two years of age with subsequent production. Tyler and coworkers (1948) found that 30-60% of the variation in mature body size of Holsteins was hereditary and suggested selection for body size be practiced.

The effect of season of calving upon milk yield has been investigated by Cannon (1933), , Frick and coworkers (1947), Morrow and coworkers (1945), Edwards (1938), and Sanders (1927a). Production was found to be uniformly

*Bioenergetics and Growth Reinhold N.Y.

lower for cows freshening in the summer months, but the season of freshening had no effect upon length of lactation. Fall freshening resulted in a maximum increase of 12-13% in milk production over summer freshening. An exception to this was found by Oloufa and Jones (1948) under condition of uniformly mild temperature. This indicates that temperature is a greater factor than the poorer late summer feeding conditions which generally prevail while cows freshening in the summer are at peak production. Sanders (1927a) found the effect of season of calving to range from -5 to +7% of the total yield and proposed that records be corrected according to the month of calving. Brooks(1931) found an inverse relationship(r= -0.87) between environmental temperature and percent fat. The same relationship existed in four breeds, but was most marked in those with higher tests. The stage of lactation was less a factor than season. Similar findings were reported by Weaver and Matthews (1928). Hays (1926) under controlled experimental conditions found an increase in fat test of 0.095% for each 10°F lowering of temperature from 85 to 24°F. thus demonstrating that temperature is the chief factor in seasonal variation in fat test. Bartlett (1929) found daily milk yield to be most variable in hot weather.

The length of the dry period has been demonstrated to affect milk production. The optimum length of the dry period was determined to be 55 days (Klein and Woodward 1943) or 65 days (Morrow and coworkers 1945) for a 12 months calving interval. This interval was found optimum for maximum 305 day production. The former workers suggest correction of records to a standard 55 day dry period, the fators ranging from 1.403 for 0 days to 0.955 for 120 days or longer. They found half the variation of successive records of cows to be explainable by the length of the dry period. Tyler and Hyatt (1950) found significantly lower production with a calving interval of 10-11 months than for 12-13 months. This was due in part to the shorter lactation, but it was suggested that cows with short calving intervals may be persistently lower producers. Significantly greater production was not obtained with an increase in calving interval beyond 13 months, although Gaines and Palfrey (1931) found that the calving interval could be extended to 18 months without seriously affecting total lifetime yield. Dickerson (1937) reported that correcting records for age, calving interval and dry period accounted for 35% of the intra-herd variation in production between cows compared with 24% for uncorrected records. Dickerson and Chapman (1939) found that increasing the length of the dry period resulted in greater percentage increases in the subsequent lactation period for low producing than for high producing cows. The length of the dry period was found to increase with age. Dickerson (1940) found that correcting calving interval to 365 days increased the repeatability of total yield. Cows with shorter lactations tended to have lower records and longer dry periods. Sanders (1927a, b,1928a,b) developed correction factors for length of dry period ranging from -14 to +25% (0 interval 40 days) and for length of service period ranging from -33 to +34% (0 interval 85 days).

Hammond and Sanders (1923) found that variation in records of individual cows could be reduced 20%, by correction for age (15%), length of dry period (2%) and for month of calving and length of service period (3%). Plum (1935) found that length of the dry period accounted for 1% and calving interval 3% of the total variance in fat production.

Turner (1926) has suggested a persistency index for prediction of total yield based on the fact that each succeeding months' production after the peak yield is a constant percentage (differing with individuals) of the preceding months production. Persistency was found to be largely independent of pregnancy, temperature, nutrition and other management factors. Alexander (1950) in a study of the inheritance of persistency found that the daughters of inbred sires varied less in average persistency than those of outbred sires, and the inbred daughters of a sire varied less than the outbred daughters of the same sire. Distinct differences were found between breeds, strains within breeds and between the daughters of different sires. The regression of daughters on dams was constant, although Turner (1927a) reported the correlation of dam-daughter persistency to be of a low order. Gaines (1927b) reported persistency to be inherited through the dam and not the sire, but Becker and McGilliard (1929) found contributions of both sire and dam.

Putnam and coworkers (1944) have reopened the question of the effect of age upon butterfat percentage. They refer to a large number of studies which supports their finding that there is a statistically significant decrease in butterfat test with age, the regression of fat test on age (Ayrshires) being -0.02509. They presented a set of conversion factors for calculating mature equivalent production in conjunction with those now used for milk yield. A further discrepancy in the application of blanket conversion factors has been reported by Copeland (1934) who showed that the increase in production with 3 time compared with 2 time a day milking varied with the level of production. The increase for Jersey cows with 400-500 pound 2 time records was 38% for subsequent 3 time records, while that for cows with 2 time records above 750 pounds was only 6%. The findings suggest that a high producing cow will come closer to maximum producing capacity on 2 time milking than will a poor producer. The limitations imposed by udder size have been suggested as an explanation of this. Lush and Shrode (1950) have suggested a slightly higher (0.833) correction factor for converting 3x to 2x milking after the first lactation (0.80) and have pointed out minor discrepancies in the factors now used for age correction.

The influence of the plane of nutrition upon production has long been under investigation. Eckles (1927) reported that fat test was higher when cows freshened in good condition. Woodward (1927) stated that an increase of 50% in production could be expected if average herd conditions are supplanted by those which obtain under official testing. Similar values were obtained by Dawson and Graves (1936) by radically altering feeding practices alone. An average production of 405 pounds of fat for 46 cows restricted to roughage alone was increased to 654 pounds when the same cows were grain fed in accordance with accepted practice. Plum (1935) found that 18% of the variance in fat production could be accounted for by feeding practices. Brody and Ragsdale (1935) have demonstrated that the gross efficiency of production varied from 15-25% with poor producers to 35-45% with good producers, the biological limit apparently being about 50%.

The influence of a number of other factors upon production has been studied. The correlation of type with production has been studied. The correlation of type with production has been shown to be of a low order, 0.30-0.38 or less (Gowen 1933b, Copeland 1938b, Tyler and Hyatt 1948b). Gowen suggests that while conformation is a poor criterion of producing ability it has the merit of showing current health of the cow. Non-significant correlations were found by Leighton and Graves (1947) for slope of rump and udder slope with production. Evaluation of udder development at 4 months (Jersey) or 6 months (Holstein) had highly significant correlations with mature equivalent production (Book and coworkers 1950). Pregnancy was found to have no effect on fat percentage, but resulted in a drain of 400 -600 pounds of milk (Gowen 1924b). Little or no relationship was found between production and the presence of supernumerary teats (Gifford 1934) or for the age of the sire and dam upon daughter's production (Gifford and Elting 1928). Washbon and Tyler (1950) found an increase in average fat production (dam-daughter difference) for the daughters of later proven sons of a sire compared with those of earlier proved sons, but this was considered to be purely environmental. The uniformity of get of a sire was found to be unrelated to production of the get (Johnson 1945), nor was there any correlation between age at first calving and mature body weight or total production for the first five lactations (Chapman and Dickerson 1936). Cows calving early had a higher total production to seven years of age however. Bartlett (1929) reported slightly less variability in daily production if morning yield was added to the subsequent evening yield rather than the previous evening yield as is commonly done in testing. The number of daily milkings was found to have no effect on persistency as measured by slope of decline in production (Ludwin 1942).

A significant development in evaluation of environmental influences upon fat production has been the formulation of an environmental index by Bayley and Heizer (1950). The index is based upon deviations of individual lactation records from an arbitrarily determined base, such deviations being calculated on the basis of the plus or minus contribution to the mature equivalent record made by the six factors concerned. The factors used, together with the level at which the deviations are zero and the nature of the deviations, are:

Factor	0 interval	Effect of change	
Lbs TDN daily/1000 lb wt.	17.0-17.5	varies	directly*
Nutritive ratio	6.4-6.8	"	inversely**
Days with calf while milking	150-203	"	"
Number of milking cows in herd	39-48	"	"
Length of preceding dry period(wks)	6	"	directly
Condition at calving	Fair	"	"

*Plus deviations result in plus contribution to index and vice versa
** " " " " minus " " " " " "

The index permits the records of dams and daughters, for example, to be dompared on the basis of the effect of the actual environment upon fat yield. This value can be compared with the actual difference in mature equivalent production to determine the effect of environment thereon. Thus a large deviation in actual dam-daughter production would be considered largely genetic if accompanied by a small difference in environmental index, or largely environmental if the environmental index difference were large. A major use of the environmental index might be to reflect differences in the environmental levels from one sire proof to another. The authors stress however, that the index measures only six environmental factors, and care should be exercised in concluding that the remainder of the production differences are entirely genetic.

PREDICTION OF THE BUTTERFAT TRANSMITTING ABILITY OF BULLS IN THE MICHIGAN INSTITUTION HERDS

I. Source of data

A preliminary survey of the herd records in several of the Michigan State Institution Holstein herds indicated that these herds constituted a large and possibly more homogeneous group of animals than might be expected in most populations of this size. About two-thirds of the bulls proved in these herds were sons of herd cows, the other third apparently having been purchased animals. For half of the herd bred bulls records were available which made it possible to calculate prediction indices. In this group there was one set of 18 sons of one sire (Marathon Bess Burke 32) of which one subgroup of 3 and one of 2 bulls were full brothers. In addition, 9 of these 18 bulls were maternal first cousins. There were two other sets of 2 and one each of 5 and 3 paternal half brothers, and two sets of 5 and4 maternal half brothers among other data from these herds. Considering the corresponding number of parent-son relationships, this formed a fairly closely related group which could be compared with an equal sized group of unrelated (purchased) bulls.

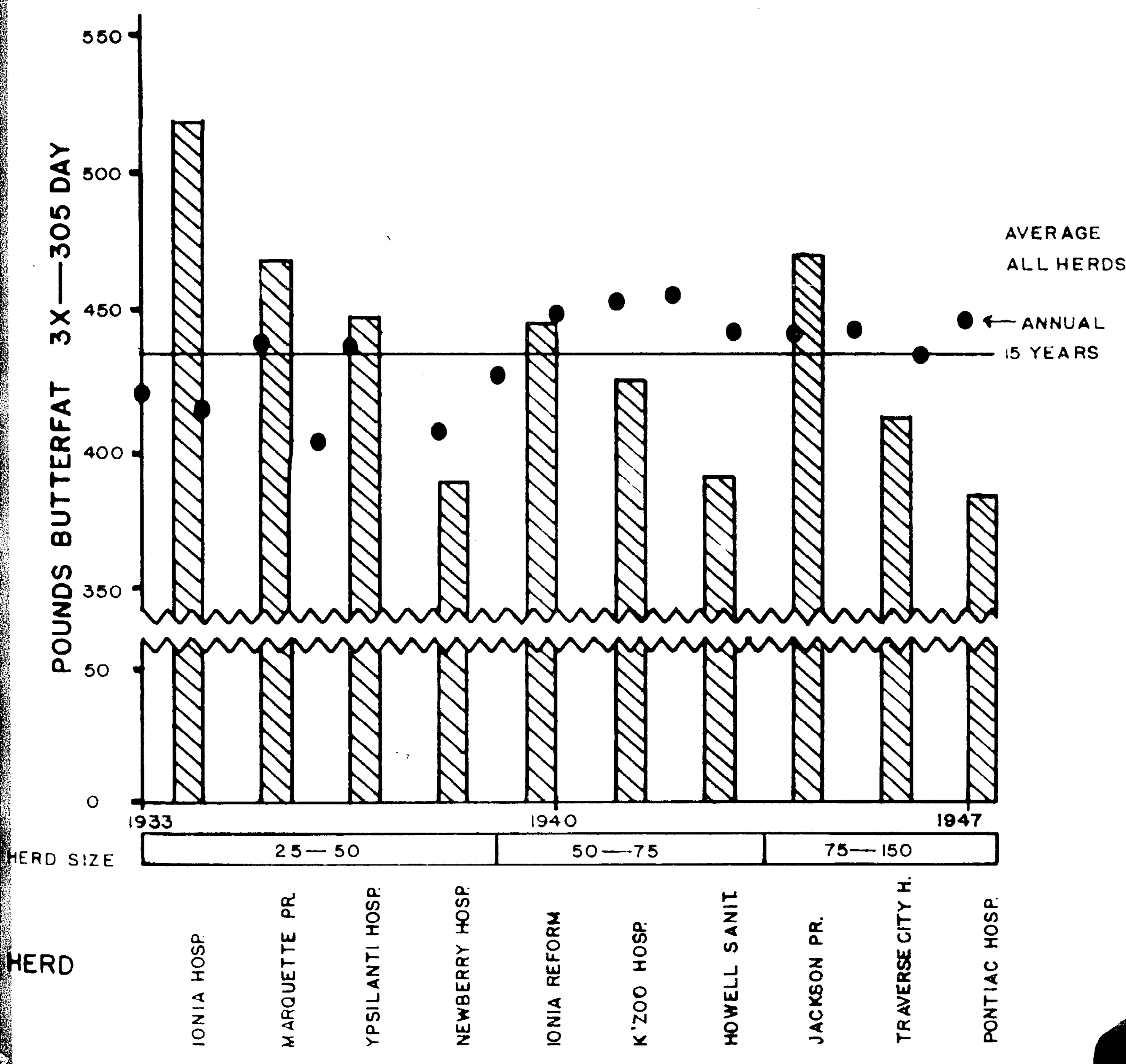
In addition to the herd records of four institutions: Traverse City, Ionia and Pontiac Hospitals and Ionia Reformatory, an important source of data was the HIR records compiled by the Holstein Friesian Association of America for these and other state institution herds. Most of the latter records were from the following institutions: Marquette and Jackson Prisons, and Newberry, Kalamazoo, Ypsilanti and Howell Hospitals. Most of these data were compiled between the years 1933 and 1947. Another bull, King Bessie Ormsby Pietertje, with 20 sons proved outside of the state institution herds was chosen at random to compare with the 20 sons of Marathon Bess Burke 32 (two of whose sons were proved in private herds in Michigan). The DHIA data of Eldridge (1948) consisting of 207 bulls proved in New York State were used as a source of comparison with unrelated material. It was believed that this represented a more random sample of the Holstein population. The data for the institution herds used in the present work are compiled and appended to this study. Eldridge's data are contained in appendices to his thesis.

Most of the animals included in the analysis were located in the state institution herds shown in Graph I. Over the period of time represented by most of these data, approximately 15 years, from 1933-1947, these 10 herds ranged in size from 30-150 milking cows. The annual average production (3x-305da.) ranged from 380-515 pounds butterfat for individual herds; the 15 year average for all herds, not adjusted for herd size, was 433 pounds. Except for some of the earlier 4x records, practically all of the cows were milked 3 times daily. The average length of lactation for all herds over this period was 314 days. Graph II shows the following:

1. Distinct differences existed between the 15 year herd averages for the several state institution herds.

2. There was a noticeable increase in annual average for all herds in the latter half of this period.

GRAPH I: DISTRIBUTION OF HIR DATA AMONG TEN INSTITUTION HERDS FOR THE YEARS 1933 — 1947



3. There was a tendency for production to be higher in the smaller herds.

The distribution of the 20 sons of 412017 among these herds was as follows (some were used in more than one herd): Traverse City Hospital-4, Pontiac Hospital-3, Ionia Reformatory-2, Lapeer Training School-2, Chatham Experiment Station-2, Private herds-2, Ionia Hospital-1, Ypsilanti Hospital-1, Kalamazoo Hospital-1, Howell Sanitorium-1, Marquette Reformatory-1, Jackson Prison-1, Newberry Hospital-1 and Flint School for the Deaf-1.

II. Methods

All records were corrected to standard conditions of age, times milked and length of lactation in accordance with accepted practice in such studies. The following factors were used to convert HIR records to 305 days, and to convert 305 day HIR records to 3x M.E. basis:

Days	Factor
306-319	0.99
320-329	0.97
330-339	0.96
340-349	0.95
350-359	0.94
360-364	0.92
365-	0.90

Age	3x	4x
2	1.25	1.10
2½	1.20	1.05
3	1.15	1.01
3½	1.10	0.97
4	1.07	0.94
4½	1.05	0.92
5	1.02	0.89
6-9	1.00	0.88
10	1.03	0.91
11-	1.05	0.92

The data were divided into the sire groups indicated in Graph II from which the following tendencies can be seen:

1. Distinct differences in group averages and more so in distribution of the data within groups existed.

2. Most of the values fell within two standard deviations on either side of the mean. In a normal distribution 95% of the values would be expected to fall within this range.

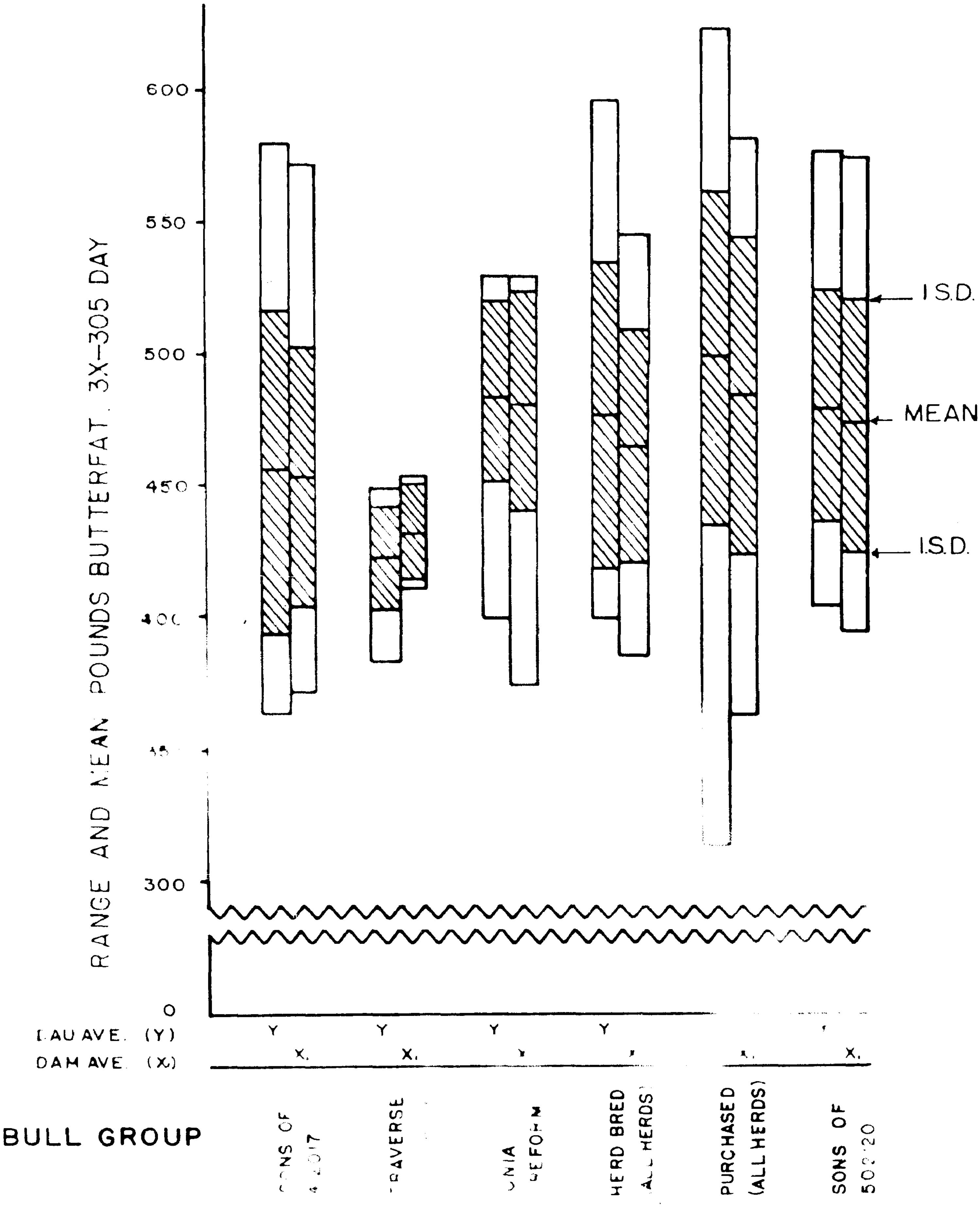
3. The most homogeneous groups were those composed of daughters of bulls within herds. The most conspicuously heterogeneous data were from unrelated bulls used in several herds. The data from more or less related bulls used in several herds were intermediate in their distribution.

4. The standard deviation of neither daughter nor mate average showed any conspicuous relationship to the size of the sample.

The averaged M.E. records for the daughters, mates, and where available, the bulls' dam and sire proofs were itemized (see appendix). Correlation coefficients ($r = xy/\sqrt{(x^2)(y^2)}$ Snedecor) were determined for dam-daughter production in each sire group. In addition, correlation coefficients were obtained between actual daughter production and that predicted by the several means indicated below.

In reporting the correlations obtained by the several methods, the symbols used to designate the various groups are as follows: (subscripts $X_1 \ldots\ldots_6$ are those used by Eldridge 1948).

GRAPH II CHARACTERISTICS OF DAUGHTER AND MATE AVERAGE PRODUCTION FOR BULLS IN STATE INSTITUTION HERDS



Y = average of the daughters of the bull

X_1 = " " " mates " " "

X_2 = " " " daughters of the dam of the bull

X_3 = " " " dam of the bull

X_4 = " " " daughters of the sire of the bull

X_5 = " " " mates " " " " " "

X_6 = " " " daughters of the maternal grandsire of the bull

The use of a subscript with Y denotes a predicted value for the average production of a bull's daughters as follows:

Y_{ep} = by equal parent index* = $(2X_4 - X_5) + X_3/2 + X_1/2$

Y_r = by regression index* (w = herd ave.) = $(2X_4 - X_5 + w/2) + (X_3 + w/2)/2 + (X_1 + w/2)\ /2$

Y_{eb} = by Eldridge equation B* = $0.1 + 0.75X_1 + 0.01X_3 + 0.23X_4 - 0.22X_5 + 0.24X_6$

Y_s = by equation = $0.75X_1 + 0.25\overline{X}_1$

Y_{px} = by equation = $(X_1 + P)/2$

Y_{ps} = by equation = $0.75X_1 + 0.25P$

$$P \quad X_4 + X_1/2 + (X_3 + X_5/2) + X_1/2\ /2$$

The value P equals the transmitting ability of the bull calculated by regressing the average of the daughters of the bull's sire (X_4) halfway toward the average of the mates (X_1) of the bull, adding to this the average of the dam (X'_3) of the bull corrected for N records by Lush's formula (1945) with r = 0.4 after regressing this value halfway toward the mates of the bull's sire (X_5) and further regressing this latter value halfway toward the mates of the bull (X_1), and halving the sum. Thus each regression utilizes

*The theoretical bases for use of these predictions are given in the review of literature of the prediction of transmitting ability.

the records of cows contemporary to those whose records are being regressed.

The prediction $Y_s = 0.75X_1 + 0.25\ \overline{X}_1$ was based on the same value found by Eldridge for regression of daughter average upon dams plus the supposition that the remaining 25% might be accounted for by population average ($\overline{X}_1$). The more complicated formulae for Y_{px} and Y_{ps} represent two of a number of attempts to improve upon Y_s by incorporating data from the pedigrees of the bulls.

RESULTS

I. Correlation of average dam-daughter production

The finding that one bull, Marathon Bess Burke 32, reg. no. 412017, had 20 sons bred and proved as sires in the several institution herds (two were proved in private herds) led to extensive use of this data for correlating actual with predicted production. It was thought that this constituted as large a group (N= 686 comparisons) of records of related animals kept under relatively uniform conditions as might be found. Therefore it should prove of interest to compare the predictability of these with less homogeneous data. The correlation between the average records of the daughters of these 20 bulls and their dams was 0.64.** This r value is in keeping with those found by Lush and Schultz (1938) and Eldridge (1948) who reported values of 0.63--0.67 for similar data. No considerable amount of inbreeding was evident from examination of herd records, thus it was assumed that the dam-daughter relationship was not significantly different from that existing in most herds.

These methods gave correlation values between actual and predicted production as follows:

**Significant at 1% level

Table I: Correlations between actual and predicted production of daughters of 20 sons of Marathon Bess Burke 32

Method of prediction†	Correlation with actual production	Percent chance of estimating actual production within: 30 pounds	50 pounds
X_1	0.64**	55	85
Y_{ep}	0.46*	30	60
Y_r	0.55**	15	60
Y_{eb}	0.58**	40	75
Y_s	0.64**	40	80
Y_{px}	0.63**	50	70
Y_{ps}	0.63**	50	80

**significant at 1%, * at 5% level
† For explanation of symbols see above (page 24).

It will be noted that none of the predicted values exceeds that for the correlation of dam-daughter average. There were no significant differences between any of these correlation coefficients.

II. Per cent chance of predicting production within certain limits.

A factor of greater practical interest than the correlation between predicted and actual production is the chance of predicting production within certain limits. From Table I it can be seen that the average of the bulls' mates was the most reliable means of predicting within 30 or 50 pounds the actual production of his daughters. Not only are these the most available data, but the chances of predicting production within the lower limit were 80% better than by using the equal parent index. Predictability with Rice's regression index was even poorer. Or it might be pointed out that the chances of predicting actual production within 30 pounds was nearly twice as great when only the mates' average was used as when the equal parent index was used. Similarly the mates' average was nearly four times as reliable as Rice's regression index. The figure of 30 pounds was chosen as representing the probable lower limit of accuracy (0.1 pound daily for a 300 day lactation). The figure of 50 pounds (about 10% of a desirable level of 3x production) was chosen as representing the optimum upper limit of error. Since the figures for several other groups (below) were based on 2x production, only the 30 pound limit was applied to them.

Additional dam-daughter correlations were determined for several groups of bulls within the institution herds and for a group of 20 sons of another bull, King Bessie Ormsby Pieterje, reg. no. 52017, not used in these herds. These data are presented below (tableII).

Table II. Correlations between mates and daughters of bull groups

Bull Group	N = no. comparisons	rYX_1 †	%predicted within 30 lbs.	rYY_s ††
Traverse City herd	15	0.57**	100	0.58**
Ionia Reform. herd	14	0.75	93	0.76
Herd-bred, all herds	23	0.52	48	0.54
Purchased, all herds	45	0.67	40	0.67
Sons of MBB32 (Table I)	20	0.64	55	0.64
Sons of KBOP	20	0.81	75	0.78

** all r values significant at 1% level
† rYX_1 = dam (X_1) - daughter (Y) correlation
†† $Y_s = .75X_1 + .25\bar{X}_1$

The correlation between equal parent prediction and actual production determined for the daughters of the herd-bred sires (sons of herd cows, not sons of MBB32) above was 0.47*. For daughters of sons of King Bessie Ormsby Pietertje (KBOP above) the correlation was 0.67**. These and the values in Table II are similar to what has been reported and to those in Table I.

III. Correlation coefficients between dam-daughter production at varying levels of production (Eldridge data).

As mentioned above, the correlation coefficients for dam-daughter production correspond closely with those of Eldridge (1948) who found r values of 0.63--0.67 for four sets of dam-daughter comparisons and values of 0.69 and 0.70 between actual production and that predicted by his regression formulae. As might be expected, the value calculated for rYY_s (Eldridge data) was of the same order as that for rYX_1 being 0.64 for the data in his group B (see Y_B'' page 8). In an attempt to discover the reasons for these correlations being what they were, Eldridge's data for the two groups (N= 207) were combined and then partitioned into several more homogeneous groups. The following correlations were found for dam-daughter averages and for actual-predicted daughter production (Table III).

Table III. Correlations for bull groups assembled from Eldridge's data.

Bull Group	N	rYX_1 [t]	rYY_{ep} [tt]
All factors 400# or more	38	0.19	-0.06
Bulls' mates 450# or more	29	0.18	0.19
Mates 350# or less, other factors 400# or more	22	0.19	0.04
Mates 350-399#, other factors 400# or more	28	0.33	0.40
All factors less than 400#	16	0.77**	0.77**

** significant at 1% level
t rYX_1 = dam(X_1)-daughter(Y) correlation
tt Y_{ep} = equal parent prediction

The use of Eldridge's regression formulae on the first group gave an r value of 0.19, the same as for rYX_1, while rYY_s = 0.22. Eldridge's formulae for prediction with the factor for the mates' average deleted gave an r value of 0.002. It is evident that when the data are partitioned in such a manner as to destroy the usual herd relationships, predictability, for practical purposes, is lost. While the last group represents a selected group as far as these data are concerned, it is suggested that it is also a group in whihch, in practice, no discrimination had been exercised.

IV. Comparison of rankings of transmitting ability of bulls with actual daughter average rankings.

Another approach to the problem was to see which of several methods of prediction would come closest to placing various daughter groups in their actual rank of production. If this method could be shown to have the advantage of placing bulls in proper rank according to transmitting ability, it might obviate the dependence upon the production level of their potential mates. Accordingly the actual daughter averages for three bull groups were ranked by production level and the production rank predicted by the EP and regression indices compared with the average rank of the respective dam groups. The average deviation of predicted production rank for these three methods ranged from 3.7 to 4.5 places out of 20 or 23 from perfect correspondence (zero deviation with actual rank of daughter average (Tables IV, V, and VI).

Table IV. Actual and predicted average daughter production and rank. Sons of Marathon Bess Burke 32.

Actual		Daughter average and rank predicted by:					
Dau. ave.	Rank	Dam ave.	Rank	EP index	Rank	Reg. index	Rank
581	1	573	1	512	2	477	2
546	2	442	10	445	13	445	12
523	3	499	5	473	5	459	4
521	4	529	2	519	1	480	1
492	5	458	7	469	7	456	7
490	6	444	9	458	8	450	9
487	7	461	6	450	10	447	11
487	7	420	17	425	18	433	18
478	9	500	4	485	3	457	6
476	10	449	8	439	16	441	17
457	11	427	14	437	17	442	16
449	12	423	16	449	11	445	12
410	13	440	12	471	6	456	7
406	14	442	10	441	15	466	3
405	15	402	19	445	13	444	15
400	16	439	13	454	9	448	10
400	16	516	3	474	4	458	5
390	18	424	15	448	12	445	12
378	19	382	20	422	19	432	19
364	20	406	18	402	20	430	20
Average deviation*			3.7±3.2		5.4±3.5		4.5±3.8

*Deviation of predicted from actual rank (column 2)

In each case the standard deviation nearly equalled its statistic, hence there was no significant difference between any of the methods. However in 3 out of 4 comparisons of dam average rank with that predicted by either EP or regression index, the average deviation of dam average rank from daughter average rank was the lesser of the two figures.

Table V. Actual and predicted daughter average production and rank. Herd-bred bulls not sons of MBB 32.

Actual		Daughter average and rank predicted by:			
Dau.ave.	Rank	Dam ave.	Rank	EP index	Rank
596	1	471	10	471	15
579	2	503	5	551	3
575	3	529	3	539	4
550	4	490	8	521	5
540	5	483	9	574	2
504	6	507	4	464	17
498	7	443	15	506	8
487	8	545	1	581	1
486	9	453	13	496	10
481	10	497	6	475	14
473	11	408	21	468	16
470	12	450	14	476	13
459	13	441	17	496	10
448	14	464	12	514	6
442	15	532	2	508	7
442	15	427	19	421	21
436	17	466	11	482	12
431	18	497	6	424	20
429	19	419	20	441	18
425	20	436	18	504	9
409	21	391	22	408	22
403	22	443	15	440	19
400	23	388	23	402	23
Average deviation			4.5 ± 3.3		4.3 ± 3.4

Table VI. Actual and predicted average daughter production and rank. Sons of King Bessie Ormsby Pietertje

Actual		Daughter average and rank predicted by:			
Dau.ave.	Rank	Dam ave.	Rank	EP index	Rank
461	1	452	2	439	4
435	2	419	3	444	2
424	3	462	1	448	1
418	4	410	4	444	2
411	5	374	11	403	14
393	6	374	11	404	12
392	7	351	16	423	6
390	8	373	13	414	9
389	9	390	7	396	17
389	9	394	6	422	7
382	11	361	15	382	20
381	12	381	9	408	11
379	13	376	10	404	12
372	14	383	8	426	5
371	15	316	20	390	18
359	16	332	18	383	19
352	17	397	5	409	10
341	18	367	14	404	12
323	19	324	19	399	16
316	20	336	17	402	15
Average deviation		3.8±3.3		4.3±3.4	

Several methods which did not utilize the dam average were also used to rank bulls according to transmitting ability. In every case the average deviation of rank of transmitting level from actual daughter average rank was about twice that when the mates average was used, the figures ranging from 7.1 to 9.2 with correspondingly high standard deviations. Again no significant difference was found between any of the methods of prediction. A more crucial test was made by selecting groups of 7 to 10 bulls from each sire group who were mated to cows whose average production fell within a range of 30 pounds. Applying the same technique above, no significant differences between the rankings of transmitting ability of the individual bulls on the basis of pedigree were found. Nor were any differences found when the mates' average was included. In both instances the average deviations were of the same order as found for the entire group.

It is apparent in all of these analyses of transmitting ability that when the only corrections of production records made are the usual ones for age, times milked and length of lactation, methods of prediction based in part on pedigree are no more reliable than the use of the dam average alone in the prediction of daughter average production. Moreover in no case were predictions based on transmitting ability alone as accurate as those which included the average of the mates to which the bulls were bred.

DISCUSSION

I. Correlation analysis of production data.

In each of the groups of unselected data studied, the correlation of production of dams and daughters was as high or higher than any other value determined. It seems doubtful that the data could have been manipulated in any other logical manner to produce higher values. In most of the literature dealing with methods of predicting production the existing dam-daughter correlation has not been adequately pointed out. In light of this, and the apparent fact that at desirably high levels of production predictability is essentially lacking, it would seem that present methods are not adequate for predicting production from pedigree. This does not mean that there are no differences in transmitting ability of bulls, but that such differences as do exist are obscured by environmental factors. Nor does the emphasis placed upon the mates' records in this and Eldridge's work necessarily refute the theory of Mendelian inheritance. Rather the greater weight given to the female side of the pedigree is apparently only a reflection of the similarity of environment which exists for dams and their daughters.

It seems logical to assume that much of the unpredictability which attends the use of a bull with high pedigree promise on cows of lesser demonstrated ability stems from differences in management likely to be placed upon the bull as a herd improver. Often, with the purchase of a good bull, the owner makes improvements in herd environment commensurate with the interest which prompted purchase of the bull. Others may place primary reliance upon the bull alone to do the job. While some bulls appear to have been herd improvers regardless of herd level, there seems to be no doubt that genetic and environmental factors are so intermingled as to confuse cause and effect. The present study, like others that have preceded it, leaves the vital question unanswered, namely, what is to be the source of high producing cows? For the average breeder at least, the answer would appear to lie in Gowen's early admonition to pay less attention to getting a bull of high pedigree promise and more to securing more calves from his high producing females. A logical follow-up of this advice would be to pay attention to supplying the optimum herd environment.

Another factor to be considered in the application of techniques to predict future production is the number of restrictions to be placed upon the individuals concerned. Two or three generation pedigrees with complete production records are relatively rare. Eldridge found only 207 bulls proved in New York DHIA herds which met his specifications. When the restriction that they be unusually good prospects as herd improvers, the number in the entire breed becomes infinitesimally small. Washbon (1948) lists only 22 Holstein bulls and 4 of two other breeds the sons and grandsons of which, according to his criteria, can be depended upon to increase production. Further, Washbon admits that even these may not stand the test of experience.

The use of already proved sires is limited by the fact that most are dead by the time they are proved (Lush 1945), and very few of those living are proved in a second herd (Beardsley et.al. 1950). The time factor involved makes dependence upon proved bulls a less useful procedure than would be the case otherwise. As far as availability of data is concerned, methods of prediction based principally upon the records of the bull's mates would be most useful, and according to this study, as reliable as any other method tested.

With this in mind it seems logical that the average breeder should pay more attention to factors of management and selection within his own herd than to pedigree promise. Experience does not indicate however, that the problem of herd improvement can be resolved simply by improved environment and selection of dams. The former does not make any permanent contribution, and progress by the latter method is painfully slow in practice. The increase in production due to the amount of selection for production now possible in most herds is low, being on the order of one pound per year regardless of herd level (Seath 1940). Chance and Mather (1949) concluded that cow families were not sufficiently differentiated to receive much consideration in selection. This pound a year improvement is about what is being accomplished by the use of all methods in common practice(DHIA). More could be achieved by increasing the selection differential by better management-- larger calf crops and fewer replacements due to disease, injury, etc. Nelson and Lush (1950) found that by selecting bulls from the better cows it was possible to raise genetic ability 40 pounds in 12 years in the face of an inbreeding program which resulted in an overall decrease of production at the rate of -4.5 pounds of fat per one percent of inbreeding.

II. Diallel crossing

Because of the poor predictability with common pedigree methods, the Traverse City records were examined to see whether data were present to afford analysis by the method of diallel crossing. This method has the advantage of reducing the source of error inherent in the mates inasmuch as the same mates are used to prove two males. In dairy cattle breeding such a method has obvious limitations.however, because of the relatively small numbers of cows that have tested daughters by more than one bull. In the Traverse City herd only 35 such cows were found despite the fact that a potential of 1500 lactations was represented. From 12 bulls mated to these 35 cows there were 15 sets of 2 or more common mates for 2 bulls, of which 8 had sets of 3 or more, and 2 had 9 mates in common. Because of the limited amount of data available, the following is reported here rather than under experimental results.

Since each of these bulls had already been proved on a large number of comparisons, an attempt was made to see whether the method of diallel crossing could be used to more accurately predict the final index of a bull on the basis of a smaller number of comparisons. This method was limited to the four bulls which had comparisons based on 6 or more common mates. It was assumed that one bull had been proved on the basis of the total number of comparisons available. His proof on the basis of the mates in common with the other bull was corrected by adding (algebraically) to the dam's average the amount required to make the two indices equal. The proof of the "unproved" bull was determined on the basis of the mates in common with the proved bull, and the same correction was then applied to give the corrected proof. The following example will illustrate this technique. The nine common mates for bulls 412017 and 353211 averaged 440 pounds. The daughters of 412017 averaged 438 giving an EP index of538 pounds. On the basis of 26 comparisons the EP index of the latter bull was 509 pounds. To make the index on the basis of the 9 comparisons equal 509 pounds, 29 pounds must be added to the production of the dams. That is, if the 509 figure is more correct because it is based on more data, the situation is as if the daughters in the 9 comparisons were from dams which transmitted at the level of 469 rather than 440 pounds.

If this value of 469 pounds for the 9 dams is used as a corrected value to determine an index for the bull 412017, the corrected index will be 407 rather than the 436 pound figure using the actual dam average. The actual proof of this bull on 67 comparisons was 418 pounds. Thus the corrected value for the dams' average gave a more conservative index, and one which was 7 pounds closer to the final index of the bull than did the uncorrected figure. Conversely if the corrected value for the dams' average is used to predict the index for the other bull, 353211, 18 pounds must be added to the actual dam average (440) to make the index for 412017 on the basis of the 9 dams equal his final index of 418 pounds. Using the corrected value for the dams' average(458) to determine an index for 353211 gives an index of 520 pounds compared with 538 pounds for the uncorrected index. The final index based on 26 comparisons being 509, the corrected provisional index came 18 pounds closer to the final figure than the uncorrected. These data are presented below in tabular form (Table VII).

Table VII. The use of diallel crossing to predict transmitting ability of bulls.

Bull	412017	353211
1. Actual ave. prod. 9 common mates	440	440
2. Dau. ave. 9 mates (1)	438	489
3. Provisional EP index (9 pairs)	436	538
4. Final EP index (67 pairs)	418	
(26 pairs)		509
5. Discrepancy: final minus provisional	18	29
6. Corrected mates' ave. (1 + 5)	458	469
7. Corrected provisional*EP index (9pr.)	407	520
8. Discrepancy: final minus corr. provis.	11	18
9. Improvement using corr. provis. index**	7	18

*Using corrected mates' average (= transmitting ability) from proof of bull A with daughter average of bull B to determine corrected provisional EP index for bull B and vice versa.

** Corrected provisional index came 7 and 18 pounds closer respectively than uncorrected provisional index in predicting final EP index.

For three of the four bulls the provisional index on the basis of the corrected dams' average was closer to the final index than that using the uncorrected average. For the four bulls the provisional corrected index averaged 428 pounds, a deviation of 4 pounds from the average final index; the average uncorrected provisional index was 440 pounds, a deviation of 16 pounds from the final index.

It was decided to see whether such a procedure might be extended to the use of individual corrected comparisons rather than averages of common mates. In this case the only requirement was that each mate of the bull to be proved have another daughter by a proved bull. The deviation of the daughter by the proved bull from EP expectation was noted and the average of these deviations added (algebraically) to the average of the dams. This method has the advantage that it does not require that the mates of the bull to be proved be mated to a single other bull, thus more comparisons will usually be available.

For 16 mates of the bull 412017, the average deviation of their daughters by other (proved) bulls was 15 pounds more than EP expectation. Adding this to the mates average (441) gives a corrected value of 456 pounds. The daughters of 412017 from these 16 mates averaged 437 pounds, thus an index of 420 was obtained with the corrected dams' average compared with 433 for the uncorrected average. The final index for the bull was 418 pounds. For the bull 353211 the correction was less than one pound. The dam average was 448, the daughter average 478 for 11 comparisons. This gave an index of 508 compared with 509 for 26 comparisons. Thus the smaller number of comparisons was apparently a good sample of the total, no correction being needed.

It is not suggested that any conclusions be drawn from this limited group of data, but the matter would seem to warrant further investigation. The procedure might be termed one of proving the dams which are used to prove a bull. If the method can be shown to increase the accuracy of prediction, it would be useful to prove a bull on dams which have one or more daughters by already proven bulls.

Such a technique might be used as follows: Assume there is in a herd a bull whose first daughters had been outstanding and who therefore was bred to a large number of cows over a short period of time following his early proving. As these cows freshened small groups would be bred to young unproved bulls. Rebreeding of a number of the cows would be necessary to secure heifer calves from each cow which had produced a daughter by the proved bull. This could be largely accomplished by the time the daughters of the proved bull had completed their first records. The records of the mates of the young bulls could then be corrected on the basis of their deviation from the figure required to give the latest index of the proved bull. The corrected figure for the average of the mates of the young bulls would be used to predict what their final proofs would be. By such a technique it should be possible to discover a group of cows which were apparently relatively prepotent for transmitting at a certain level of production. As they were found they should be maintained as a group of tester brood cows, i.e., they should no longer be pushed to their limit but be managed so as to encourage regular breeding and longevity.

III. Environmental indices

Rather than simply suggest that primary attention be directed toward improvement of environment, it seems desirable that methods be developed to measure the effects of environment in order to more accurately assess the genetic worth of animals. A corollary of this is based on the fact that some of these "environmental" factors may be inherited and thus selected for independently of but in conjunction with production per se. For example, body size and persistency are not merely environmental factors which surround the producing machine, but are in part, inherited components of the machinery for butterfat production. The work of Bayley and Heizer (1950) appears to be the first large scale effort in this direction. It would seem that the state institution herds might be an ideal proving ground for establishing environmental indices because of the large number of cows kept under somewhat uniform and better than average conditions. The possibility of keeping extensive records may also be somewhat greater than exists in average herds.

It is suggested therefore that this step be taken by the state institution herds of Michigan, and that the records so accumulated be made available to a central agency, probably one connected with the College of Agriculture. It would be necessary to determine prediction values for each factor under the conditions which exist in these herds before their general applicability could be established. Some factors, such as climate, must necessarily vary from one region to another regardless of other conditions of environment. Certain discrepancies in the literature must be resolved, notably the question of whether body weight or metabolic body size more accurately reflects production, and whether a separate set of age correction factors for fat test should be used.

The environmental factors discussed in the review of literature should provide an adequate array to initiate such a program. Others will undoubtedly be discovered and should be added as soon as their influence is known or suspected. A work sheet similar to that used by Bayley and Heizer could be used to accumulate data. It is suggested that such a work sheet would be more useful for large herds if the data for herd practices were recorded on a separate sheet, and the factors measured be arrayed in columns and the cows in rows. The following (pages 45,46) is suggested as a form of work sheet that might be used. This sheet differs from that used by Bayley and Heizer in that only original herd data are called for, all calculations, as for length of dry period and days with calf while milking, would be made at the central agency. This would compensate in part for the time required to make the additional observations called for and eliminate one source of error.

In addition to the worksheet data the monthly cow summaries of production should be available for calculation of persistency. Evaluation of udder development as calves should be made. Some "extension work" might be necessary to impress herd managers with the potential value of such data for the project should be worth whatever extra time would be required to compile the data. If time and the expense of testing become a factor in the number of cows that can be tested, some simplifications of the present testing procedure might be worth investigating. Tyler and Chapman (1944) have suggested a simplified method of estimating 305 day production by multiplying the sum of the first 10 test periods by 30.5 to save time and avoid some error of computation. A correlation of 0.993 was obtained between this technique and that in DHIA use. Alexander and Yapp (1949) have suggested a further simplification involving testing only three times during the lactation period. They found that testing during the second, sixth and tenth months was sufficiently accurate to merit adoption as a means of lowering the cost of testing and increasing the number of cows tested.

It is suggested that as the yearly data sheets are completed for each herd they be placed upon punch cards at the central agency to facilitate handling. The data for monthly and total production, sire and dam numbers, and calculated values for length of dry period, days with calf, daily TDN, persistency, etc, could be added at the same time.

WORK SHEET

Owner_______________________Address_______________________Year_______

Herd Practices

1. Size of milking herd___________

2. Grain ration--amounts and basis on which fed to fresh and dry cows

   Contents:

3. Roughage--amounts and kind fed to fresh and dry cows, seasonal variation

   Silage

   Hay

   Other

4. Incidence of disease

5. Climatic conditions

   Average barn temperature while stabled________Dates_____

   Unusual conditions (drought, excessive heat or cold, etc.)

6. Remarks

   How were measurements made (actual or estimated)

   Other

COW DATA SHEET

Cow No.	Body weight/ month lactation				Measure. 1st mo.			Prev. dry date	Date frsh	Cond. when frsh	No. serv.	Date con- ceiv.	Date dry	Remarks
	1st	3rd	6th	10th	Heart girth	Body lngth	Wthrs ht.							

SUMMARY

Correlation analysis of the butterfat production records of the daughters and mates of several groups of bulls in the state institution herds of Michigan showed the following:

1. The correlation between daughter and mate average was on the order of 0.60--0.65 for most groups.

2. None of the accepted or experimental methods of predicting daughter average gave higher values. Several were distinctly, but not significantly, below the value for dam-daughter correlation.

3. There were no significant differences between the values obtained with any of the methods used.

4. The institution data showed either no increase in homogeneity over data from more diverse sources, or no increase in predictability due to whatever increase in homogeneity that might have existed.

5. The percent chance of predicting daughter average production within certain limits was somewhat greater using only the dam average than by any method involving pedigree prediction.

6. There were no significant differences between the rankings of bulls according to transmitting ability when compared to the rankings of daughter average production. The most accurate rankings were those which included the averages of the mates of the bulls.

7. Partitioning of Eldridge's data into more homogeneous groups on the basis of dams' production and/or pedigree promise

resulted in a significant loss of predictability of daughter production.

It was concluded that environmental differences were of such magnitude as to obscure any genetic interpretations that might be placed upon such data.

A proposed worksheet for accumulating data to be used in the formulation of an environmental index was constructed.

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Appendix Table I

Data for Sons of Marathon Bess Burke 32 reg. No. 412017
own daughters ave. 448, mates 479 3x - 305 da. M.E.

Bull Reg. No.	Dau. Prod. Y	Mates Prod. X_1	Dams Prod. X_3	Prod. of dau. of M.G. Sire
640046	523	499	477	462
609774	457	427	477	462
540339	546	442	477	462
565365	487	420	441	430
565366	476	449	441	430
504402	581	573	483	430
620920	364	406	376	430
650015	492	458	542	430
553353	410	440	586	430
548515	406	402	559	430
640043	378	382	506	430
528469	400	516	447	430
522685	487	461	461	455
531686	478	500	469	467
588188	390	424	526	656
675184	490	444	525	490
504401	400	439	520	467
650025	449	423	532	417
675183	521	529	598	464
537726	405	442	661	456
	457	454	505	457

Appendix Table II

2X Production of daughters and mates of bulls proved in The Traverse City and Ionia Reformatory Herds.

Traverse City Bulls

Reg. No.	Dau. Prod.	Mates Prod.
813094	306	335
553353	329	341
609774	347	330
700278	346	347
412017	343	359
486040	336	335
566774	335	340
729194	353	363
659862	346	345
353211	355	345
721464	341	343
480572	348	349
650025	358	356
522685	358	352
720335	339	343
	342	345

Ionia Reformatory Bulls

Reg. No.	Dau. Prod.	Mates Prod.
343285	367	354
808309	424	424
675183	375	391
629478	376	405
480572	365	383
774578	399	413
401108	398	348
576509	418	408
873672	400	419
545551	389	406
522685	399	372
748700	408	390
694844	413	407
522365	320	300
	389	387

Appendix Table III

3X Production data for Institution herd-bred bulls other than sons of Marathon Bess Burke 32

Bull Reg. No.	Dau. Prod.	Mates Prod.	Dams' Prod.	Prod. of Sires Dau.	Prod. of Sires Mates
	Y	X_1	X_3	X_4	X_5
5[illegible]5551	442	532	573	430	467
430587	431	497	307	430	467
425812	409	391	486	375	366
756888	540	485	739	581	573
660470	504	507	353	581	573
728591	487	545	644	581	573
601752	498	443	546	581	573
634064	550	490	532	581	573
653204	429	419	562	400	439
694843	436	466	505	515	540
721464	403	443	495	410	440
663129	473	408	598	579	503
694844	575	529	598	515	540
462108	448	464	598	480	430
551021	425	436	654	515	540
720335	459	441	532	500	430
700278	470	450	532	491	512
602293	596	471	407	480	425
650022	442	427	408	431	443
701944	481	497	591	473	434
670896	486	453	566	473	434
568009	579	503	598	529	463
714235	400	388	465	401	436
	477	465			

Appendix Table IV

3X Production of daughters and mates of purchased bulls proved in institution herds

Bull Reg. No.	Dau. Prod.	Mates' Prod.	Bull Reg. No.	Dau Prod.	Mates' Prod.
609133	417	459	486040	438	439
678668	531	463	682582	471	428
629478	515	540	493589	498	450
659862	500	430	651543	480	460
671583	587	581	723465	419	415
744578	596	534	585068	469	427
729194	520	497	713093	503	489
600154	528	493	678045	446	517
432090	499	546	646346	393	420
573627	456	448	566744	431	443
477989	473	434	697436	401	436
344502	453	451	480572	491	512
696989	538	519	556386	455	444
341217	499	406	519074	474	569
700526	581	486	290298	436	364
602205	612	632	353211	467	431
700089	617	532	401108	529	463
708507	600	504	746901	446	507
574194	554	645	618734	543	573
621262	624	577	669545	410	442
738394	478	490	669566	576	518
708582	488	425	708580	560	501
742591	509	538		500	484

Appendix Table V

2X Production data for sons of King Bessie Ormsby Pietertje
Re. No. 520107, Dau. Prod. 444, mates 504

Bull Reg. No.	Dau. Prod. Y	Mates Prod. X_1	Dams' Prod. X3
717602	461	452	465
752532	381	381	484
723901	371	316	541
727778	382	361	419
763855	435	419	552
688260	424	462	483
644439	359	332	483
593854	389	390	419
702034	390	373	525
695524	352	397	458
738394	341	367	500
708578	389	394	513
652274	392	351	605
669545	323	324	561
669547	316	336	552
669546	393	374	485
688266	379	376	552
711322	372	383	552
676466	418	410	570
763855	411	374	471
	384	379	